2010 LIGHTING TECHNOLOGY OVERVIEWS AND BEST-PRACTICE SOLUTIONS

University of California
ciee
california institute for energy and the environment

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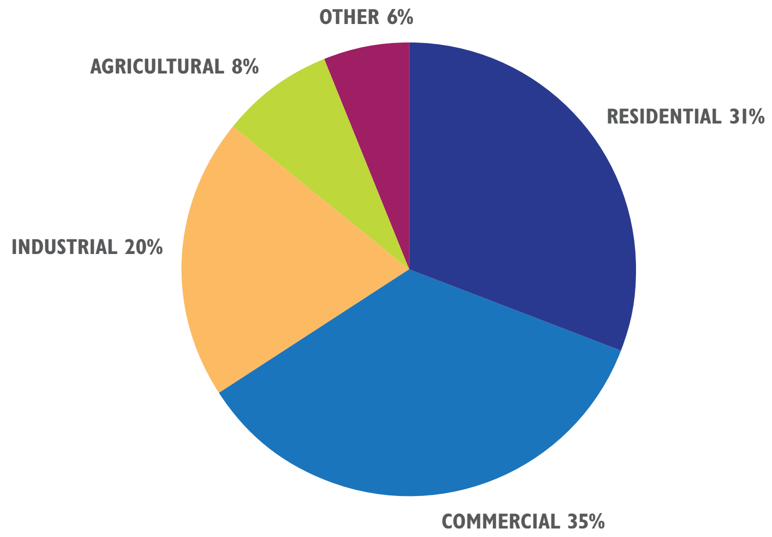
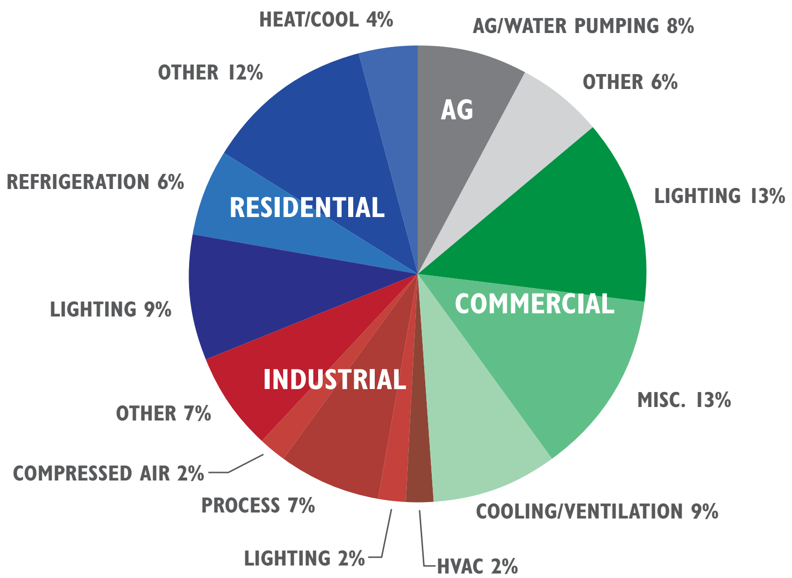
CALIFORNIA ELECTRICITY, USE BY SECTOR

CALIFORNIA ENERGY COMMISSION, "CALIFORNIA ENERGY DEMAND 2003–2013 FORECAST," 2003



CALIFORNIA ELECTRICITY, END USE

CALIFORNIA ENERGY COMMISSION, "CALIFORNIA ENERGY DEMAND 2003–2013 FORECAST," 2003



INTRODUCTION

This document provides overviews of state-of-the-art commercial, residential, and exterior lighting strategies and technologies followed by detailed analysis that demonstrates the significant energy or electricity savings potential of several of these best-practice alternatives. Each lighting example included in this document represents a product concept or practice that may warrant market transformation support by the California Investor Owned Utilities (IOUs) and others. This lighting portfolio originally was developed during a December 2008 lighting roundtable, initiated by the Energy Division of the California Public Utilities Commission (CPUC) and held at the California Lighting Technology Center at UC Davis. The meeting attendees consisted of experts and representatives from utilities, the public sector, researchers, manufacturers, sustainability professionals, policy makers, and the lighting industry. Meeting participants identified the solutions contained in this report as the most relevant to each of their respective industries or programs. The portfolio has been updated with the most current available information and expanded to include best-practice savings estimates for six key lighting solutions.

The 14 items described in this report are included as priorities for further study and development within the Statewide Lighting Market Transformation Program contained in the IOU's 2009–2011 Energy Efficiency Program applications to the CPUC, filed March 2, 2009. While specific lighting products appear as examples in this report, these are only representative illustrations of specific product categories or technologies that may be used to implement best-practice design strategies. Many of these example technologies were developed through the California Energy Commission's Public Interest Energy Research (PIER) Program and public/private development partnerships. These technologies may require a higher initial investment when compared to standard lighting solutions; however, these technologies deliver significantly higher energy, peak demand, and CO_2 savings over their lifetimes.

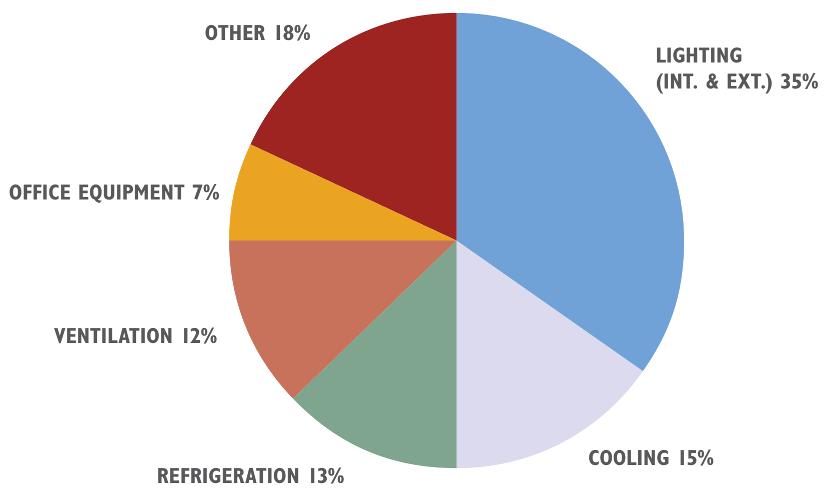
This list of lighting strategies and technologies is appropriate for active consideration, development, and support as California moves toward implementation of the Strategic Lighting Plan (SLP), a set of coordinated strategies to accelerate lighting market transformation for development and use of best practice technologies. The SLP has four integrated goals of Best Practices, Research Development and Demonstrations (RD&D), Marketing and Education, and Policies that will lead to the SLP vision:

> ***By 2020, advanced products and best practices will transform the California lighting market to deliver improved quality, zero net energy (ZNE) buildings, and a 60–80% reduction in statewide electrical lighting energy consumption.***

The first overview was prepared in 2009 as a primer, outlining both the benefits and the market barriers currently facing these energy-efficient lighting technologies. The 2010 LTO has been updated to include the most recent product data and expanded to include a best-practice analysis for six target applications showing that best practices save roughly 50% more than standard practices over a 10-year period.

COMMERCIAL ELECTRICITY, END USE

CALIFORNIA ENERGY COMMISSION, CALIFORNIA COMMERCIAL END-USE SURVEY, 2006



COMMERCIAL LIGHTING

Lighting represents approximately 35% of the energy consumed by the commercial sector.[1] Commercial applications include a range of fixtures from task lights on office desks to overhead luminaires in industrial warehouses. In commercial settings, there is great potential to reduce energy use and provide an improved visual environment by including a combination of best-practice design strategies, efficient sources, and smart controls in both new construction and retrofit projects.

The featured overviews include emerging design strategies, products, and systems. Widely adopted, these practices and technologies can reduce lighting power densities in commercial spaces while maintaining high-quality lighting, providing a tremendous energy-saving potential for California. For example, new products available for task-ambient office lighting systems can save 40–60% in new construction or retrofit applications with power densities of just 0.6–0.7 W/ft^2.[2] Development of market transformation programs designed to overcome the market barriers to the task-ambient lighting designs could reduce peak demand by half, saving twice the energy and reducing CO_2 emissions, compared to the current Title 24 code of 1.1 W/ft^2 or typical lighting retrofits that only address the ambient lighting system.[3]

FEATURED OVERVIEWS

- Task-Ambient Office Lighting
- Integrated Classroom Lighting Systems
- Multi-level Switching with Occupancy Sensors
- HID Electronic/Dimmable Ballasts
- LED Downlights
- Dimmable/Controllable Fluorescent Ballasts
- Daylight Strategies and Technologies

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[1] California Energy Commission, California Commercial End-Use Survey, 2006.

[2] California Lighting Technology Center, Developing Lighting Technologies: Integrated Office Lighting, May 2008.

[3] Refer to notes 1, 2, 3, 4a, 4b, and 4c on page 43 of this document.

TASK-AMBIENT LIGHTING

TOTAL TECHNICAL POTENTIAL ENERGY-SAVINGS ESTIMATES:[1]

- 40–50% energy savings over current energy codes
- 600–700 MW demand reduction potential statewide
- 2,000–3,000 GWh annually
- Annual energy savings of approximately $0.15–$0.25 per square foot of building space
- $300M–$400M annual energy savings for California
- Immediate to one year simple payback when used in new construction projects
- 4–7 year simple payback in retrofit projects

[1] California Lighting Technology Center, http://www.cltc.ucdavis.edu..

Office spaces traditionally rely on a lighting design approach referred to as general lighting, where ceiling-mounted luminaires provide an overall uniform level of illumination sufficient for both task and ambient (fill) lighting. This strategy results in the level of illumination being sufficient for the tasks requiring the most light in virtually all locations, regardless of whether these tasks are performed at those locations or not. General lighting wastes energy by lighting these task-oriented work areas, increases cooling costs, creates unwanted glare on computer screens, and eliminates personal control of light levels. This method is prevalent, as it is simple to use in achieving recommended light levels for office work stations.

Until recently, task-ambient systems were rare. Now, these lighting systems have shown the potential to yield a 40–50% energy savings over standard general lighting practices, provide superior lighting and increase user satisfaction. Ambient lighting provides a uniform, diffuse, low level of light for the general office space, while energy-efficient, high-quality personal task lighting is added to specific work areas. This alternative practice provides light precisely where it is needed and creates a tailored lighting environment for each office occupant.

ENERGY-SAVING OPPORTUNITIES:

California has approximately 1.3 billion square feet of commercial office space[1], much of which was constructed before implementation of California's Title 24 energy regulations. This building stock represents an excellent opportunity for California to reduce lighting power densities and energy consumption through the implementation of task-ambient lighting systems. Direct, recessed, or ceiling-mounted luminaires can be replaced with direct/indirect suspended pendants or high-performance recessed lighting which may consume significantly less energy. Personal task lighting then can be used to supplement work areas as required by individual occupants. The addition of personal controls for both ambient and task lighting, combined with occupancy and photosensors, can further increase energy savings.

Studies indicate that task-ambient lighting systems in commercial office environments can achieve 40–50% energy savings compared to traditional, recessed, or lay-in troffer systems.[2] Studies also show that the addition of personal controls to office workstations, typically a key component of the task-ambient lighting system, can lead to improved occupant satisfaction, increased productivity, and increased energy savings. One such study found that occupants adjusted light levels 10–15% below those required by existing energy code, even after task-ambient lighting systems were installed.[3]

CURRENT MARKET STATUS:

Research on task-ambient lighting systems has increased significantly in the past several years. Many manufacturers offer or are developing ambient and task lighting components designed to work as an integrated system. Although the benefits of a task-ambient approach have been documented, actual implementation lags far behind.

[1] California Sustainability Alliance, et al. "Greening California's Leased Office Space: Challenges and Opportunities," May 5, 2009.

[2] Gauna, et al. "Developing Lighting Technologies: Integrated Office Lighting." PIER Final Report, California Energy Commission, May 2008.

[3] Newsham, G. et al. "Effect of dimming control on office worker satisfaction and performance." Institute for Research in Construction, NRCC-47069. http://www.nrc-cnrc.gc.ca/obj/irc/doc/pubs/nrcc47069/nrcc47069.pdf.

EXAMPLE PRODUCTS IN THE MARKETPLACE:

FINELITE: INTEGRATED OFFICE LIGHTING SYSTEM (IOLS)

www.finelite.com

- Overall lighting energy-savings potential of up to 60%
- LED task lighting provides appropriate light levels
- System includes a central power supply that incorporates a personal occupancy sensor, yielding additional energy savings and convenience for the user

TAMBIENT: TASK-AMBIENT LIGHTING

www.tambient.com

- Eliminates the need for task lights and ceiling luminaires
- Establishes comfortable luminance ratios
- Saves energy

LEDALITE: ERGOLIGHT CONTROLS

www.ledalite.com

- Personal lighting and controls
- Integrated daylight sensor maintains ambient light levels while saving energy
- Occupancy sensor gradually dims light before turning off in unoccupied workspaces

This is especially true for California's older building stock. In addition, lighting designers and architects continue to rely on traditional general lighting methods because of perceived simplicity, familiarity with design requirements, and low initial installation cost.

BARRIERS TO MARKET ADOPTION:

The major barriers include the lack of efficient task lighting that delivers an appropriate amount of light to the workstation, high initial cost of quality task lights and personal controls, misconceptions about the complexity of task-ambient lighting design, and perceived lack of necessity. Lighting designers and installers who can demonstrate payback and lifecycle savings to their clients will see an increased adoption rate. However, if the designers, installers, and end users of the systems are not aware of the long-term savings or hold the perception that the systems will be complex and costly to maintain, they will be less likely to invest in them.

INTEGRATED CLASSROOM LIGHTING SYSTEMS

ENERGY-SAVINGS ESTIMATES:

30–50% energy savings compared to Title 24.[1]

[1] California Lighting Technology Center, Integrated Classroom Lighting System demonstration. http://cltc.ucdavis.edu/content/view/672/358

Many classrooms provide mediocre lighting and have high energy costs. Although high-efficiency systems are available, they require a piecemeal approach when including automatic controls for occupancy, daylighting, and dimming. Specifying control components individually greatly increases design time and cost. Additionally, each component carries an individual warranty, causing confusion and potential delayed repair time if performance problems occur.

Integrated lighting systems for classrooms and conference rooms deliver high-quality lighting, increased flexibility, daylighting, and energy efficiency into an affordable, easy-to-use, and easy-to-maintain single-source solution. By increasing lighting quality and distribution with suspended indirect fixtures, these systems achieve a lower power density than standard classroom systems. With fewer fixtures, lamps, and ballasts, the operational and maintenance costs are reduced. This also means installation costs are often less than costs for traditional classroom fixtures. All this, in addition to improved user controls, means an integrated system can provide benefits in many applications.

ENERGY-SAVING OPPORTUNITIES:

Typically, energy savings are 30–50% more than standard retrofits designed to current Title 24 requirements.[1] Increased savings come from reduced lamp quantity, the addition of user scene controls or dimming, and the addition of occupancy and daylight sensors. These systems maintain Illuminating Engineering Society of North America (IESNA) recommended light levels at the desk level, provide even vertical illumination at the whiteboard, and deliver dimming control for audio/visual presentations or other events.

CURRENT MARKET STATUS:

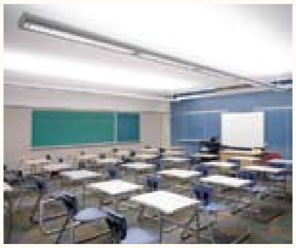
The ICLS and R-ICLS can be installed in all classrooms, conference rooms, and large offices. Several manufacturers offer lighting systems that integrate luminaires, occupant controls, and intelligent sensors into a single package. Examples include Finelite Inc.'s ICLS, Peerless' PIER 4.5 CLS, and Litecontrol's CS/AV.

BARRIERS TO MARKET ADOPTION:

For integrated lighting systems, increased installation costs typically present a large barrier to widespread market adoption. Integrated lighting systems provide excellent lighting quality, improved occupant controls, and simplified specification; however, electrical contractors remain unfamiliar with these systems and their installation requirements. This unfamiliarity often leads contractors to increase installation estimates. School districts can save significant energy by specifying a classroom lighting system, but paybacks may initially be lengthy, until contractors become familiar with the technology and begin to lower estimated project contingencies. In addition, these systems often require post-installation commissioning, which may increase overall project costs.

[1] Refer to notes 6a, 6b, 6c, 7, 8, and 9 on page 43 and 44 of this document.

EXAMPLE PRODUCTS IN THE MARKETPLACE:



FINELITE INC.: INTEGRATED CLASSROOM LIGHTING SYSTEM (ICLS)
www.finelite.com

- This solution can be ordered as a single package (i.e., luminaires and controls)
- Provides three different lighting modes: audiovisual, general, and focus
- This product was used in the first PIER 4.5 ICLS, the second NYSERDA ICLS, and third LCF R-ICLS studies

PEERLESS: PIER 4.5 CLASSROOM LIGHTING SYSTEM
www.peerless-lighting.com

- Reduces lighting consumption by up to about 60% over ASHRAE 90.1-2004/2007
- Supports green building practices such as LEED for Schools
- Uniform light on walls and ceilings, reduced glare, enhanced visual comfort, and more light cutting across the space horizontally

LITECONTROL: CONTROL SOLUTIONS (CS/AV)
www.litecontrol.com

- Dual technology occupancy sensors to switch off the lighting when the room is vacant
- Modular wiring box and modular wiring leads for easy connections between the power supply, occupancy sensor, switch boxes, and fixture rows

MULTI-LEVEL SWITCHING WITH OCCUPANCY SENSORS

ENERGY-SAVINGS ESTIMATES:

The energy savings from multi-level switching was measured to be 34–52% (depending on switch settings) in a CLTC study. A separate study by Lawrence Berkeley National Laboratory in 1998 recorded 24% energy savings.[1] This combination with savings from the automatic shut-off feature of the occupancy sensor, estimated at 25%.[2]

[1] Rubenstein, Francis. The Usefulness of Bi-level Switching. Lawrence Berkeley National Laboratory. 1998. http://gaia.lbl.gov/btech/papers/44281.pdf.

[2] Federal Energy Management Program. http://www1.eere.energy.gov/femp/procurement/eep_light_controls.html.

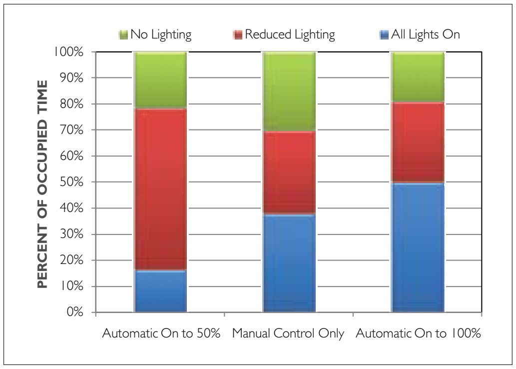
Lighting control options for private offices include occupancy sensors and multi-level switching. Occupancy sensors save energy by turning off lights when the office is vacant. Multi-level switching allows the occupant to choose the level of lighting in their office. This saves energy when the occupant chooses to work with a reduced electric lighting load. This is particularly likely in perimeter offices where daylight is available. Wall-mount, multi-level switching controls with an integrated occupancy sensor are widely available and save energy while increasing user satisfaction.

ENERGY-SAVING OPPORTUNITIES:

CLTC studied energy use in eight private perimeter offices and discovered significant energy savings through use of these controls. The control has the user-selectable option to take one of three actions when the occupant walks in the office:[1]

1. Turn on all of the lights
2. Turn on the lights to a low level
3. Do nothing (manual control only)

THREE LIGHTING CONTROL SCENARIOS FOR PRIVATE OFFICES



All options automatically shut off the lighting when the office is unoccupied. The study showed that while all options saved energy, the automatic on to a low level (50% in the study) saved the most energy. This is surprising, considering existing beliefs that turning lights on manually is best. However, when lights are automatically turned on to a low level, many occupants will start working without activating all the lights. However, if the lights must be turned on manually, occupants will choose to use all the lighting more often.

CURRENT MARKET STATUS:

Multi-level switching has been a requirement in California's Building Energy Efficiency Standards since 1983. California's 2008 Building Energy Efficiency Standards, effective January 1, 2010, also require the addition of an occupancy sensor for offices 250 ft² or smaller. Because the multi-level switching requirement has been in place for 25 years, while the occupancy sensing requirement is new, there should be an abundance of simple retrofit opportunities where the multi-level occupancy sensor can be installed with the existing multi-level circuitry.

[1] California Lighting Technology Center, "Bi-level Switch Study," 2008. http://cltc.ucdavis.edu/images/documents/guides_reports/2010_ wattstopper_bi-level_switch_study.pdf.

EXAMPLE PRODUCTS IN THE MARKETPLACE:

WATTSTOPPER/LEGRAND: PASSIVE INFRARED DUAL RELAY WALL SWITCH SENSOR
www.wattstopper.com
- Used in CLTC study
- Two relays for control of two separate lighting loads or circuits
- Selectable walk-through, test, and presentation modes

LEVITON: ODS0D-IDW SENSOR
www.leviton.com
- SP-Dual circuit
- Self-adjusting
- Passive infrared

SENSOR SWITCH: WALL SWITCH DECORATOR SENSOR
www.sensorswitch.com
- PIR/Microphonics™ Detection
- Two self-contained relays
- Programmable push-button

BARRIERS TO MARKET ADOPTION:

Buildings older than 25 years may not have existing multi-level circuitry. In these cases, adding the multi-level switching to enable this control product is unlikely to be cost effective. Buildings constructed between 1983 – 2008 should provide simple retrofit opportunities because offices are likely to have multi-level circuitry without occupancy sensors installed. In these cases, the installation is much more cost-effective, but may have a longer-than-desirable payback period.

LIFECYCLE ANALYSIS EXAMPLE:

As an example, consider a perimeter office of 128 ft^2 with a lighting power density of 1.5 W/ft^2. The office has two manually controlled switches. To start, there is no occupancy sensor and both switches are in the "on" position an estimated nine hours per day. The total lighting energy consumption per office is 232 kWh per year.

Since the office already has multi-level circuitry installed, adding occupancy-sensing product will save an estimated 25% of lighting energy.

If the combination multi-level circuitry and an occupancy sensor are installed with an automatic on-to-low-level feature enabled, an additional 11% can be saved.

The combined savings from the retrofit is 33%, or 155 kWh per year. Assuming a $150 materials and installation cost and a California average electricity cost of $0.128 per kWh, the estimated simple payback is 7.5 years.

HID ELECTRONIC/ DIMMABLE BALLASTS

ENERGY-SAVINGS ESTIMATES:
Immediate energy use and cost reductions of approximately 25% with additional savings from dimming with daylight, occupancy, and time controls.

There are more than 50 million High Intensity Discharge (HID) fixtures California.[1] These fixtures are used during on-peak demand periods in retail stores, warehouses, service station canopies, gymnasiums, auditoriums, convention halls, etc. During off-peak hours, they are used in those places together with street and security lighting.

Most HID fixtures are powered by magnetic ballasts that operate at the 60 Hz line frequency. The high-voltage arc within the lamp starts and stops 120 times per second. The HID fixtures' frequent starts and stops have several serious effects, including a decreased efficiency and a shortened lamp life, which can lead to increased maintenance costs. A warm-up time of several minutes is required before useful light levels are achieved. In addition, frequent starting causes the cathode material to sputter off, coating the lamp capsule and causing the light output to degrade.

When these HID systems are dimmed, the problems with the frequent starts and stops are exacerbated, and it takes more than 30 seconds to brighten. If a lamp is switched off when hot, it cannot restart for five or more minutes. If an attempt to restart is made from a dimmed condition, it may not restart at all. Either situation affects safety and diminishes user acceptance.

New generations of electronic HID ballasts are currently available. The ballasts start quickly and operate the lamps at frequencies of 30–300 kHz. The ballast output is 20–30% higher, and the lamps dim through a broad range without longevity consequences. Lumen depreciation is lower and the product life cycle is longer. They brighten rapidly from a re-strike and come to full brightness in seconds from a dimmed condition. Lamps operated by electronic ballasts have 50% longer life than those operated by magnetic ballasts.

ENERGY-SAVING OPPORTUNITIES:

Electronic high-frequency ballasts when used in combination with appropriately sized HID lamps, can reduce energy consumption by 20-25%. When compared to traditional HID lamps operating on magnetic ballasts[2], they can reduce consumption of High Pressure Sodium (HPS) and Metal Halide (MH) lamps by approximately 25%.[3] Replacement of Mercury Vapor fixtures with the high-frequency electronically ballasted HPS or MH can save over 50%.

CURRENT MARKET STATUS:

HID lamps with electronic high-frequency ballasts have only penetrated about 2–3% of the market. There are several large installations with good performance and acceptance. This technology can be demonstrated and proven. Incentives and demonstration programs in Department of General Services facilities and the University/College systems can lead to large-scale adoption.

[1] Assumes California is 10% of the U.S. lighting industry market based on Analysis of Standards Options for High-Intensity Discharge Lighting Fixtures, American Council for an Energy-Efficient Economy, January 2008, Page 12.

[2] California Lighting Technology Center, eHID Ballast Comparison, August 2009.

[3] Mendoza, Ted, and Louie Ortega, Electronic HID Ballast Case Study, December 2008.

EXAMPLE PRODUCTS IN THE MARKETPLACE:

ADVANCE: DYNAVISION®
www.advancetransformer.com
- Continuous full range dimming: 50 – 100% of full power
- Analog dimming by dimmer, ambient sensor, light sensor, or any other compatible sensor
- Lumen maintenance of more than 90% over lamp life (dependent on lamp type)

METROLIGHT: SMART ELECTRONIC BALLAST FOR HID™
www.metrolight.com
- Full-range digital or analog dimming 33 – 100%
- Internet connectivity and reporting
- More than 90% lumen maintenance
- Lamp color uniformity
- Field programmable and upgradable
- Rapid lamp starts and fast ramp-ups from dim

VENTURE LIGHTING: SUPER HID 320®
www.venturelighting.com
- Superior lamp power regulation improves color uniformity and lumen maintenance
- Optimum wave shape lowers current crest factor and lowers audible noise
- Improved ballast efficiency
- Cooler operation, longer system life
- Thermal protection

BARRIERS TO MARKET ADOPTION:

The one-for-one replacement makes this a lucrative choice for energy reduction and better performance, but as with many new technologies, cost is a major barrier to achieving market saturation. Incentives and the increase in demand will help to drive costs to an acceptable level. There also are some reservations as to the longevity of these units. Manufacturers will have to offer extended warranties to increase buyer confidence.

LED DOWNLIGHTS

ENERGY-SAVINGS ESTIMATES:
A typical retrofit of 60W incandescent downlights to LED downlights will save up to 75%. Replacing CFL downlights saves 40–50%.[1]

Downlights are lighting fixtures that consist of a recessed fixture housing ranging from 4–12" in diameter, a light source, and a trim kit. Downlights are available for incandescent, HID, CFL, and LED light sources. For many lighting designers, the downlight is the fixture of choice because of its general aesthetic and the variety of options.

LEDs are solid state devices that require special electrical and thermal management systems. The thermal design will significantly affect LED life. Because LEDs are thermally sensitive, recessed downlight fixtures (fixture housings that are above the ceiling in unconditioned, sometimes insulated environments) represent a challenging application for LED downlight alternatives. It is important to carefully verify performance and warranty for all potential LED downlight solutions.

ENERGY-SAVING OPPORTUNITIES:

Downlights are popular in many applications. Downlights are frequently specified for commercial office space, hospitality, and residential lighting projects. Consequently, a reliable LED alternative would create a significant energy savings opportunity.

CURRENT MARKET STATUS:

Several LED downlights are commercially available, but there is a wide range in performance and cost. It is sometimes difficult to separate the underperforming products based on product literature, because the manufacturers either do not adequately understand the technology and create unreliable specifications or intentionally cite misleading information.

ENERGY STAR® requirements for recessed downlights include: 1) maximum allowable aperture must be less than or equal to 8 inches in diameter for circular, or on side for rectangular; 2) minimum light output is 345 initial lumens for ≤ 4.5" aperture and 575 initial lumens for > 4.5" aperture; 3) must provide a mimimum of 75% of total initial lumens within the 0-60° zone; 4) have minimum 35 lm/W efficacy; 5) have 2700K, 3000K, or 3500K CCT for residential or 2700K, 3000K, 3500K, 4000K, 4500K, or 5000K CCT for non-residential; and 6) have a label certifying air leakage less than 2.0 CFM at 75 Pascals when tested in accordance with ASTM E-283 for insulated ceilings. LEDs must 1) have color spatial variation within 0.004 from the weighted average point on the CIE 1976 (u',v') diagram; 2) have color variation within 0.007 on the CIE 1976 (u',v') diagram over the lifetime; 3) minimum 75 CRI; 4) not draw power in off-state; 5) have minimum three-year guarantee; and 6) have thermal management.

BARRIERS TO MARKET ADOPTION:

Initial cost is a significant market-adoption barrier for LED downlights when compared to incumbent technologies. However, cost will decrease as adoption increases. When CFL downlights first were introduced, the price per unit was triple that of incandescent downlights. Now, they are competitively priced. Color temperature, color quality, and color consistency will also pose as a major obstacle to widespread adoption as it will be difficult for consumers to predict how multiple LED products will compare. Wide variation in product reliability also will act as a barrier; as consumers experience unreliable products, their acceptance of similar LED technologies will decrease. As testing methodologies improve and manufacturers are held to a common standard, quality will stabilize. Manufacturer warranties with longevities that match product lifetime claims will also increase consumer confidence and catalyze market adoption.

[1] California Lighting Technology Center, Energy-efficient LED Downlights Case Study, 2009.

Navigant Consulting Inc., Energy Savings Estimates of Light Emitting Diodes in Niche Lighting Applications, September 2008.

EXAMPLE PRODUCTS IN THE MARKETPLACE:

CREE LED LIGHTING SOLUTIONS: LR6 DOWNLIGHT

www.creelighting.com

- Nominal delivered light output of about 650 lumens
- Nominal input power of 12 W
- 92 CRI
- High correlated color temperature
- Dimmable to 25%

COOPER LIGHTING: HALO LED DOWNLIGHT

www.haloltg.com

- Consumes 75% less energy compared to 65 W BR30 incandescent lamp
- Uses less than 15 W
- 600 lumen output
- Projected 50,000 hour life
- Dimmable

PHILIPS LIGHTOLIER: CALCULITE

www.lightolier.com

- Remote-phosphor technology for color consistency
- Up to 2000 lumens
- Up to 50 lm/W
- CRI is 79 ±2% for 3000K products
- Dimmable

	STANDARD INCANDESCENT (BR30)	4-PIN CFL DOWNLIGHT SYSTEM	LED DOWNLIGHT SYSTEM
Total # of downlights	10	8	10
Delivered lumens per downlight	620	850	650
Power per downlight (watts)	65	28	12
Material cost per downlight	$20	$38	$90
Installation cost per downlight	$30	$30	$30
Total lamp lumens	6200	6800	6500
Total power (watts)	650	224	120
Total initial installed cost	$500	$544	$1200
Operating cost per year	$99.65	$34.34	$18.40
Additional initial cost vs. Incandescent	n/a	$44	$700
Annual savings vs. Incandescent	n/a	$65.31	$81.25
Simple payback	n/a	0.67	8.62
CRI[2]	100	+75	75–94

[1] Numbers are based on the lighting design for a generic room used for three hours.

[2] CRI minimum based on ENERGY STAR criteria.

DIMMABLE/CONTROLLABLE FLUORESCENT BALLASTS

ENERGY-SAVINGS ESTIMATES:

Energy savings vary depending on controls strategy and application:[1]

Scheduling and tuning	10–25%
Personal controls	0–35%
Daylight harvesting (35% in daylight zones)	12–17%
Occupancy controls	15–35%
Variable load shedding (peak only)	15–20%

Combinations of control strategies offer combined energy savings, increasing value, and cost effectiveness:[2]

	ADDITIVE SAVINGS
Tuning	10%
+ Occupancy	25%
+ Daylight harvesting	40%
+ Personal control	50%

[1] ACEEE, Integrated Daylighting Systems (Dimming Ballasts) Emerging Technologies Report, 2006. http://www.aceee.org/emertech/2006_LightingControls.pdf.

[2] Lutron, 2009.

Dimmable, controllable fluorescent ballasts are used to adjust the light output of fluorescent sources gradually, through manual or automatic controls. Dimming ballasts can be analog or digital, individually addressable and can be controlled based on a variety of energy saving and peak demand reduction strategies, such as daylighting and demand response controls. While such strategies can also be implemented with non-dimming ballasts, through on/off control of individual luminaires or zones of luminaires, dimming ballasts offer improved visual comfort and occupant acceptance. Gradual changes in light levels, variety of scene controls, and maintenance of light distribution all contribute to increased user acceptance. Individually addressable ballasts also offer increased flexibility and effectiveness in implementing energy and peak demand strategies.

ENERGY-SAVING OPPORTUNITIES:

Dimmable, controllable fluorescent ballasts can save energy through a variety of individual and combined controls, especially in office and classroom applications:

- **Tuning**–adjusting max output to match requirements
- **Scheduling**–time-based controls
- **Scene**–for different functions (AV, note taking, small group, etc.)
- **Personal**–occupants adjust lights that illuminate their work area
- **Daylighting**–adjust light output based on available daylight
- **Occupancy**–adjust light output (on/off or low/high) based on occupancy
- **Demand response (DR)**–reduce light output based on DR utility signals

CURRENT MARKET STATUS:

Dimmable, controllable fluorescent ballasts are available from a variety of manufacturers. Some manufacturers offer complete controls solutions while the others offer only ballasts that may be combined with sensors and controllers from other controls manufacturers. Dimming ballasts comprise only 4% of the commercial fluorescent ballast market. Daylighting controls are installed in about 2% of new commercial buildings and in a negligible portion of retrofit applications.[1] In the past, efficiency was a challenge for this product category. Now, dimming ballasts are nearly as efficient as programmed start models (within 1%) and only 4% less efficient than high-performance instant start ballasts.[2]

BARRIERS TO MARKET ADOPTION:

The main barrier to market adoption is cost, especially in retrofit applications that require rewiring components. Dimmable, controllable ballasts are significantly more expensive than non-dimming ballasts. While installation is easier in new construction, commissioning is significantly more expensive in both new and retrofit installations. Lastly, daylight harvesting systems often require recommissioning to keep them at their expected performance level. This adds additional costs and labor.

[1] ACEEE, Integrated Daylighting Systems (Dimming Ballasts) Emerging Technologies Report, 2006. http://www.aceee.org/emertech/2006_LightingControls.pdf.

[2] http://www.cee1.org/com/com-lt/com-lt-main.php3

EXAMPLE PRODUCTS IN THE MARKETPLACE:

ADVANCE:
MARK 10™ POWERLINE
www.advancetransformer.com

LUTRON: ECOSYSTEM BALLASTS
www.lutron.com

OSRAM SYLVANIA:
QUICKTRONIC®
www.sylvania.com

LIFECYCLE ANALYSIS:

Energy saving from dimming ballasts is largely dependent on the combination of technologies used, rather than calculating savings from the addition of the ballast alone. All of the system components must be considered. Dimmable ballasts add more layers of controls to a lighting system. When included, they can enable occupancy sensors, photosensors, timers, or individual users to adjust light to various output levels in the dimming range allowed by the ballast. The lighting control technologies used with dimming ballasts dictate the cost saving and payback time. For example, dimming ballasts combined with individual user control are estimated to have an 11% savings on energy.[3] Although the addition of dimming ballasts without other elements such as sensors will not save energy, they are an important inclusion in energy efficient fluorescent lighting systems and are necessary if light levels will change in response to environmental factors.

[3] Galasiu, Anca D et al. Energy Saving Lighting Control Systems for Open-Plan Offices: A Field Study. Leukos. Volume 4. July 2007. Pages 7-29.

DAYLIGHT STRATEGIES AND TECHNOLOGIES

ENERGY-SAVINGS ESTIMATES:[1]

- Electricity demand savings equal to the installed ambient lighting power density generally 0.8–1.2 W/ft² multiplied by the floorspace in the daylit zone
- Annual electricity consumption savings of 1.7 kWh/ft² in the daylit zone for the following example: An installed LPD of 1.2 W/ft², 2,860 hours of operation per year, and 50% energy savings

[1] Calculations based on Title 24.

California has an abundance of clear, sunny days. Properly designed buildings can capitalize on California's available daylight by reducing or extinguishing electric lights in appropriate spaces. The daylight zone for side daylighting, referring to the depth of available daylight in a building, is 1.5–2.5 times the height of the window. Additional spaces can benefit from daylighting through the use of skylights and tubular daylighting devices. Daylight harvesting controls maximize energy savings by automatically dimming or extinguishing electric lights in response to available daylight.

ENERGY-SAVING OPPORTUNITIES:

Energy savings from the installation of daylight harvesting controls can save up to 100% of the lighting energy in the daylight zone when adequate daylight is available. Available studies have measured 40–80% annual lighting energy savings for commercial office spaces.[1] In addition, the availability of daylight corresponds well with the peak electricity demand curve for commercial buildings. Turning off electric lights in daylit zones of commercial office buildings results in demand savings equal to the installed ambient lighting power density, generally 0.8–1.2 W/ft², multiplied by the daylight zone area.

CURRENT MARKET STATUS:

Daylight harvesting controls are installed in less than 2% of new commercial buildings and in a small number of retrofit buildings.[2] California's new 2008 Building Energy Efficiency Standards, effective January 1, 2010, require enclosed, single-story spaces larger than 8,000 ft², with ceiling heights greater than 15 feet, to have at least half the floor area in the daylit zone.[3] This regulation should catalyze market adoption of daylight harvesting controls for new commercial buildings by including large warehouses and retail stores. Wal-Mart, a retailer with an aggressive energy-efficiency program, has constructed stores with skylights, dimming ballasts, and daylight harvesting controls since 1996.

BARRIERS TO MARKET ADOPTION:

Installation and commissioning costs are a major barrier to widespread adoption. For optimal operation, most daylight harvesting controls need to be commissioned to correlate the photosensor signal to the daylight in the space. This requires a trained commissioner and adds additional cost to the installation. Closed-loop control systems (which monitor the balance of electric light and daylight in the space) need to be re-calibrated if the space geometry and reflectance change significantly. Open-loop control systems (which monitor only the daylight available at a window or skylight) are more robust and less expensive to maintain than closed-loop systems. However, the open-loop signal is not necessarily a good indicator of the amount of daylight in the space and may not provide adequate information for control of the electric lights. Control technology improvements are needed to meet the user expectations and reduce installation and maintenance costs. Simplified daylight harvesting controls with automatic and continuous commissioning are under development at CLTC in partnership with WattStopper/Legrand. The first auto-commissioning daylight controller, the LS-102, is commercially available through WattStopper/Legrand.

[1] ACEEE, Integrated Daylighting Systems (Dimming Ballasts) Emerging Technologies Report, 2006. http://www.aceee.org/emertech/2006_LightingControls.pdf.

[2] Ibid.

[3] Title 24 2008, page 102.

EXAMPLE PRODUCTS IN THE MARKETPLACE:

WATTSTOPPER/LEGRAND: LS-102

www.wattstopper.com

- Automatic and continuous commissioning daylighting controller that provides closed-loop control in a single zone for on/off switching

LUTRON: ECOSYSTEM DAYLIGHT SENSORS

www.lutron.com

- Dimming ballast system compatible with control components
- Calibrated through the Light Control System software

LEVITON: CENTURA

www.leviton.com

- Closed-loop dimming control system
- Compatible with occupancy sensors, switches, and handheld remotes

LIFECYCLE ANALYSIS:

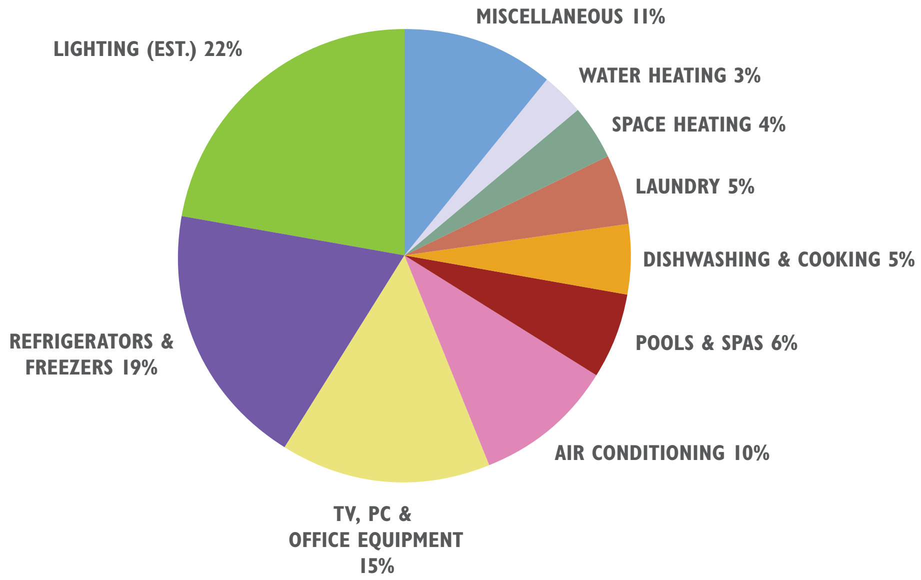
Annual electricity savings of 1.7 kWh/ft^2 in the daylit zone. These savings are based on the following assumptions: an installed LPD of 1.2 W/ft^2, 2,860 hours of operation per year, 50% energy savings, and an electricity rate of $0.128 kWh. The simple payback is a function of the available daylight in the building and the cost of adding additional daylight sources, the existing electrical wiring layout (i.e., Is it simple to switch a row along a window or is there significant electrical work needed), and the size of the area to be controlled. Two examples for side daylighting are provided:

An **OPEN OFFICE PLAN** has windows along a south facing wall, and the light fixtures are already switched in rows parallel to the window. Adding daylight harvesting to the existing plan requires the installation of the control to automatically switch only the row of electric lights near the window. For a daylight harvesting system controlling the electric lights in a 640 ft^2 open office area at a cost of $300 for installing the controls, the simple payback is about two years. Over a 15-year lifecycle, the cost to save the electricity is only $0.02 per kWh, which is substantially less than the cost of electricity.

Considering the example above, the same 640 ft^2 office space is now divided into **SIX INDIVIDUAL OFFICES**. While the savings are expected to be similar, the materials and installation cost are greater because each office requires a photosensor and control pack. At a cost of $250 per office for installing the controls, the simple payback is 11 years. Over the 15-year lifecycle, the cost to save the electricity is $0.09 per kWh, which is less than the cost of electricity.

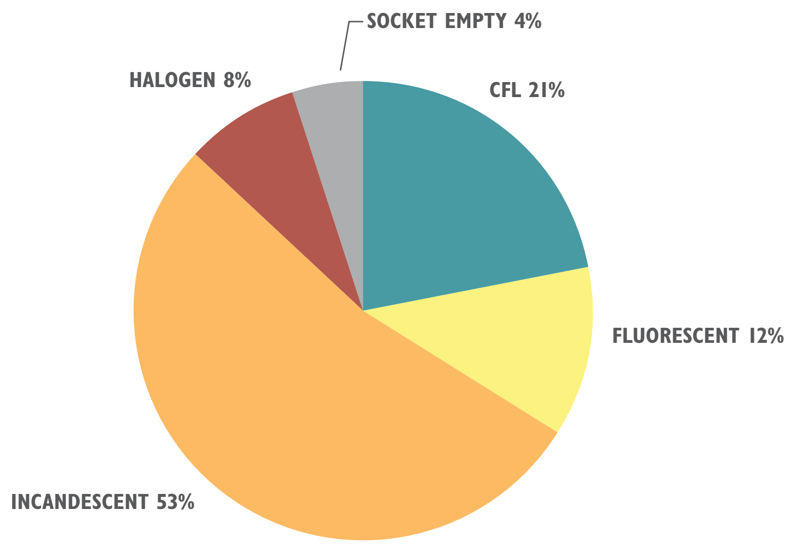
STATEWIDE AVERAGE ELECTRICITY USE PER HOUSEHOLD

CALIFORNIA LONG-TERM ENERGY EFFICIENCY STRATEGIC PLAN, 2008



RESIDENTIAL LIGHTING TECHNOLOGY LAMP SOCKET STOCK

KEMA, INC., FINAL EVALUATION REPORT: UPSTREAM LIGHTING PROGRAM, VOLUME 2 (APPENDICES), 2010.



RESIDENTIAL LIGHTING

Lighting represents approximately 22% of the electricity use in a home.[1] Energy-use awareness is rapidly becoming a common household conversation topic as outreach efforts are launched from all sectors of the energy and appliance industries. In lighting, new light emitting diode (LED) products are flooding the marketplace, each with claims of energy efficiency and longevity. Consumers search for guidance about whether these products will live up to their claims. In parallel, new compact fluorescent lamp (CFL) products continue to be introduced, and many efficiency proponents advocate an increase in the uptake of CFLs in the home.

Development of market transformation programs that help clarify appropriate applications for these products and help reduce their cost is key to reaching California's long-range energy-efficiency goals. For instance, a typical kitchen lighting system for can range from 700W with incandescent lighting to 300–400W for CFLs and 100–150W for emerging LEDs. Four years ago, CFL downlights were roughly $100 each, and they now cost 50% less. Currently, LED downlights are approximately $100 each, and a market transformation program could reduce their costs by a similar amount. Market transformation programs, incentives, demonstrations, and concise information will accelerate adoption of these lighting products and systems.

FEATURED OVERVIEWS

- Dimmable CFLs
- Halogen IR
- LED Fixtures and Systems
- Residential Occupancy Controls
- Super Lamp

[1] California Public Utilities Commission, "California Long-Term Energy Efficiency Strategic Plan," September 2008.

DIMMABLE CFLs

ENERGY-SAVINGS ESTIMATES:
Retrofit of incandescent to CFLs saves 75%. Dimming CFLs increase this savings.

The landscape has changed. Light sources intended to replace inefficient incandescent lamps are gaining popularity. While consumers push to reduce personal energy bills, legislation has mandated statewide reductions in the residential and commercial sectors. For example, Huffman AB 1109 calls for reducing California's energy consumption for general-purpose indoor lighting by 50% by 2018. Homes and businesses are switching to Compact Fluorescent Lamps (CFLs) because of their energy-savings potential and longer life (6 – 12 times) to help lower costs.

Dimming an incandescent light source in a residential application is inexpensive and simple to do. Residential incandescent lamps can be connected to easily accessible dimmers purchased from a local hardware store or do-it-yourself (DIY) retailer. However, standard CFLs cannot be used with most commercially available dimmers.

ENERGY-SAVING OPPORTUNITIES:

The general rule for CFL energy savings is 75% compared to comparable incandescent products. Dimmable CFLs, when used in appropriate applications, can further increase energy savings.

CURRENT MARKET STATUS:

A large number of standard CFL products are on the market today, and the compact fluorescent lamp has become a showpiece for energy efficiency. Although consumer product awareness is high, consumer confidence remains relatively low. Complaints about color and lifespan hinder efforts to increase CFL adoption rates. California boasts a 21% adoption rate, higher than other states, but this rate is still low compared to market goals.

A large number of standard CFL products are on the market today, but the number of dimmable CFL products stocked in stores is relatively low. In a recent survey, not more than 7% of the CFLs stocked were dimmable. Various types of retail location were surveyed, from discounters to large membership clubs.[1]

BARRIERS TO MARKET ADOPTION:

Most commercially available dimmable CFL products are not approved by both the CFL manufacturer and dimmer manufacturer to work together. For example, at the start of 2009, Lutron had approved only three dimmers to work with two Phillips dimmable CFLs. Lutron accounts for about 50% of the dimmers on the market. Leviton has not approved any. The lack of choice and compatibility among dimming products is primary market adoption barrier.

A second market barrier is low consumer awareness regarding dimming capabilities of standard CFLs. When a user switches to a standard CFL and keeps existing incandescent wall dimmers, the standard CFL will not function properly and may cause the lamp or dimmer to fail. Low consumer confidence in CFLs for dimming applications, creates a major market barrier to larger standard CFL market.

1 The Cadmus Group, Inc.: Energy Services, "Compact Fluorescent Lamps Market Effects Final Report," April 2010.

EXAMPLE PRODUCTS IN THE MARKETPLACE:

OSRAM SYLVANIA: DULUX EL DIMMABLE REFLECTOR CFL
www.sylvania.com
- Saves up to 75% in energy compared to similar lumen output incandescent lamps
- 6,000–10,000 hour average rated lamp life
- Flicker-free starting
- 82 CRI
- 3,000K color temperature

MAXLITE: DIMMAX DIMMABLE CFL
www.maxlite.com
- 6,000-hour average rated lamp life
- Instant-on, flicker-free electronics
- 84 CRI
- 2700K color temperature

PHILIPS: ENERGY SAVER DIMMABLE REFLECTOR FLOOD
www.lighting.philips.com
- 8,000-hour average rated lamp life
- Compatible with selected dimmers
- 82 CRI
- 2700K color temperature

HALOGEN IR

ENERGY-SAVINGS ESTIMATES:
30% over a 60W incandescent.

Traditional incandescent lamps emit most of their energy within the infrared region of the electromagnetic spectrum, resulting in a very low efficacy—typically in the range of 10–15 lm/W. Tungsten Halogen IR lamps offer the potential for significant increases in efficacy as a function of increased filament temperature because of enhanced infrared coatings. A halogen fill gas also allows the filaments to operate at a higher temperature without a corresponding loss in lamp lifetime because of the regeneration of the filaments through a halogen cycle. The potential efficacy for traditional Halogen capsules for traditional Halogen IR configurations can be in the 19–20 lm/W region. Various forms of this enhanced halogen configuration have been developed in the "A" lamp configuration. Halogen IR capsules have been used in PAR lamp configurations for a number of years.

A combination of both multilayer coatings and internal optics has indicated that the efficacy can be potentially increased to about 25–30 lm/W for "A" lamp configurations. This increase in efficacy is because of a much more sophisticated multi-layer coating, which is highly transmissive to visible and highly reflective to infrared, thereby increasing the efficiency of filament heating. Additional efficiency is achieved by the internal capsule being configured as an optical reflector allowing for a much more precise internal reflection of the infrared on to the filaments itself. Ongoing research has indicated that this efficiency might be as high as 40 lm/W (Measured in the laboratory with very high efficiency coatings in combination with enhanced internal optics). However, there are no products on the market at this efficacy at this time.

A further opportunity in California exists with downlighting applications that currently use 65W bulged reflector (BR) lamps in the 10–11 lm/W region with a traditional filament. These lamps are ideal application for second-generation Halogen IR configurations, which would bring the efficacy to about 20 lm/W. In summary, there are three HIR opportunities for residential applications:

1. Near-term HIR "A" lamp configurations with an efficacy of ~20 lm/W
2. Mid-term HIR "A" lamp configurations with an efficacy of ~30 lm/W
3. Mid-term HIR/BR lamp configurations with an efficacy of ~20 lm/W

ENERGY-SAVING OPPORTUNITIES:
Near-term opportunity exists with halogen "A" lamp configurations in both 40 and 60 W versions, for the California marketplace. Commercial versions of both the 40 and 60 W lamp are currently available. A 60W lamp at about 15 lm/W can be replaced with a 40W operating at about 20 lm/W. This represents about 30% savings.

CURRENT MARKET STATUS:
The industry currently markets various wattages of conventional halogen technology in "A" lamp configurations, but predominantly to the long life market. The manufacturing community therefore has capability to quickly commercialize "standard" halogen technology in "A" lamp configurations at normal voltage for the 40–100W equivalents. A number of manufacturers have test marketed various kinds of Halogen infrared products addressing for "A" lamps. A report recently done by Chris Calwell of Ecos indicates that 20 lm/W Halogen IR configurations are available, but in limited quantities. Discussions with manufacturers indicate that this availability could significantly change depending upon market pressures. Halogen lamps with next-generation multi-layer infrared coatings are still in the development phases, but laboratory prototypes do exist in the 30 lm/W region.

EXAMPLE PRODUCT IN THE MARKETPLACE:

PHILIPS: ECO CLASSIC

www.philips.com

- 42 W
- Uses up to 30% less energy than a standard bulb
- Lasts up to two years
- Fully dimmable

BARRIERS TO MARKET ADOPTION:

In the near-term, high initial costs are associated with 20 lm/W Halogen IR products because of limited production volumes. Customers searching for a light quality comparable to the incandescent may purchase the Halogen IR as a niche product, but they are generally more expensive than other options.

Production barriers also exist for the next-generation enhanced tungsten Halogen IR. Multi-layer coatings and internal optics require complex processes to cost-effectively produce lamps at high volume. However, if the production challenges are overcome, the 30 lm/W Halogen IR will have a greater cost benefit associated with it and could potentially achieve significant energy savings without the compromise in quality or appearance.

Lastly, competition from other longer-life sources such as CFLs and light emitting diodes (LED) may draw market share away from Halogen IR. The more efficacious Halogen IR products may not reach the marketplace if this occurs.

LED FIXTURES AND SYSTEMS

ENERGY-SAVINGS ESTIMATES:[1]
Typical LED-equivalent products for residential use can achieve up to 80% energy savings over existing incandescent sources and up to 40% over CFL sources.

Residential lighting products range from consumer do-it-yourself kits to architectural specification-grade fixtures. The majority of residential light fixtures still use incandescent lamps. Because incandescents are high color-quality sources, metrics like correlated color temperature (CCT) and color rendering index (CRI) are important to consider when evaluating a product for the home. Many of these residential lighting applications have low profile or small form factor fixtures. This presents a challenging design problem when converting a traditional residential fixture from an incandescent to LED light source. Small form factors have reduced surface area, which is essential for dissipating heat generated by the LED. Proper thermal management is critical to maintain long-term light output and product life.

ENERGY-SAVING OPPORTUNITIES:

Lighting plays a significant role in residential energy consumption and presents an excellent energy-savings opportunity. LEDs offer leverage to accelerate market adoption. A significant amount of residential use coincides with California peak demand periods. Residential lighting use increases in late afternoon when many Californians arrive home from the day's activities. For example, a typical kitchen built before the 2005 Title 24 code uses 700W where an LED kitchen with a similar light output might use as little as 100–150 W.

CURRENT MARKET STATUS:

A variety of residential LED lighting products are available, ranging from affordable battery-powered products to architectural products for high-end homes. Quality and product reliability is not directly related to the cost. There are expensive products that underperform as well as affordable options that are very reliable. It is difficult for consumers to discern between the two at this stage of market adoption.

BARRIERS TO MARKET ADOPTION:

Initial cost is a significant barrier for consumer-grade LED products when compared to traditional technologies. Color temperature, color quality, and color consistency pose major obstacles to widespread adoption. It will be difficult for consumers to predict how different products will compare. To help avoid premature erosion of consumer confidence, color quality information should be researched, documented, and made available by both the public and private sectors in a well-designed, easy-to-understand format. Some information campaigns are under development to assist with consumer education on LED luminaires. The DOE Lighting Facts (TM) icon, for example, now appears on many LED products. These efforts are expected to increase market adoption, but additional support is needed.

Wide variation in product reliability also will affect buyer confidence in the technology. As consumers gain experience with unreliable products, their adoption of similar technologies will decrease. Product warranties that reflect the lifespan of the products should be offered to show manufacturer confidence in longevity claims. From the development side, manufacturers will need to adhere to high quality standards. However, these standards do not yet exist. Development of these standards will be critical to market growth.

[1] Navigant Consulting Inc., "Energy Savings Estimates of Light Emitting Diodes in Niche Lighting Applications", September 2008.

EXAMPLE PRODUCTS IN THE MARKETPLACE:

PROGRESS LIGHTING: STARLITE COLLECTION LED CHANDELIER
www.progresslighting.com
- Uses 3W per shade
- Dimmable with most standard controls

PERMLIGHT: LED PORCH LIGHT
www.brillialed.com
- Thermally conductive LED arrays
- LED drivers including dimmable and wide-input voltage range

COOPER LIGHTING: HALO LED DOWNLIGHT
www.haloltg.com.com
- ENERGY STAR® compliant
- CCT choices of 2700K, 3000K, 3500K, and 4000K
- Dimmable to 15%
- Rated for 50,000 hours

RESIDENTIAL OCCUPANCY CONTROLS

ENERGY-SAVINGS ESTIMATES:

- Assuming a 50% occupancy rate for residential spaces, California could save 11% in total annual residential energy consumption.
- Nationwide, savings could reach 100 billion kWh

Occupancy controls, used primarily in commercial applications, are viable energy-saving strategies for residential applications. In California, 22% of household energy consumption is attributed to lighting. The addition of occupancy and motion controls could reduce this use. Title 24 for Residential applications only requires occupancy controls for permanently installed, low-efficacy sources used in exterior or common areas. Many opportunities exist to extend residential occupancy controls beyond these niche applications.

ENERGY-SAVING OPPORTUNITIES:

Residential Occupancy Controls have a 50% potential energy savings. Their two-room (bathroom and laundry) savings is 798 – 1,793 GWh / yr, and their carbon offset is 262 – 589 thousand metric tons CO_2/yr.

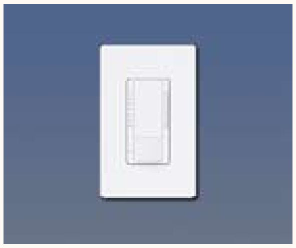
CURRENT MARKET STATUS:

There are no maintenance or environmental issues associated with occupancy sensors. Some sensors may require recycling as electronic waste. Occupancy controls are widely available but appear very underused in residential applications. These controls potentially could be installed in a majority of residences, or about 11.9 million homes.

BARRIERS TO MARKET ADOPTION:

Lack of consumer awareness of available occupancy controls and incentives presents a significant market barrier. Few hours of use decrease cost-effectiveness. In addition, residential new construction energy code does not require occupancy controls, with the exception of a few niche applications.

EXAMPLE PRODUCTS IN THE MARKETPLACE:



LUTRON:
MAESTRO DIMMER WITH OCCUPANCY SENSOR
www.lutron.com

- Turns lights off after the room is vacated
- Vacancy only version (manual-on / auto-off) meets California Title 24 requirements
- Also available as a switch with remote sensor

LEVITON:
RESIDENTIAL OUTDOOR OCCUPANCY SENSOR (RS110-1FB)
www.leviton.com

- Control dual floodlights in backyards, entrance ways, and porches
- 2,500 ft^2 coverage area
- Controls up to 500 W

WATTSTOPPER / LEGRAND:
RS-150BA-N PIR WALL SWITCH VACANCY SENSOR WITH NIGHTLIGHT
www.wattstopper.com

- Meets California Title 24 requirements
- Fixed 30-minute time delay
- Integral LED nightlight

SUPER LAMP

ENERGY-SAVINGS ESTIMATES:[1]

- 405 million potential sockets
- Total potential reduction in installed power: 16.8 GW (7.5 times largest power plant in California, San Onofre nuclear plant)

[1] California Lighting Technology Center, "Efficiency Opportunities for Edison-based Luminaires," 2007. http://cltc.ucdavis.edu/images/cltc lamp report.pdf.

The Super Lamp, a technology development initiative including Pacific Gas & Electric, Southern California Edison, San Diego Gas & Electric, Sacramento Municipal Utility District, the Natural Resources Defense Council, and the California Lighting Technology Center (CLTC), is aimed at promoting the introduction and dissemination of high-quality, high-efficacy, screw-base light sources that address major issues consumers previously have raised about technologies such as the compact fluorescent lamp (CFL). The goal of the initiative is to make high-efficacy technologies — the CFL, integral light emitting diode lamp (LED), or others — the mainstream choice for screw-base sockets in California.

ENERGY-SAVING OPPORTUNITIES:

Preliminary results from KEMA's ongoing CPUC Residential Lighting Metering Study indicate that CFLs occupy only 21% of sockets in California households. The Super Lamp is aimed at replacing the incandescent lamps that still occupy 61% of California sockets. At an average of 50 sockets for each of the 12 million California households, this represents a total of about 405 million potential sockets.

CURRENT MARKET STATUS:

This initiative is aimed at promoting the introduction into the market of products that are technically feasible but not yet available. The Super Lamp technical specification[1] has been published, and CLTC is accepting prototypes for testing.

BARRIERS TO MARKET ADOPTION:

Several barriers have hindered greater adoption of high-efficacy technology for screw-base sockets in California, including negative perceptions of past fluorescent technology, lack of commercially available products, and unsatisfactory user experiences with current technology. Complaints about noise and flicker have been common, as well as early failures. Early failures can frequently be ascribed to operation in environments that are outside the product's design performance criteria; for example, most CFLs and some LED integral lamps are not designed for operation in enclosed fixtures or with electronic or dimming switches. Other important issues are color, run-up time, size, and mercury content.

[1] Spec sheet available at http://cltc.ucdavis.edu/images/documents/articles/lda/2010_super_lamp_specification.pdf

EXTERIOR LIGHTING

Exterior lighting is often on for extended periods of time, if not 24 hours a day. By combining high-quality sources with bi-level controls, the energy use can be reduced with immediate results. In the past, high pressure sodium lamps were the most efficient choice. However, the quality of light was sacrificed for efficiency. Improved ballasts for induction lamps, emerging LED luminaires, and new improvements in HID sources broaden the scope of choices. When combined with the right sensors to maximize efficiency without compromising safety, exterior lighting can be vastly improved, typically saving more than 50% in retrofit applications. A parking lot conversion to smart parking lot lighting will save 30–50%. The statewide total technical potential could be up to 2,000 GWh per year. Market transformation, incentive, demonstration, and education programs will assist in rapidly moving these technologies into practical applications.

FEATURED TECHNOLOGY OVERVIEWS

- Smart Exterior Lighting for Commercial Applications
- Next-generation Street Lighting

SMART EXTERIOR LIGHTING FOR COMMERCIAL APPLICATIONS

ENERGY-SAVINGS ESTIMATES:[1]

- Average savings, 30–50% energy savings (highly technology/application dependent)
- 300–2,000 GWh annual total technical potential statewide
- Demand reduction of 60–460 MW

[1] California Lighting Technology Center, www.cltc.ucdavis.edu.

Exterior lighting, including parking, area, and security lighting, represents 3,067 GWh and 1.4% of California's energy usage.1 Exterior lighting is generally controlled by facility management systems, photocells, and/or astronomical time clocks and is operated about 11 hours per day during summer and 14 hours per day during the winter. Parking garages generally are lit 24 hours per day. A significant portion of the energy used in exterior applications occurs during periods of limited occupancy in the illuminated area. Bi-level controls, which switch lighting between high and low levels rather than on and off, offer a method to harness the total technical potential of these unoccupied exterior applications. When completely turning off the lights is not acceptable, switching to a low level provides sufficient light for security and way finding. This creates opportunities for bi-level lighting systems that lower lighting levels during unoccupied periods.

Smart, exterior lighting is technology neutral; it does not favor one type of light source over another. Many types of traditional exterior light sources, as well as new technologies such as light emitting diode (LED) and induction lighting, can be used with motion sensor lighting controls. This will make smart, exterior lighting flexible and competitive, as well as meet design preferences in most applications.

ENERGY-SAVING OPPORTUNITIES:

Recent demonstration projects sponsored by the California Energy Commission have shown that motion sensors, in combination with specially equipped luminaires, can safely reduce light levels during vacant periods in many exterior, commercial applications.[2] Demonstrated applications include pedestrian walkways and bikeways; parking lots and garages; and perimeter building security lighting. Energy savings result from improved source efficiency and from the addition of controls. Security is maintained because light levels are never completely turned off, which preserves a sense of personal security for Californians. Safety is enhanced because light levels are conspicuously brought up to full brightness when someone is present. There is also an increased maintenance savings because many types of lamps, when dimmed, have significantly longer lives.

Typical savings of 30–40% can result from the addition of occupancy controls. Motion-activated lighting controls and bi-level luminaires can be added to lighting systems in parking lots, parking garages, outdoor pathways, and security lighting. Retrofit projects may involve replacing luminaires, or simply installing controls in line with exis ing systems, depending on the needs of the particular application.

CURRENT MARKET STATUS:

Although the technology for bi-level control of exterior lighting is not new, products were not readily available until recently. Now, several major manufacturers, including Lithonia Lighting , BetaLED, Day-Brite, Emco, Gardco Lighting, Widelite, and Everlast Lighting have developed or are developing bi-level lighting technology for exterior applications. Several of these manufacturers participated in the California Energy Commission's Public Interest Energy Research (PIER) Program Research & Development projects to develop the smart bi-level technology, and also participated in the subsequent demonstrations of seven bi-level systems, including pole mount, deck mount, edge mount, wall pack, and bollard

[1] Sam Pierce (RLW Analytics). 2003. California Outdoor Lighting Baseline Assessment. California Energy Commission, PIER Program. P500-03-082-A-18. This category does not include landscape lighting or commercial and industrial architectural outdoor lighting.

2 http://www.terradex.com/PublicPages/CIEE/PIER_01.aspx, http://www.pierpartnershipdemonstrations.com

EXAMPLE PRODUCTS IN THE MARKETPLACE:

GARDCO LIGHTING: LED BOLLARDS
www.sitelighting.com
- Uses motion-sensing technology to switch between low-light and high-light modes
- Bi-level LEDs increase lifetime because of the reduced temperatures
- Stacked modular louvers control glare and uniformly distribute light
- 41 W high mode and 8 W low mode

BETALED: THE EDGE
www.betaled.com
- LED provides long life source for increased maintenance savings (about 70,000 hrs)
- 75 CRI
- Good source efficacy, increasing annually. Current source efficacy of 70–90 lm/W
- No mercury, can be easily recycled
- Fully dimmable

EVERLAST: BI-LEVEL 100 W INDUCTION
www.everlastlight.com
- Energy-efficient induction lamps
- Integrated occupancy sensor controls light output
- Applications: parking garages, gas stations, schools, shopping malls
- CCT: 5000 K

systems, using Metal Halide, Induction, and LED illumination sources. Successful projects by early adopters are expected to catalyze market acceptance and lead to increased offerings.

BARRIERS TO MARKET ADOPTION:

Perceived safety issues with the bi-level system pose a barrier to market adoption. Safety is paramount in public spaces; therefore, control algorithms must be robust to successfully demonstrate that dynamic lighting changes can still produce recommended illumination under different exterior conditions, regardless of whether the light is in high or low mode.

A second barrier to the market is the current lower luminaire efficacy of LEDs, a lighting source often employed in bi-level exterior applications, compared to many High Intensity Discharge (HID) sources. High Pressure Sodium (HPS) lamps achieve 80-120 lm/W compared to 60–70 lm/W for typical general illumination LEDs. While LED luminaire efficacy still lags behind many types of HID luminaires, LED luminaires are poised to become an energy-efficient, environmentally friendly alternative to traditional exterior luminaires. Current studies anticipate LEDs will achieve source efficacies of about 200 lm/W for low color rendering index (CRI) devices and 130 lm/W for very high CRI devices by 2027.[3] In the two years since the release of these estimates, private research and development shows manufacturers may reach this target much sooner.

Economics may present an additional barrier to market acceptance. Initial product cost is estimated to be high, as with many emerging technologies, but successful demonstrations and utility participation are anticipated to drive down initial costs. Increasing efficacies of alternative light sources such as LED and induction also will reduce luminaire pricing and increase energy savings.

[3] Navigant Consulting, Inc., Energy-Savings Potential of Solid State Lighting in General Illumination Applications: Final Report. Prepared for U.S. Department of Energy, December 2006. http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/ssl_energy-savings-report_10-30.pdf.

NEXT-GENERATION STREET LIGHTING

ENERGY-SAVINGS ESTIMATES:[1]

- 20–40% energy savings (highly technology/application dependent)
- 5,000–10,000 GWh annual potential energy savings[2]
- Instant to six-year simple payback in new construction projects when compared to traditional HPS luminaires[3]
- 8–15 year simple payback in retrofit projects compared to HPS luminaires
- The addition of network-enabled monitoring and diagnostics could lead to an additional 10–20% maintenance cost savings

[1] California Lighting Technology Center, www.cltc.ucdavis.edu.

[2] Assumes 10% of national savings estimate.

[3] Assumes 12/7 operation. Incremental cost increase over HPS. Energy savings compared to HPS.

About 38 million street lights are estimated to be in operation in the U.S[1]. This amount is anticipated to grow at an annual rate of 1–1.2% over the next two decades[2]. Concerns regarding energy efficiency and light pollution are growing at an equivalent pace. Many states have passed legislation regulating the types, amounts, and placement of outdoor stationary lighting to reduce sky glow and light pollution. In addition, some states have passed energy-efficiency standards such as California's Titles 20 and 24, which affect roadway lighting. With growth and environmental concerns apparently at odds, lighting manufacturers have begun to offer innovative street light solutions that solve both problems. These technologies include the use of alternative light sources such as induction, Metal Halide (MH), and light emitting diodes (LED) used in combination with electronic generators, ballasts, and drivers. Digital communication control functionality also is beginning to infiltrate the market and may present a viable solution to reduce maintenance and operating costs associated with street lighting.

ENERGY-SAVING OPPORTUNITIES:

Roadway lighting consumes about 4% of the total energy in the United States[3]. This equates to 412 TWh ($kWh \times 10^9$) of electricity per year. About 60% of existing luminaires use High Pressure Sodium (HPS) lamps, which could potentially be replaced with lower wattage, longer-life, high color rendering index (CRI) alternatives. Proposed alternative sources offer significantly increased correlated color temperature (CCT) and CRI. Humans require less of this type of light to see compared to HPS, which has a very low CCT and CRI. The use of high CCT, high CRI light sources can lead to a lower installed demand (less lumens required) and increased energy savings. By using white light sources with better color rendering ability, the average power demand of these luminaires could be reduced by 20–40%.

CURRENT MARKET STATUS:

The primary consumers of roadway fixtures are state departments of transportation, such as CALTRANS, municipal operating authorities (MOA), and utility companies. The majority of highway systems are maintained by the states, with lighting requirements passed down from the Federal Highway Administration. Street lighting, residential and commercial, is typically determined at the municipal level. The specifications for new construction and retrofits usually include style and wattage of fixture, but not necessarily type, leaving significant potential for innovative products to penetrate the market assuming their cost and light characteristics are comparable to traditional High Intensity Discharge (HID) sources.

In addition to new construction projects, roadway lighting maintenance is estimated at 38% annual turnover of fixtures, providing another significant sales market. Municipal street light maintenance is usually handled by city public works departments or regional utility companies. The city of Los Angeles for example, maintains more than 240,000 street lights through the city's Bureau of Street Lighting. At 38% annual replacement, this equates to more than 91,000 lamp replacements in Los Angeles alone.

[1] Parking lots and garages not included.

[2] Navigant Consulting, Inc., U.S. Lighting Market Characterization Volume I: National Lighting Inventory and Energy Consumption Estimate. Prepared for U.S. Department of Energy, September 2002. http://apps1.eere.energy.gov/buildings/publications/pdfs/corporate/lmc_vol1.pdf.

[3] Navigant Consulting, Inc., Energy-Savings Potential of Solid State Lighting in General Illumination Applications: Final Report. Prepared for U.S. Department of Energy, December 2006. http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/ssl_energy_savings_potential_report_2006_final4.pdf.

EXAMPLE PRODUCTS IN THE MARKETPLACE:

HADCO: EVOLAIRE™ STREET AND AREA LUMINAIRE

www.hadco.com

- Articulating panels allow for precise positioniong of the coverage area
- LED source panels are removable and replaceable
- Midnight dimming option automatically reduces light during late night hours

EVERLAST LIGHTING: INDUCTION COBRAHEAD

www.everlastlight .com

- Integrated occupancy sensor dims fixture to 40% power for increased energy savings
- 50–70% energy savings over HPS and HID
- 82–85 CRI
- Full cutoff heavy duty aluminum/hybrid interior design with increased durability for harsh environments

PHILIPS: COSMOPOLIS™ HID OUTDOOR LIGHTING SYSTEM

www.lighting.philips.com

- Ceramic Metal Halide source
- Excellent lamp efficacy: 117 lm/W
- 70CRI
- Bright, white light

BARRIERS TO MARKET ADOPTION:

The primary market barrier to adoption of innovative street light technologies is cost. Alternative sources such as induction and LED can be two to five times more expensive than traditional HID luminaires. Lifetimes of alternative sources are steadily increasing, and lifecycle maintenance savings may alleviate some of the initial cost. Increasing efficacies of alternative light sources also are expected to reduce luminaire pricing and increase energy savings.

A second market barrier is the current lower luminaire efficacy of many alternative sources compared to a traditional HPS lamp. HPS lamps achieve 80–120 lm/W compared to 60–90 lm/W for typical induction and general illumination LEDs. Lamp efficacy is continuously increasing, however. Recent research and development results released by Cree LED state its next-generation LEDs have achieved 161 lm/W.[4] Some Ceramic MH lamps, on the other hand, now can directly compete with HPS in terms of luminaire efficacy. The CosmoPolis™ Outdoor Lighting System offers a high system efficacy at 117 lm/W, directly comparable to HPS.

[4] Cree, Inc. Cree XLamp® Lighting–Class LEDs, product specification sheet. http://www.cree.com/products/pdf/XLamp%20Lighting%20Class.pdf, accessed November 30, 2008.

BEST PRACTICES:
TOTAL TECHNICAL POTENTIAL SAVINGS ESTIMATES FOR SIX TARGET APPLICATIONS

BEST PRACTICE:
Coordinated technologies, systems and design approaches, which (through research and experience) demonstrate the ability to consistently achieve above standard results while avoiding negative environmental impacts. Best Practice changes over time as improved components, technologies, systems, and design approaches become available.

STANDARD PRACTICE:
Standard practice includes techniques, policies, methodologies, procedures, technologies, and systems that are typically employed by practitioners and generally do not achieve optimal results (in terms of energy efficiency, demand-responsiveness, high-quality, environmental sustainability, smart grid connectedness, and integration with renewable energy generation sources). For lighting, standard practices may include efficiency "floors" required by building codes.

The analyses contained in this section illustrate the energy and economic impact, over the next 10 years, of two very different approaches to lighting retrofit projects: best-practice lighting retrofits and standard-practice lighting retrofits. Best-practice alternatives require a paradigm shift from project stakeholders. People must look past initial costs with short simple paybacks, and focus on long-term energy and cost savings needed to meet the California Energy Efficiency Strategic Plan 2008 (CEESP) and 2009 Strategic Lighting Plan (SLP) goals. Once consideration is made for the lifecycle benefits of best-practice technologies, it becomes clear that continued implementation of standard lighting solutions will potentially trap 50% of the savings achievable through best practices approaches by 2020. Thus it is critical to convert California toward definition and adoption of best practices as soon as possible.

CALIFORNIA-SPECIFIC COMPARISON OF EXISTING, STANDARD AND BEST-PRACTICE LIGHTING SOLUTIONS FOR SIX KEY APPLICATIONS

TARGET APPLICATIONS	EXISTING PRACTICE	STANDARD PRACTICE	BEST PRACTICE
OFFICE LIGHTING	Based on lighting power density: W/ft^2 = 1.75	Title 24 2008 lighting power density (area method): W/ft^2 = 1.1	Task-ambient lighting design including bi-level occupancy controls and daylighting: W/ft^2 = 0.70
CLASSROOMS & CONFERENCE ROOMS	Based on lighting power density: W/ft^2 = 2.0	Title 24 2008 lighting power density (area method): W/ft^2 = 1.0	Integrated classroom lighting systems including occupancy controls daylighting: W/ft^2 = 0.70
INTERIOR HID	Standard HID lamps and magnetic ballasts	Same as existing practice	Electronic ballast replacements
COMMERCIAL INTERIOR	Incandescent downlights	CFL downlights	LED downlights
RESIDENTIAL INTERIOR	Incandescent downlights	CFL downlights	LED downlights
COMMERCIAL EXTERIOR	Existing outdoor stationary lighting, 87% is HID	Same as existing practice	Smart bi-level HID, induction or LED luminaires

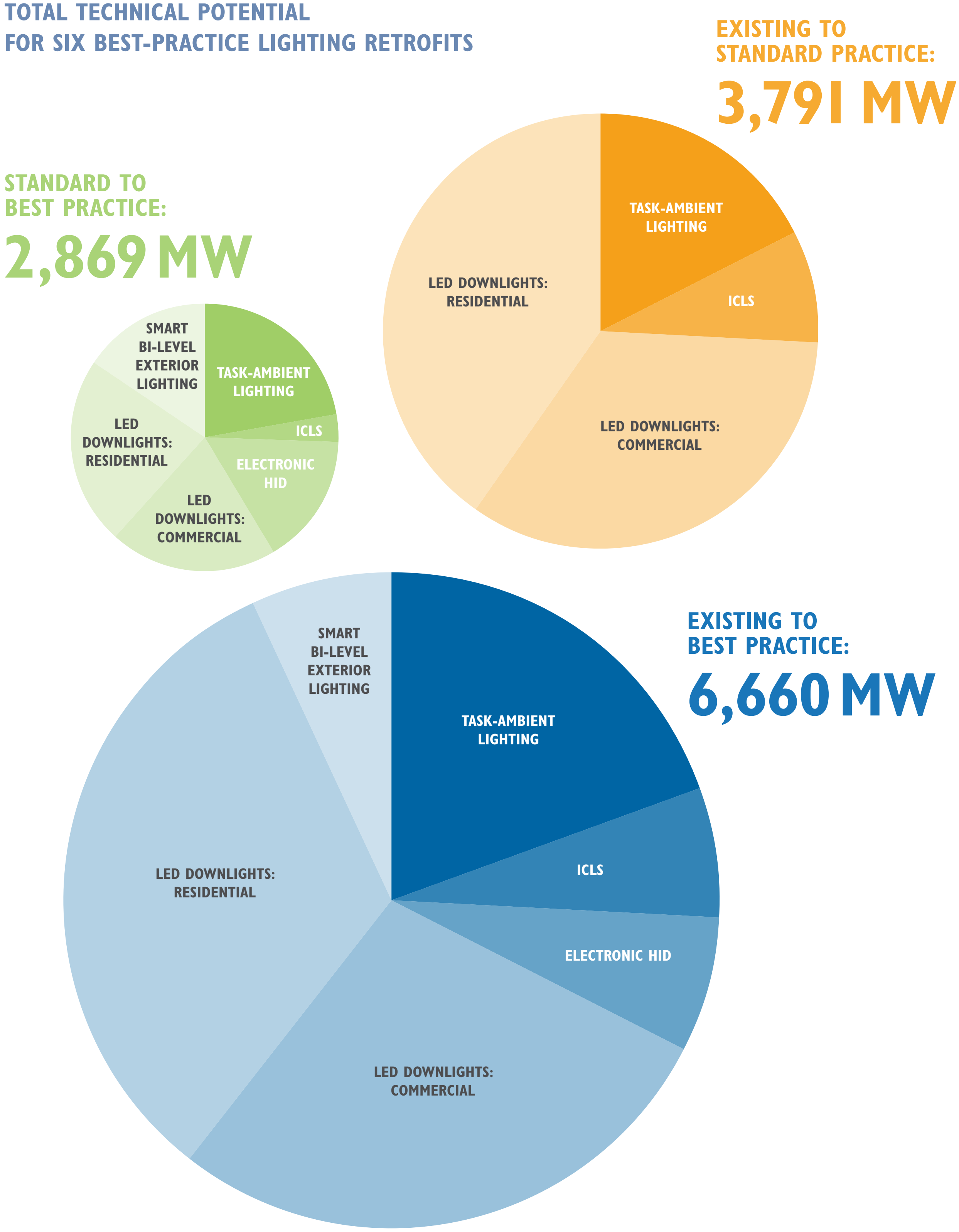
These examples demonstrate that twice the initial investment will result in twice the energy and cost savings. Best practices provide California with twice the energy and peak demand savings, over the next 20 years, at the same overall cost per kWh saved. This example is based upon the six specific lighting applications and best practice solutions described above. For only these six examples, the accumulated 10-year best practice savings compared to standard practice is 90,565,093 MWh or 780 million metric tons of CO_2, as well as 2,869 MW of electric demand reduction. The assumptions used to determine the figures in this section are located in the notes section at the end of this document.

Accumulated savings for these six best-practice lighting retrofits is approximately twice that of standard-practice retrofit measures.

- 180,722 GWh saved for best practice compared to existing practice
- 90,156 GWh saved for standard practice compared to existing practice
- 6,660 MW demand reduction for best practices compared to existing practice
- 3,791 MW demand reduction for standard practice compared to existing practice
- 1557 million metric tons of CO_2 saved by best practice compared to existing practice
- 777 million metric tons of CO_2 saved by standard practice compared to existing practice

DEMAND SAVINGS SUMMARY

TOTAL TECHNICAL POTENTIAL FOR SIX BEST-PRACTICE LIGHTING RETROFITS

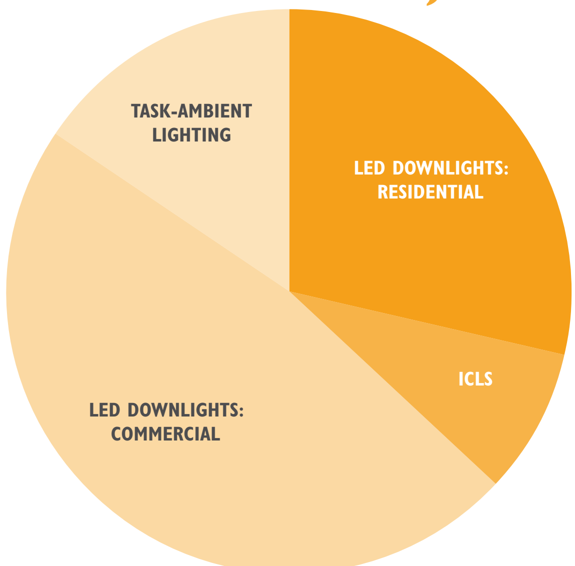


ACCUMULATED ENERGY SAVINGS

TOTAL TECHNICAL POTENTIAL FOR SIX BEST-PRACTICE LIGHTING RETROFITS

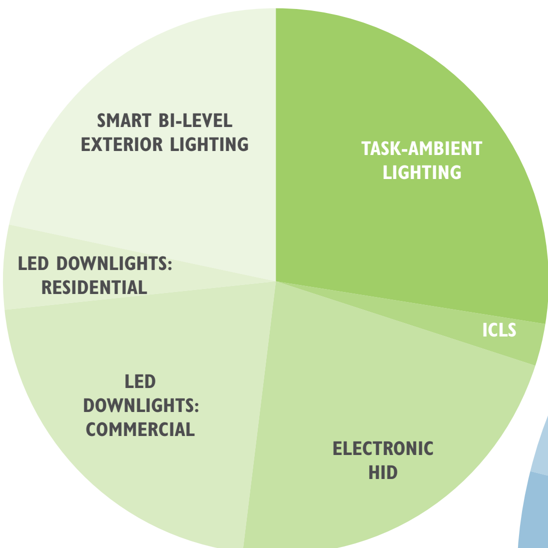
EXISTING TO STANDARD PRACTICE:

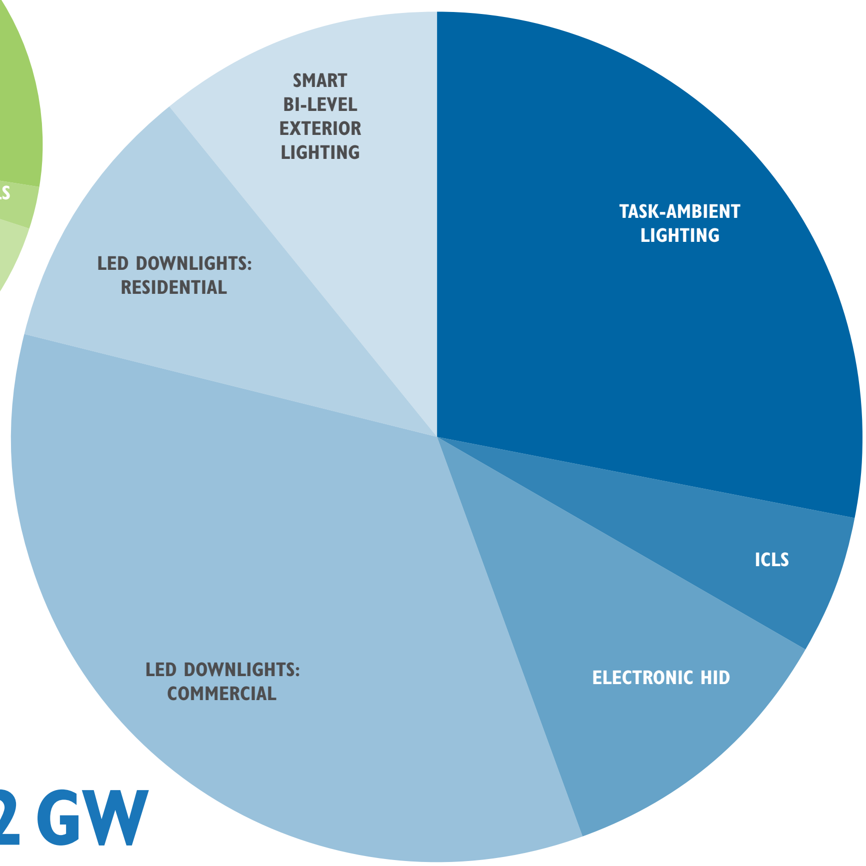
90,156 GW



STANDARD TO BEST PRACTICE:

90,565 GW





EXISTING TO BEST PRACTICE:

180,722 GW

ACCUMULATED ENERGY SAVINGS (GWh)

TOTAL TECHNICAL POTENTIAL FOR SIX BEST-PRACTICE LIGHTING RETROFITS

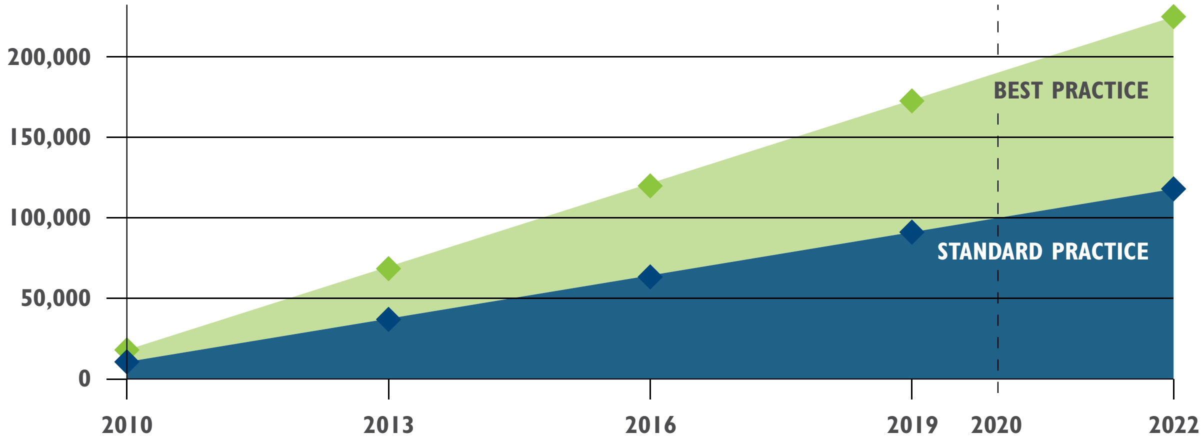
The total initial investment for these best-practice alternatives is also approximately twice as much as an investment in standard practice solutions; although, if the initial investment were expressed in terms of dollars spent per kWh saved ($/kWh), the best-practice solutions are comparable, and in some cases less expensive than their standard-practice equivalents.

Estimated initial investment cost for statewide implementation of lighting retrofits:

- $24 billion for best practices
- $12 billion for standard practices

Initial investment cost per kilowatt hour saved:

- $1.32/kWh for best practices
- $1.29/kWh for standard practices



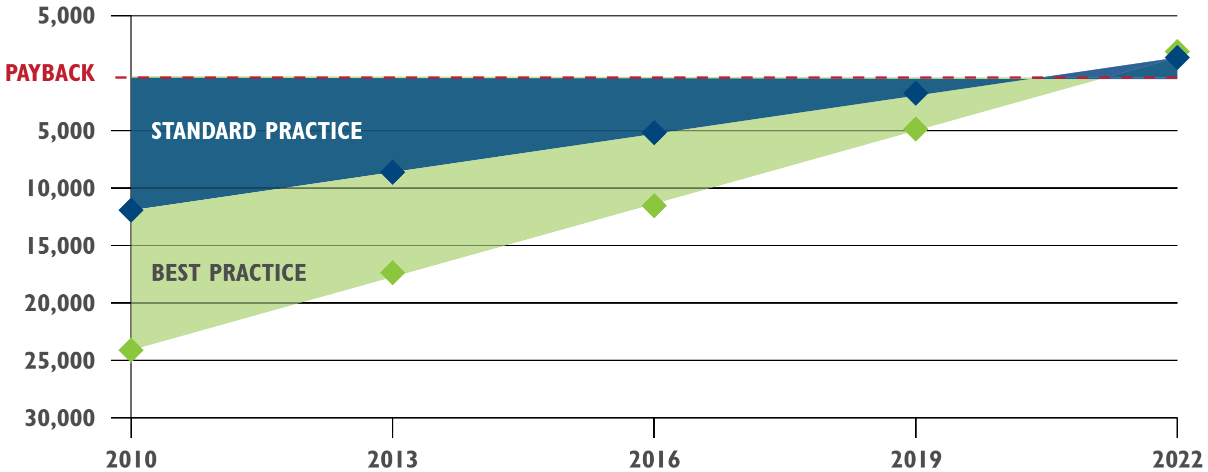
ACCUMULATED ENERGY SAVINGS SUMMARY

SIX TECHNOLOGIES ENERGY SAVINGS	YEAR SPAN	EXISTING TO STANDARD PRACTICE ACCUMULATED ENERGY SAVINGS (MWh/yr)	EXISTING TO BEST PRACTICE ACCUMULATED ENERGY SAVINGS (MWh/yr)
1 YEAR OF SAVINGS	2010–2011	9,015,698	18,072,207
2 YEARS OF SAVINGS	2010–2012	18,031,395	36,144,414
3 YEARS OF SAVINGS	2010–2013	27,047,093	54,216,620
4 YEARS OF SAVINGS	2010–2014	36,062,790	72,288,827
5 YEARS OF SAVINGS	2010–2015	45,078,488	90,361,034
6 YEARS OF SAVINGS	2010–2016	54,094,185	108,433,241
7 YEARS OF SAVINGS	2010–2017	63,109,883	126,505,488
8 YEARS OF SAVINGS	2010–2018	72,125,580	144,577,654
9 YEARS OF SAVINGS	2010–2019	81,141,278	162,649,861
10 YEARS OF SAVINGS	2010–2020	90,156,975	180,722,068
11 YEARS OF SAVINGS	2010–2021	99,172,673	198,794,275
12 YEARS OF SAVINGS	2010–2022	108,188,370	216,866,481

INITIAL INVESTMENT ($ MILLION) TO PAYBACK POINT

TOTAL TECHNICAL POTENTIAL FOR SIX BEST-PRACTICE LIGHTING RETROFITS

Although the initial investment is significantly higher for the best practice technologies, both the standard and best practice investments approach the payback point at a similar time. The assumption that the standard practice will payback in a drastically faster time frame is not supported once the calculations on both scenarios are compared.



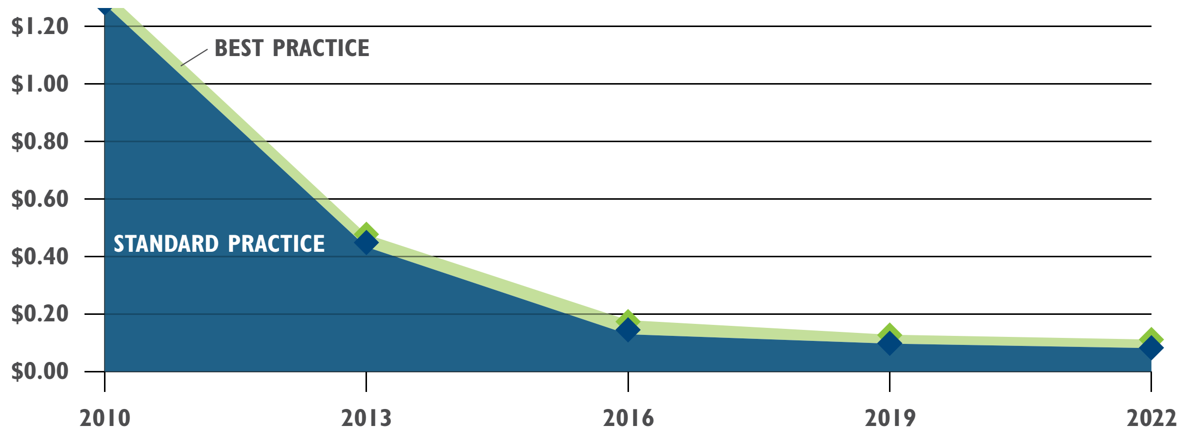
TECHNOLOGY IMPLEMENTATION COST SUMMARY

TECHNOLOGY / PRACTICE	APPLICATION	NUMBER OF UNITS	BEST PRACTICE COST PER UNIT	STANDARD PRACTICE COST PER UNIT	TOTAL BEST PRACTICE INVESTMENT	TOTAL STANDARD PRACTICE INVESTMENT
TASK-AMBIENT LIGHTING	Commercial office space	4,520,000	$1,360	$950	$6,147,200,000	$4,294,000,000
ICLS	Classrooms and conference rooms	356,931	$4,500	$2,500	$1,606,189,500	$892,327,500
ELECTRONIC HID	HID lamps in all interior applications	10,500,000	$200	—	$2,100,000,000	—
LED DOWNLIGHTS	Commercial interiors	39,408,600	$170	$97	$6,699,462,000	$3,822,634,200
LED DOWNLIGHTS	Residential interiors	43,486,800	$120	$68	$5,218,416,000	$2,957,102,400
SMART BI-LEVEL EXTERIOR LIGHTING	HID lamps in all exterior applications	4,776,300	$550	—	$2,626,965,000	—
				TOTAL	**$24,398,232,500**	**$11,966,064,100**

COST OF ENERGY SAVINGS ($/kWh)

TOTAL TECHNICAL POTENTIAL FOR SIX BEST-PRACTICE LIGHTING RETROFITS

Based on 10 years of estimated savings, the capital cost of the lighting retrofit per kilowatt hour saved ($/kWh saved) is significantly reduced and becomes comparable to typical electricity costs (state average electricity cost $0.128/kWh): $0.13/kWh for best and standard practices.



Considering a lifecycle approach, stakeholders must consider moving past standard lighting retrofit measures. Best-practices are economically viable alternatives that deliver double the energy savings, significantly reduce demand and green house gas emissions, and represent a logical approach to long-term energy efficiency.

ANNUAL ESTIMATED ENERGY SAVINGS

TOTAL TECHNICAL POTENTIAL FOR SIX BEST-PRACTICE LIGHTING RETROFITS

	EXISTING TO STANDARD PRACTICE		EXISTING TO BEST PRACTICE		STANDARD TO BEST PRACTICE	
TECHNOLOGY	**ENERGY SAVINGS (MWh/yr)**	**ENERGY SAVINGS (%)**	**ENERGY SAVINGS (MWh/yr)**	**ENERGY SAVINGS (%)**	**ENERGY SAVINGS (MWh/yr)**	**ENERGY SAVINGS (%)**
TASK-AMBIENT LIGHTING	2,590,000	37%	5,090,000	73%	2,500,000	57%
ICLS	751,698	50%	977,207	65%	225,509	30%
ELECTRONIC HID	—	0%	2,000,000	25%	2,000,000	25%
LED DOWNLIGHTS: COMMERCIAL	4,294,000	54%	6,221,000	78%	1,927,000	52%
LED DOWNLIGHTS: RESIDENTIAL	1,380,000	60%	1,835,000	79%	455,000	49%
SMART BI-LEVEL EXTERIOR LIGHTING	—	0%	1,949,000	40%	1,949,000	40%
TOTAL	**9,015,698**	**28%**	**18,072,207**	**50%**	**9,056,509**	**40%**

ANNUAL ESTIMATED ENERGY CONSUMPTION

TOTAL TECHNICAL POTENTIAL FOR SIX BEST-PRACTICE LIGHTING RETROFITS

TECHNOLOGY	EXISTING SYSTEM TOTAL ENERGY (MWh/yr)	STANDARD PRACTICE TOTAL ENERGY (MWh/yr)	BEST PRACTICE TOTAL ENERGY (MWh/yr)
TASK-AMBIENT LIGHTING	6,972,000	4,382,000	1,882,000
ICLS	1,503,395	751,698	526,188
ELECTRONIC HID	8,000,000	8,000,000	6,000,000
LED DOWNLIGHTS: COMMERCIAL	7,987,000	3,693,000	1,766,000
LED DOWNLIGHTS: RESIDENTIAL	2,310,000	930,000	475,000
SMART BI-LEVEL EXTERIOR LIGHTING	4,872,000	4,872,000	2,923,000
TOTAL	31,644,395	22,628,698	13,572,188

DEMAND SAVINGS SUMMARY

TOTAL TECHNICAL POTENTIAL FOR SIX BEST-PRACTICE LIGHTING RETROFITS

TECHNOLOGY	EXISTING SYSTEM TOTAL POWER (MW)	STANDARD PRACTICE TOTAL POWER (MW)	BEST PRACTICE TOTAL POWER (MW)	OPERATING TIME (HR/YR)
TASK-AMBIENT LIGHTING	1,789	1,124	483	3,898
ICLS	642	321	225	2,340
ELECTRONIC HID	1,826	1,826	1,370	4,380
LED DOWNLIGHTS: COMMERCIAL	2,386	1,103	528	3,347
LED DOWNLIGHTS: RESIDENTIAL	2,740	1,218	564	843
SMART BI-LEVEL EXTERIOR LIGHTING	1,112	1,112	667	4,380
TOTAL	10,496	6,705	3,837	

TECHNOLOGY	NOTES
TASK-AMBIENT LIGHTING	1, 2, 3, 4, 5
ICLS	6, 7, 8, 9
ELECTRONIC HID	10, 11, 12, 13, 14
LED DOWNLIGHTS: COMMERCIAL	11, 15, 16
LED DOWNLIGHTS: RESIDENTIAL	11, 15, 16
SMART BI-LEVEL EXTERIOR LIGHTING	11, 12, 17, 18

NOTES

1. Assumes 1.02 billion ft^2 of office space in California based on the California Commercial End-use Survey, Itron, March 2006 (Table E-1, Page 8).

2. Assumes 1.75 W/ft^2 for existing spaces based on 2008 Buildings Energy Data Book, U.S. Department of Energy, March 2009, Page 3–26: Lighting Average Power Density. It states that large offices (>25,000 ft^2) have a lighting power density of 1.3–1.8 W/ft^2 and small offices (<25,000 ft^2) have a lighting power density of 1.7–2.2 W/ft^2. The average of 1.3, 1.8, 1.7, and 2.2 is 1.75 W/ft^2. This value is also supported by reviewing the lighting power densities of multiple PIER demonstrations, including the Department of Mental Health, the Department of Motor Vehicles, Gexpro, UCOP, National Guard headquarters, UCSB recreation center, and Ziggurat buildings. The average lighting power densities for these buildings is 1.79 W/ft^2.

3. Assumes 1.1 W/ft^2 for office standard practice based on 2008 Building Energy Efficiency Standards for Residential and Nonresidential Buildings, Page 119 (Office: 250 square feet = 1.1).

4. **a.** Assumes 0.7 W/ft^2 for a task-ambient lighting approach based on Developing Lighting Technologies Integrated Office Lighting, California Lighting Technology Center, May 2008, Table 3, Page 30. The weighted average of 18 offices at 0.74 W/ft^2, 11 offices at 1.31 W/ft^2, and 54 offices at 0.56 W/ft^2 is 0.7 W/ft^2.

b. Assumes 0.53 W/ft^2 for task-ambient with multi-level occupancy sensors based on 2009 Lighting Technology Overview, California Lighting Technology Center, 2009, Page 8. Multi-level occupancy sensors can save 25% (0.7 – 0.7*25% = 0.53 W/ft^2).

c. Assumes 0.47 W/ft^2 for task-ambient with multilevel occupancy sensors and daylight harvesting based Saving Lighting Control Systems for Open-plan Offices: A Field Study; A.D. Galasiu, G.R. Newsham, C. Suvagau, and D.M. Sander; Leukos Vol. 4, No. 1, P. 7–20, July 2007, Page 26. If the daylight harvesting system were installed on its own, it could save 20%, but not all spaces can use daylight, so 10% savings was used as a conservative estimate (0.53–0.53*10% = 0.47 W/ft^2).

5. Assumes 3,898 h/yr based on the 2008 Buildings Energy Data Book, U.S. Department of Energy, March 2009, Figure 3.6.8, Page 3–26. It is the weighted average of large and small offices (4,190 h*66% + 3,360*34% = 3898 hr).

6. **a.** Assumes 0.29 billion ft^2 of classroom space in California from the Fact Book 2008: Handbook for Education Information, California Department of Education, 2008, Page 126 and an assumption that the average classroom is 900 ft^2. It takes the 299,503 classrooms for the 2007 school year and estimates 317,031 classrooms for the 2010 school year (317,031*900 = 0.28 billion ft^2).

b. Assumes 0.04 billion ft^2 of classroom space for California Universities and Colleges based on www.collegebound.net/content/article/california-colleges-and-universities/146. There are 399 colleges/universities and an assumption that the average college has 100 classrooms/institution (399*100*900 = 0.03 billion ft^2).

c. Assumes 0.32 billion ft^2 for classrooms in California (0.29 + 0.03 = 0.32).

7. Assumes 2.0 W/ft^2 for existing systems and 0.7 W/ft^2 for best practice was based on an estimate from averaging the W/ft^2 from three studies:

1. Lighting Research Program: Project 4.5 Integrated Classroom Lighting System Final Report, Finelite, October 2005.

2. Classroom Lighting System Demonstration Research Study Final Report, Finelite and the Lighting Research Center, Date Unknown.

3. Lighting California's Future Retrofit Integrated Classroom Lighting System project being conducted by the CLTC.

8. Assumes 1.0 W/ft^2 for classroom standard practice based on 2008 Building Energy Efficiency Standards for Residential and Nonresidential Buildings, Page 119.

9. Assumes 2,340 h/yr (11 h/day for 200 days and 4 h/day for 35 days) based on reviewing multiple school retrofits from the California Energy Commission's Bright School Program.

10. Assumes 80 billion kWh/yr for indoor HID lighting systems in U.S. from Analysis of Standards Options for High-Intensity Discharge Lighting Fixtures, American Council for an Energy-efficient Economy, January 2008, Page 3.

11. Assumes California is 10% of the U.S. lighting industry market based on Analysis of Standards Options for High Intensity Discharge Lighting Fixtures, American Council for an Energy-efficient Economy, January 2008, Page 12.

12. Assumes 4,380 h/yr U.S. Lighting Market Characterization Volume I: National Lighting Inventory and Energy Consumption Estimate, Navigant Consulting, Inc., September 2002, Page xiii. The assumption was based on 12 hours instead of 11 (12*365 = 4380).

13. Assumes 1 W/ft^2 for existing and standard practice based on a HID retrofit does not necessarily save energy and 2008 Building Energy Efficiency Standards for Residential and Nonresidential Buildings, Page 119. The lighting power densities were averaged for work buildings (0.9 – 1.0), storage buildings (0.6), and convention centers (1.4).

14. Assumes 0.75 W/ft^2 for best practice based on 2009 Lighting Technology Overview, California Lighting Technology Center, 2009, Page 9. It is assumed that best practice is 25% lower that standard practice (1.0 W/ft^2 – 1.0 * 25% = 0.75 W/ft^2).

15. Values based on Energy Savings Estimates of Light Emitting Diodes in Niche Lighting Applications, Navigant Consulting, Inc., October 2008 and 2009 Lighting Technology Overview, California Lighting Technology Center, 2009, Tables 3-2, 3-3, 3-4 on Pages 32 – 34. The number for the entire US were prorated for California and reduced by 10% (see Note 9).

16. Assumes 28 W CFL downlight for standard practice based on 2009 Lighting Technology Overview, California Lighting Technology Center, 2009, Page 12.

17. Assumes 56 TWh/y for existing and standard practice outdoor stationary lighting and assumes 87% of outdoor stationary lighting is HID based on U.S. Lighting Market Characterization Volume I: National Lighting Inventory and Energy Consumption Estimate, Navigant Consulting, Inc., September 2002, Page 11.

18. Assumes Smart bi-level energy savings of 40% based on 2009 Lighting Technology Overview, California Lighting Technology Center, 2009, Page 29.