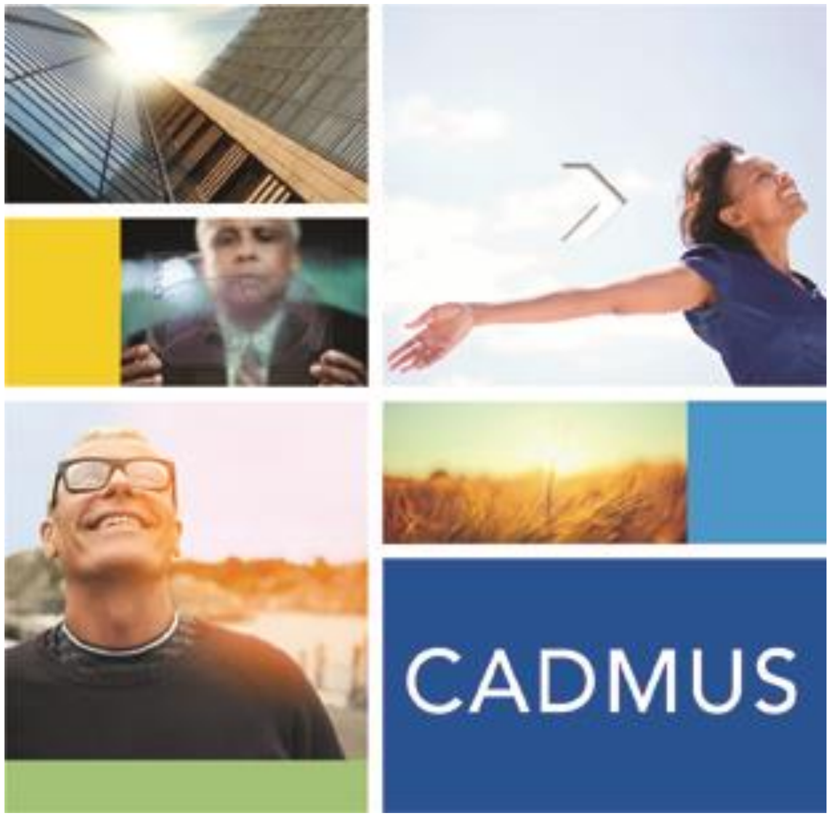

California Lighting Solutions Workbook
2014 Update Report

December 19, 2014

Southern California Edison
Pacific Gas & Electric
San Diego Gas & Electric

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Executive Summary

Southern California Edison (SCE), Pacific Gas & Electric (PG&E), and San Diego Gas & Electric (SDG&E) are the California investor-owned utilities (IOUs) that implement the statewide Lighting Market Transformation (LMT) program.

In the 2010-2012 program cycle, Cadmus developed the initial version of the Lighting Solutions Workbook (Workbook 2012). The workbook is an Excel-based planning tool that supports the LMT program's strategic decision-making and helps prioritize lighting solution activities using assembled information from numerous sources.

For the 2013-2014 program cycle, Cadmus updated the workbook as follows:

- Expanded the menu of efficient lighting controls technologies available with associated saving potential calculations.
- Incorporated codes and standards requirements in the main worksheet to allow for:
  - Comparison between existing installed technologies and the minimum codes and standards compliant technologies
  - Estimation of the technical savings potential without the savings associated with codes and standards
- Updated the workbook following a review of literature and data sources that have become available since Workbook 2012 was published.
- Updated the workbook to incorporate the final results of three large California lighting market surveys, which became available in 2014:
  - 2011-2013 Commercial Saturation Survey (CSS)
  - Commercial Market Share Tracking (CMST)
  - 2012 California Lighting and Appliance Saturation Survey (CLASS)
- Aligned the workbook nonresidential building subsectors and lighting applications with the subsectors and applications used in the CSS.
- Restructured the workbook to simplify and make market sector-level information more easily accessible.

As part of the 2014 Workbook update, Cadmus developed lighting market indicators to help the LMT program track changes in the California lighting market over time. For the residential lighting market indicators, we relied on lighting point-of-sale (POS) data (which we obtained for this analysis) and lighting shelf surveys (conducted by DNV GL) to develop lighting market indicators based on retail sales volume, price, and availability. For the nonresidential lighting market, we relied on lighting program participation data from the IOUs.

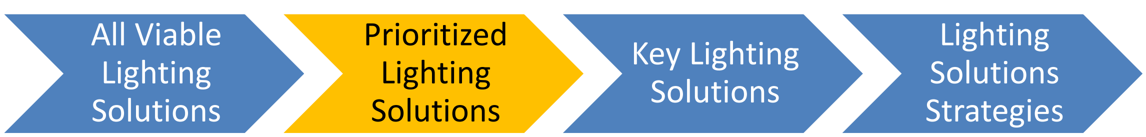
In this report, we also discuss the potential of installed lighting saturation as a lighting market indicator, which can be tracked through the results of periodic statewide saturation surveys such as the 2012 CLASS, 2011-2013 CSS, and the CMST.

Introduction

Southern California Edison (SCE), Pacific Gas & Electric (PG&E), and San Diego Gas & Electric (SDG&E) are the California investor-owned utilities (IOUs) that implement the statewide Lighting Market Transformation (LMT) program. The LMT program is responsible for establishing a process through which the IOUs can develop and test market transformation strategies for efficient lighting technologies. The California statewide energy efficiency strategic plan requires 60% to 80% reduction in statewide lighting energy consumption by 2020 through market transformation.[1] Lighting is a $100 billion industry worldwide,[2] with products being improved or introduced at a fast rate. To help the strategic plan achieve its targets, the LMT program seeks to select a manageable number of lighting solutions for market transformation strategy development.

Early in 2010, the LMT program staff developed a process to select key lighting solutions for market transformation strategy development, shown in Figure 1. To prioritize lighting solutions, the LMT program staff needed a logically structured planning and design tool that summarized, in one convenient place, information on savings potential, market barriers, and technology saturation. This tool was intended to support strategic decision-making and assist in prioritizing activities using assembled information rather than anecdotal or single sources of information. LMT program staff developed the first iteration of this tool in 2010 and called it the Lighting Technology Roadmap.

Figure 1. The LMT Program Process



The original Roadmap, a Microsoft Excel spreadsheet, consisted of two tabs—one in which data were organized by technology and one in which data were organized by market sector. Initially the Roadmap was not at the proper level of granularity for LMT's purposes, and many of its data fields had not been populated. Also, the fact that it organized lighting market information separately by technology and market sector made it challenging to assess the potential of a particular technology in a specific market sector.

[1] California Public Utilities Commission, California Energy Efficiency Strategic Plan, January 2011 update, page 95.

[2] McKinsey and Company, Lighting the Way: Perspectives on the Global Lighting Market, Second Edition, August 2012.

The IOUs engaged Cadmus during the second quarter of 2011 to continue developing the Roadmap and to devise an approach for improving the tool. Our main directive was to create a function that distinguished lighting applications and technologies with a significant savings opportunity from others, and that identified ones that no longer needed programmatic support. This function also needed to produce a comprehensive overview of the lighting technology landscape by market sector, built on the foundation of consumers' current use of technologies and needs across various markets and applications.

With input from the IOUs and other stakeholders, we renamed the Lighting Technology Roadmap the Lighting Solutions Workbook and delivered its first version during the 2010-2012 program cycle.[3]

About the 2012 Version of the Lighting Solutions Workbook

The 2012 version of the Lighting Solutions Workbook (Workbook 2012), like the original Roadmap, is an Excel tool. It consists of a main Market Solutions tab that contains market intelligence organized by market sector,[4] building type, and applications within each building type. The tab then branches out to reflect the lighting and control technologies most common in each application and the efficient replacement options available. It contains 112 rows and 22 columns of data across all major markets, applications, and technologies and has links to data housed in supporting worksheets.

These supporting worksheets contain calculations, tables, or other types of information referenced in the main tab. All references are cited in the supporting worksheets.

The Workbook 2012 includes energy saving potential, technology saturation, and market barriers to support strategic planning efforts. The underlying data in this comprehensive tool comes from data sources such as the Database for Energy Efficient Resources (DEER) and the 2007 Integrated Energy Policy Report, both specific to California, as well as market saturation studies, evaluations, potential studies, and consensus from a select group of lighting experts.

Purpose of the 2014 Update

For the 2013-2014 program cycle, the IOUs retained the services of Cadmus to update the workbook. The update involved incorporating more recent market surveys, forecasts, and lighting technology assessment information; making structural changes to simplify the workbook; and developing a new market indicators section. The market indicators will help the IOUs and the California Public Utilities Commission's (CPUC) Energy Division track market transformation over time.

3 The first version of the workbook, Workbook 2012, and the associated Cadmus report are available from: http://www.lightingmarkettransformation.com/lmt-program-documents

4 The lighting market is categorized as three large sectors in the workbook: residential (interior and exterior), nonresidential interior, and nonresidential exterior.

Additionally, although Workbook 2012 supported the basic prioritization of lighting technologies (the objectives that drove its development in the first place), the LMT program staff identified gaps between information in the workbook and information it needed to make strategic market intervention decisions. Cadmus was asked to address the following gaps in the 2013-2014 update version of the workbook:

- Workbook 2012 did not put a strong emphasis on the saving potential of lighting controls. Because lighting controls play an increasingly important role in codes and standards and in energy-efficient lighting programs, the LMT program staff needed the workbook to delineate lighting control systems and their associated savings more clearly.
- Workbook 2012 listed codes and standards applicable to each lighting technology in the Market Solutions tab. However, the actual requirements were contained in a supporting sheet, which meant it was hard to assess the following:
  - Where current use of technologies lagged significantly behind codes and standards requirements.
  - Where the current use has outpaced codes and standards requirements.
  - How the potential savings resulting from an efficient replacement option could be reduced by the rising baseline associated with codes and standards.

In Workbook 2014, Cadmus has completed the revisions required to address the LMT program needs listed above, as well as several other updates. [5] These updates are:

- Expanded the menu of efficient lighting controls technologies available with associated savings potential calculations.
- Incorporated codes and standards requirements in the main worksheet to allow for:
  - Comparison between existing installed technologies and the minimum codes and standards-compliant technologies.
  - Estimation of the technical savings potential without the savings associated with codes and standards.
- Updated the workbook following a review of literature and data sources that have become available since Workbook 2012 was published.
- Updated the workbook to incorporate the final results of two large California lighting market surveys, which became available in 2014:
  - 2011-2013 Commercial Saturation Survey (CSS)
  - Commercial Market Share Tracking (CMST)
  - 2012 California Lighting and Appliance Saturation Survey (CLASS)

[5] When completed, Workbook 2014 and the final report will be available from: http://www.lightingmarkettransformation.com/lmt-program-documents/

- Aligned the workbook nonresidential building subsectors and lighting applications with the subsectors and applications used in the CSS.
- Restructured the workbook to simplify and make market sector level information more easily accessible.

In response to the interest in tracking lighting market transformation in California, Cadmus purchased point-of-sale (POS) data to inform development of market indicators based on replacement lamp sales price and volume. We also reviewed the past California shelf surveys and IOU program participation trends for potential market indicators. The results of analysis and review of these indicators are included in this report.

Organization of this Report

This report is organized into two main sections: Lighting Solutions Workbook 2014 Update and California Lighting Market Indicators. We will describe all changes to Workbook 2012 in the first section and describe the development of California lighting market indicators in the second section. Finally, we will provide recommendations for future updates to the workbook.

Literature Review and Workbook 2014 Data

Literature Review

For the 2014 update to the workbook, Cadmus collected and reviewed numerous lighting studies and reports with the goal of finding more recent market and technology data, filling information gaps, and identifying market indicators that could be used to characterize the California lighting market over time. This review was performed during the second and third quarters of 2013.

Table 1 lists all materials reviewed, with information on the sector, technology, topic, and vintage of the underlying data. Note that not all of the reviewed studies and reports were used in the 2014 update. Additional sources specifically reviewed for lighting controls and the codes and standards updates to the Workbook 2014 are listed in the sections discussing those updates.

Table 1. List of Literature and Data Sources Reviewed for the 2014 Update to the Workbook

	Article Title or Data Source	Author	Data Year(s)	Sector	Technology/ Topic	California Specific?	Publication Date	Used in Workbook 2014?
1	2010 U.S. Lighting Market Characterization	Navigant	2010	All	Lamp types, average wattage, and hours of use, prevalence of lighting controls	No	2012	Yes
2	California Commercial Market Share Tracking Survey (CMST)	Itron	2012-2013	Nonresidential	Market share survey for linear fluorescent technology	Yes	2014	Yes, and in the market indicators analysis
3	California Commercial Saturation Survey (CSS/CMST)	Itron	2011-2013	Nonresidential	Lighting saturation survey	Yes	2014	Yes
4	California Database for Energy Efficient Resources (DEER)	CEC	N/A	All	Estimates of energy and peak demand savings for various lighting efficiency measures	Yes	2011 and 2013 update	Yes
5	California Energy Demand 2014-2024 Final Forecast, Volume 2: Electricity Use by Utility Planning Area.	California Energy Commission (CEC)	2014-2024	All	Lighting energy use forecast for IOU territories	Yes	2014	Yes
6	2013 California Energy Efficiency Potential and Goals Study	Navigant	2012-2024	All	Savings projections by sector and region	Yes	2013	Yes
7	California Industrial Energy Efficiency Market Characterization Study	Xenergy	Before 2001	Nonresidential	Lighting energy use in the industrial sector	Yes	2001	Yes
8	California Lighting and Appliances Saturation Survey (CLASS)	KEMA (DNV GL)	2012	Residential	Lighting saturation survey	Yes	2014	Yes

	Article Title or Data Source	Author	Data Year(s)	Sector	Technology/ Topic	California Specific?	Publication Date	Used in Workbook 2014?
9	Final Evaluation Report: Upstream Lighting Program, Volume 1 and Volume 2	KEMA (DNV GL)	2006-2008	Residential	Household characteristics and lighting inventories	Yes	2010	Yes
10	Residential Lighting End-Use Consumption Study	KEMA (DNV GL)	2008-2012	Residential	Lighting end-use consumption annual estimates	No	2012	Yes
11	Solid-state lighting research and development: multiyear program plan	DOE	2010-2012	All	SSL market characteristics and projections	No	2013 (2014 update was published in April 2014, after completion of literature review)	Yes
12	2010-2012 PG&E and SCE Multi-family Energy Efficiency Rebate Program Process Evaluation and Market Characterization Study	Cadmus	2010-2012	Residential	Multifamily market size and characteristics	Yes	2013	No
13	2013-2014 Residential Lighting Solutions Pipeline Plan	Cadmus	2013-2014	Residential	Market barriers for residential LED downlights	Yes	2012	No
14	Adoption of Light-Emitting Diodes in Common Lighting Applications	Navigant	2009-2012	All	LED lamp installs by type	No	2013	No
15	Assessment of the Early Effects of EISA and AB 1109 in California	KEMA (DNV GL)	2009-2012	Residential	Shelf availability, consumer purchasing behavior	Yes	2013	No

	Article Title or Data Source	Author	Data Year(s)	Sector	Technology/ Topic	California Specific?	Publication Date	Used in Workbook 2014?
16	California LED Lamp Market Characterization Report	KEMA (DNV GL)	2011	Residential	Shelf study, life, wattage, other lamp details	Yes	2012	No
17	California Retail Lighting Shelf Survey Online Tool	KEMA (DNV GL)	2008-2013	(Presumed to be) Residential	Retail lighting shelf study	Yes	2013	No, used in the market indicators analysis
18	Energy Information Administration (EIA) statistics on energy consumption	EIA	N/A	All	General sector energy consumption	No	2013	No
19	Energy-Efficient Lighting for Commercial Markets	Pike Research	2010-2011	Nonresidential	Global commercial space characteristics	No	2011	No
20	ENERGY STAR® Qualified LED Lamp & General Service Incandescent Lamp Price Tracking	EPA ENERGY STAR	2011-2013	Residential	Pricing trends for ENREGY STAR lighting products	No	2012	No
21	LED market effects study	KEMA (DNV GL)	2013	Residential	LED market characteristics	Yes	Not Available	No
22	Exterior Lighting Guide	DOE	2010	Nonresidential	Information on lighting and controls	No	2010	No
23	Freedonia Industry Study #2773: Lamps to 2015	Freedonia	2010	All	Individual light hardware demand and characteristics	No	2011	No
24	Light Bulb Point-of-Sale Data	Not Identified Upon Request	2010-2012	(Presumed to be) Residential	Lighting sale price and volume	Yes	2013	No, used in the market indicators analysis
25	NEEP Residential Lighting Strategy Report	NEEP	2009-2011	Residential	Program savings projection, NTG, regional saturation	No	2012	No

	Article Title or Data Source	Author	Data Year(s)	Sector	Technology/ Topic	California Specific?	Publication Date	Used in Workbook 2014?
26	NEEP Residential Lighting Strategy Report – 2013 Update	NEEP	2012	Residential	Program update, general information	No	2013	No
27	Next Generation Light Bulb Optimization	PG&E	2011	Residential	Lighting preferences	Yes	2012	No
28	The Southern California (SCE) Advanced Light Emitting Diode (LED) Ambient Lighting Program Customer Preference and Market Pricing Trial	Opinion Dynamics Corporation	2011-2012	Residential	Install base, purchaser preferences	Yes	2012	No
29	West Coast Medium Market Assessment	SCE	2011	Nonresidential	Install characteristics	Yes	2012	No

Lighting Controls Updates

The technological advances that make dimming compatible with various lighting technologies—and that make networked controls feasible in lighting retrofits—have positioned lighting controls as a major target for lighting energy-efficiency programs. Also, since lighting controls have proven to be such cost-effective energy-efficiency measures in new construction, the 2013 version of the California building energy-efficiency standards, Title 24, has incorporated stringent mandatory requirements for lighting controls.

With lighting controls playing an increasingly important role in energy-efficiency programs, the LMT program team needs to have promising lighting control technologies and their associated savings clearly delineated in the workbook.

Cadmus' directive in the lighting controls updates in Workbook 2014 was to allow users to compare the magnitude of possible savings from the implementation of various lighting control strategies both in a single building type or across building types and for a particular market sector. Similar to the technical potential of efficient lighting solutions, the workbook should allow the user to see the technical potential of a particular control strategy that results from early replacement of all existing manual or 24 hours a day/seven days a week (24/7) controls.

Interior lighting controls allow for the adjustment of light levels in response to the following:[6]

- Occupancy. The presence/absence of occupants or schedules of operation
- Daylight Harvesting. The availability of adequate daylight
- Personal Tuning. The individual occupants' preferences
- Institutional Tuning. Group preferences for light levels or owner/manager preferences applied to all occupants, ballast tuning,[7] or lumen maintenance[8]

Workbook 2012 captured efficient lighting controls and the associated savings in a simplified manner. The workbook proposed occupancy/vacancy sensors, daylighting, and timeclock/photocells as the most

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6 Note that the resulting light adjustment levels in response to the control signals listed here could be on/off, bi-level (on, half-off, off), stepped dimming, or continuous dimming. Bi-level controls are not considered a separate type of lighting control, but are a resulting adjustment of light levels in response to occupancy (including scheduling), institutional tuning, or personal tuning.

7 Ballast tuning is a strategy used to lower light levels (and the resulting energy usage) by adjusting the ballast factor in a lamp-ballast combination during installation or using integrated controls in the ballast.

8 Title 24 Part 6, 2013 defines lumen maintenance as a strategy used to provide a precise, constant level of lighting from a lighting system regardless of the age of the lamps or the maintenance of the luminaires. The lumen maintenance can be accomplished by using photoreceptors tied directly to the ballasts, signals from an energy management system programmed with the expected depreciation of lamps, or manual verification and dimming of the ballasts based on depreciation of light levels.

common efficient lighting control strategies; however, these are a limited selection of the controls options listed above.

In Workbook 2012, each efficient lighting replacement technology was paired with the most common efficient control strategy, and therefore it was not possible to compare the saving potential of various lighting control strategies. For example, occupancy/daylight controls (as a combination) were proposed as the efficient control replacement option for manual controls on general lighting in small commercial and large/medium office buildings.

The control saving potential calculations assumed, implicitly, that 100% of the existing interior lighting controls are either no controls (that is, 24/7 operation), manual, or timeclock controls. Existing exterior lighting controls were assumed to be 100% no control, manual, motion sensor, or photocell/timeclock controls.

Figure 2 shows an example of how lighting controls, existing and efficient, were presented in Workbook 2012.

Figure 2. Existing and Efficient Controls Strategies as Reflected in Workbook 2012 (partial screenshot)

Sub-Sector	Application	Avg Daily HOU	Active During Peak?	Baseline Use (GWh/	Current Lighting Practices: Lighting Produ	Current Lighting Practices: Controls	Percent Incidence of Current Practice	Replacement Lighting Practice: Lighting Product	Replacement Lighting Practice: Controls	Lamp (+ Eff Ballast) Tech Savings Potential (GWh/Yr)	Controls Tech Savings Potential (GWh/Yr)
Common to All Sub-Sectors	Exit Signs	24	Yes	114	LED Fixture	None	100%	LED Fixture	None	0	0
	General Lighting for Lobbies, Corridors	12	Yes	2,690	Linear Fluorescent	Manual	100%	High Efficiency Linear Fluorescent T-8/T-5	Occupancy/Bi Level	257	1210
								LED Panel Lighting	Occupancy/Bi Level	473	1210
	General Lighting for Stairwells	24	Yes	297	Linear Fluorescent	None	100%	High Efficiency Linear Fluorescent T-8/T-5	Bi-level (50% auto off/on)	28	134
								LED Panel Lighting	Bi-level (50% auto off/on)	52	134
Small Commercial (Office, Retail, Clinics, Minimart)	General Lighting	8	Yes	3,920	Linear Fluorescent	Manual	62%	High Efficiency Linear Fluorescent T-8/T-5	Occupancy/Daylight	232	515
								LED Panel Lighting	Occupancy/Daylight	427	515
					Halogen Track Lighting	Manual	21%	LED Track Lighting	Occupancy/Daylight	452	173
					Incandescent	Manual	17%	LED	Occupancy/Daylight	396	141
								CFL	Occupancy/Daylight	340	141
Large/Medium Offices	General Lighting	7	Yes	2,945	Linear Fluorescent	Manual	93%	High Efficiency Linear Fluorescent T-8/T-5	Occupancy/Daylight	260	578
								LED Panel Lighting	Occupancy/Daylight	479	578
					Incandescent Task Lights	Manual	7%	LED Task Lights	Occupancy	130	46
Large/Medium Non-food Retail (e.g., Malls, Big Box), Warehouses, Manufacturing	Low/Medium Bay Lighting	12	Yes	2,866	Linear Fluorescent	Timeclock	89%	High Efficiency Linear Fluorescent T-8/T-5	Timeclock/Daylight	243	572
								LED Fixture	Timeclock/Daylight	447	81
					Incandescent	Timeclock	11%	LED Fixture	Timeclock/Daylight	192	81
								CFL MSB	Timeclock/Daylight	165	81
								PS MH/CMH	Timeclock/Daylight	91	81
	High Bay Lighting	12	Yes	9,529	Linear Fluorescent	Timeclock	52%	Linear Fluorescent T-8/T-5 HO	Timeclock/Daylight	470	1229
					HID (Metal Halide/HPS)	Timeclock	48%	PS MH/CMH	Timeclock/Daylight	851	1147
								LED Fixture	Timeclock/Daylight	2157	1147
								Induction	Timeclock/Daylight	472	1147
								Linear Fluorescent T-8/T-5 HO	Timeclock/Daylight	1684	1147

In light of the LMT program team's interest in a clear delineation of controls strategies, Cadmus identified four issues with the Workbook 2012 approach:

- The workbook did not capture the full array of efficient control technologies that are available today. For example, the workbook did not include institutional tuning (such as ballast tuning or lumen maintenance) as an efficient control option.
- The workbook did not allow for an easy comparison of saving potentials resulting from a variety of possible efficient control strategies.
- Prior savings estimates for controls in the workbook were based either on individual demonstration studies or an average value in a broad range (for example, 20% to 50%) that was, in turn, based on the results of a few demonstration studies. However, the most reliable savings estimates are based on numerous studies, with pre- and post-installation measurement, where the control's savings can be isolated from the savings associated with the lighting retrofit (if any).
- The implicit assumption in savings calculations is that current lighting practice consists entirely of no controls or manual controls, and this reflected the lack of information on saturation of lighting controls in California at the time Workbook 2012 was developed. Additional saturation studies, such as the 2011-2013 CSS or the 2012 CLASS provide information on the saturation of controls in residential and commercial applications.

To address these issues in the update, Cadmus expanded the types of control technologies for nonresidential applications to include Occupancy, Daylighting, Personal Tuning, Institutional Tuning, and Multiple (that is, combination of) lighting controls. This expansion allows for an easy comparison of the saving potential from various lighting control regimes in Workbook 2014.

The branching structure in Workbook 2012 was not flexible enough to allow for the expansion of efficient control technologies. This resulted in changes to the workbook structure that are further described in the section of this report titled Changes to the Workbook Structure and Summary Sheets.

Figure 3 shows the types of controls reflected in Workbook 2014.

Figure 3. Existing and Efficient Controls Technologies as Reflected in Workbook 2014 (partial screenshot)

Application			Existing Installed / Baseline Technology				Efficient Replacement Technology		Potential (existing to efficient)	
Building Sub-Sector	Lighting Application	[Gwh/year] Application Energy Consumption Across California (IOU Territory)	Baseline Lighting	[%] Lighting Saturation	Baseline Control	[%] Control Saturation	Efficient Lighting	Efficient Control	[Gwh/year] Lighting Savings (lamp and/or ballast)	[Gwh/year] Control Savings
Office	Area Lighting (Low/Medium Bay)	4,282	Linear Fluorescent	98%	Manual Switch	79%	High Efficiency Linear Fluorescent T-8/T-5	Occupancy	619	581
Office	Area Lighting (Low/Medium Bay)	4,282	Linear Fluorescent	98%	Manual Switch	79%	High Efficiency Linear Fluorescent T-8/T-5	Daylighting	619	713
Office	Area Lighting (Low/Medium Bay)	4,282	Linear Fluorescent	98%	Manual Switch	79%	High Efficiency Linear Fluorescent T-8/T-5	Personal Tuning	619	925
Office	Area Lighting (Low/Medium Bay)	4,282	Linear Fluorescent	98%	Manual Switch	79%	High Efficiency Linear Fluorescent T-8/T-5	Institutional Tuning	619	951
Office	Area Lighting (Low/Medium Bay)	4,282	Linear Fluorescent	98%	Manual Switch	79%	High Efficiency Linear Fluorescent T-8/T-5	Multiple Measures	619	1057
Office	Area Lighting (Low/Medium Bay)	4,282	Linear Fluorescent	98%	Manual Switch	79%	LED Panel Lighting	Occupancy	858	581
Office	Area Lighting (Low/Medium Bay)	4,282	Linear Fluorescent	98%	Manual Switch	79%	LED Panel Lighting	Daylighting	858	713
Office	Area Lighting (Low/Medium Bay)	4,282	Linear Fluorescent	98%	Manual Switch	79%	LED Panel Lighting	Personal Tuning	858	925
Office	Area Lighting (Low/Medium Bay)	4,282	Linear Fluorescent	98%	Manual Switch	79%	LED Panel Lighting	Institutional Tuning	858	951
Office	Area Lighting (Low/Medium Bay)	4,282	Linear Fluorescent	98%	Manual Switch	79%	LED Panel Lighting	Multiple Measures	858	1057

The control strategies listed in Workbook 2014 align with the strategies suggested in a comprehensive review of documented lighting controls savings by Williams et al.[9] This review and meta-analysis is currently the most comprehensive source for documented lighting control savings for commercial buildings.

Williams et al. reviewed 240 saving estimates from 88 papers and case studies, on which they applied multiple analytical filters in order to remove potential biases introduced to the estimates by different approaches to the implementation of controls or the calculation of savings. Based on this meta-analysis, the best estimates of average lighting energy savings potential are 24% for occupancy, 28% for daylighting, 31% for personal tuning, 36% for institutional tuning, and 38% for multiple approaches.

Cadmus updated the previous saving assumptions for occupancy and daylighting controls and used the new values for personal tuning, institutional tuning, or multiple approaches. Where specific building-type control saving estimates from a large sample size were available based on this meta-analysis and other sources we reviewed, we used those estimates.

Table 2 shows a partial list of sources Cadmus reviewed for occupancy sensor controls, comparing the values in the Williams et al. paper with values from other sources. Values used in the workbook's saving estimate calculations are highlighted in red. The complete list, provided in a supporting worksheet in the workbook, lists sources reviewed and the average saving percentages expected for daylighting, personal tuning, institutional tuning, and multiple controls based on those sources. Full citations for the sources listed in Table 2**,** along with those reviewed for daylighting, personal tuning, institutional tuning, and multiple controls are listed in Table 3.

It is important to note that the applicability of various control types is not universal in buildings. For example, daylighting is only possible in side-lit areas in the perimeter of a building or top-lit areas of a building. This parameter is built into the average controls saving estimate numbers cited in the sources reviewed by Williams et al. and in the calculations in Workbook 2014.

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9 Williams et al. "Lighting Controls in Commercial Buildings." *Leukos*, Vol. 8, No. 3. January 2012.

Table 2. Average Controls Savings Estimates for Occupancy Controls Based on Sources Reviewed (Values Used in Workbook 2014 are Highlighted in Red.)

Control Savings Classification	Total Savings, %	Sector Type	Building Type	Space Type	Measure Types	With Luminaire Retrofit?	Source	Notes
Occupancy	24%	All	All	Not Specified	Occupancy sensors, time clocks, energy management system	No	Williams et al., 2012	
Occupancy	22%	Nonresidential	Office	Not specified	Not specified	No	Williams et al, 2012	
Occupancy	31%	Nonresidential	Warehouse	Not specified	Not specified	No	Williams et al., 2012	Small sample size
Occupancy	45%	Nonresidential	Lodging	Not specified	Not specified	No	Williams et al., 2012	Small sample size
Occupancy	18%	Nonresidential	Education	Not specified	Not specified	No	Williams et al., 2012	Small sample size
Occupancy	36%	Nonresidential	Public assembly	Not specified	Not specified	No	Williams et al., 2012	Small sample size
Occupancy	23%	Nonresidential	Healthcare outpatient	Not specified	Not specified	No	Williams et al., 2012	Small sample size
Occupancy	7%	Nonresidential	Other	Not specified	Not specified	No	Williams et al., 2012	Small sample size
Occupancy	10%	Nonresidential	Office	Open interior office	ONLY: Occupancy sensors	Presumed no	Lighting Controls For Offices and Public Buildings, December 2000	Baseline of wall switches
Occupancy	10%	Nonresidential	Office	Open interior office	ONLY: Timeclock/ Schedule	Presumed no	Lighting Controls For Offices and Public Buildings, December 2000	One building.
Occupancy	22%	Nonresidential	Varied	Break Room	ONLY: Occupancy sensors	Presumed no	VonNeida et al., August 2000	Averaged four different shut-off settings (5, 10, 15, 20 minutes)
Occupancy	55%	Nonresidential	Varied	Classroom	ONLY: Occupancy sensors	Presumed no	VonNeida et al., August 2000	Averaged four different shut-off settings (5, 10, 15, 20 minutes)

Control Savings Classification	Total Savings, %	Sector Type	Building Type	Space Type	Measure Types	With Luminaire Retrofit?	Source	Notes
Occupancy	44%	Nonresidential	Varied	Conference Room	ONLY: Occupancy sensors	Presumed no	VonNeida et al., August 2000	Averaged four different shut-off settings (5, 10, 15, 20 minutes)
Occupancy	33%	Nonresidential	Varied	Private Office	ONLY: Occupancy sensors	Presumed no	VonNeida et al., August 2000	Averaged four different shut-off settings (5, 10, 15, 20 minutes)
Occupancy	53%	Nonresidential	Varied	Restroom	ONLY: Occupancy sensors	Presumed no	VonNeida et al., August 2000	Averaged four different shut-off settings (5, 10, 15, 20 minutes)
Occupancy	65%	Nonresidential	Office	Stairwells	Bi-level	Yes	SCE, October 2011	Demonstration study in two buildings in Southern California.
Occupancy	50%	Nonresidential	Office	Corridor	Bi-level	Yes	SCE, October 2011	Demonstration study in two buildings in Southern California.
Occupancy	43%	Nonresidential	Office	Lobbies/ Corridors	Bi-level	N/A	Calculated based on SCE, October 2011 and NC3 database	Calculated
Occupancy	22%	Nonresidential	Parking Garage	N/A	Bi-level	N/A	California Utilities Statewide Codes and Standards Team, October 2011	Simulated
Occupancy	5%	Nonresidential	Not Specified	N/A	ONLY: Shut-off	N/A	Cadmus Professional Estimate	Estimate

Table 3. List of Data Sources Reviewed for Lighting Controls Saving Calculation Estimates

Abbreviated Citation	Full Citation	Population Description	Publish Date	Reviewed for
Williams et al., 2012	Williams, A., Atkinson, B., Garbesi, K., Page, E., and Rubinstein, F., "Lighting Controls in Commercial Buildings," *Leukos,* Vol 8, No 3, January 2012, p. 161-180	Meta-study	January 2012	All control strategies
Lighting Controls For Offices and Public Buildings, December 2000	Energy Efficiency and Renewable Energy (EERE) Federal Energy Management Program (FEMP), LT-8: How to Select Lighting Controls For Offices and Public Buildings, December 2000	Case Study: Federal GSA office building, San Francisco, California.	December 2000	All control strategies
VonNeida et al., August 2000	VonNeida, B., Maniccia, D., and Tweed, A., "An analysis of the energy and cost savings potential of occupancy sensors for commercial lighting systems," IES Paper #43, August 2000	M&V study of sixty organizations chosen from active participants in the US. Environmental Protection Agency's Green Lights Program.	August 2000	Occupancy
Rubinstein et al, September 2012	Wei, J., Enscoe, A., and Rubinstein, F., Responsive Lighting Solutions, Prepared for the General Services Administration, Lawrence Berkeley National Laboratory, September 2012.	5 federal buildings in California	September 2012	Occupancy, Personal Tuning, Institutional Tuning
SCE, October 2011	Southern California Edison, Smart Corridors: Bi-level Lighting for Office Applications, Prepared for Design & Engineering Services Customer Service Business Unit, October 2011.	Two advanced lighting control technologies were installed in a class A office building in Long Beach and an educational building in Irvine, California.	October 2011	Occupancy (bi-level)
SCE, March 2011	Southern California Edison, Requirements for controllable lighting, 2013 California Building Energy Efficiency Standards, Codes and Standards Enhancement Initiative, Prepared by Avery, D., Benya, J., Neils, M., Rubinstein, F., Neils, D., March 2011.	N/A	March 2011	Multi-level controls as defined in California Title 24, 2013

Abbreviated Citation	Full Citation	Population Description	Publish Date	Reviewed for
California Utilities Statewide Codes and Standards Team, September 2011	California Utilities Statewide Codes and Standards Team, Automated Lighting Controls and Switching Requirements in Warehouses and Libraries, for 2013 California Building Energy Efficiency Standards, Codes and Standards Enhancement Initiative, September 2011.	N/A	September 2011	Multiple (i.e., combina-tion of) – occupancy and daylighting
California Utilities Statewide Codes and Standards Team, October 2011	California Utilities Statewide Codes and Standards Team, Parking Garage Lighting and Control, for 2013 California Building Energy Efficiency Standards, Codes and Standards Enhancement Initiative, October 2011.	N/A	October 2011	Occupancy and daylighting

At the request of the LMT team, Cadmus also reviewed the savings associated with advanced lighting controls. Although there is not a formal definition for advanced lighting controls, the term is commonly used to describe systems where the controls use a mesh network independent of the relay switch panels in the building. Advanced lighting controls provide more granular controls for spaces and occupants and can work effectively in combination with each other.

Since these controls can sit on top of the existing lighting electrical system, they are more practical for retrofit scenarios. At their core, such controls allow for basic functionality that is already incorporated in the workbook (occupancy, personal tuning, institutional tuning, and multiple controls), and therefore the controls savings resulting from advanced lighting controls are already incorporated in Workbook 2014 to a large extent. The improved user experience or integration of control strategies might make even higher controls savings possible. However, Cadmus determined that the few demonstration studies performed on these systems (often along with luminaire retrofit) did not provide saving estimates so widely applicable that they would warrant a separate entry for this type of technology in the workbook.

To address the issue with implicit assumptions about the existing saturation of automatic controls, Cadmus has added a new column to the Market Solutions tab of the workbook; this column lists the controls market share assumed for no controls (i.e., 24 hour operation) or manual switch. The values listed in this column are based on the controls saturations observed in the 2013 CSS (for commercial buildings) and 2012 CLASS (for residential buildings), or the 2010 U.S. Lighting Market Characterization report, or on Cadmus' professional judgment.

Codes and Standards Updates

The early rollout of the requirements of the Energy Independence and Security Act (EISA) of 2007 in California and the increased federal efficiency standards in place for linear fluorescent and incandescent reflector lamps are quickly changing the lighting market. Additionally, the upcoming version of California's building energy efficiency standards, Title 24 2013 (effective July 1, 2014), establishes stringent requirements for lighting controls in residential and nonresidential new construction and most major retrofits.[10] As such, the LMT team's request for the 2014 update was to improve the workbook's incorporation of codes and standards.

Previously, Workbook 2012 listed codes and standards applicable to each existing installed/baseline lighting technology in a column on the Market Solutions tab and the actual requirements in a supporting worksheet dedicated to codes and standards. Because the actual requirements were listed separately, it was hard for the LMT team to use Workbook 2012 to assess:

- Where current use of technologies lagged significantly behind codes and standards requirements
- Where the current use has outpaced codes and standards requirements
- How the potential savings resulting from an efficient replacement option could be reduced by the rising baseline associated with codes and standards when those baselines are triggered

To address the limitations above, Cadmus added four new columns in Workbook 2014 that list:

- Minimum C&S Compliant Lighting
- Minimum C&S Compliant Control
- Potential (C&S Compliant to Efficient) Lighting Savings
- Potential (C&S Compliant to Efficient) Control Savings

Figure 4 shows a partial section of the market solutions tab in Workbook 2014 that outlines these four new columns in red. Note that the inclusion of minimum codes and standards for lighting and controls in the workbook is for reference only, and it is not meant to imply that a single luminaire replacement will trigger code compliance.

[10] Retrofits in buildings where less than 40 ballasts are changed and spaces where less than 10% of the luminaires are altered do not trigger compliance with Title 24 2013.

Figure 4. Minimum Codes and Standards Compliant Lighting and Controls Technologies and Potential Savings in Workbook 2014 (partial list)

Existing Installed / Baseline Technology				Minimum C&S Compliant		Efficient Replacement Technology		Potential (existing to efficient)		Potential (C&S compliant to efficient)	
Baseline Lighting	[%] Lighting Saturation	Baseline Control	[%] Control Saturation	Compliant Lighting	Compliant Control	Efficient Lighting	Efficient Control	[Gwh/year] Lighting Savings (lamp and/or ballast)	[Gwh/year] Control Savings	[Gwh/year] Lighting Savings (lamp and/or ballast)	[Gwh/year] Control Savings2
Linear Fluorescent	19%	Manual Switch	100%	Linear Fluorescent T-8 / Code Compliant T-12	Shut-off	LED Panel Lighting	Occupancy	24	20	20	16
Linear Fluorescent	19%	Manual Switch	100%	Linear Fluorescent T-8 / Code Compliant T-12	Shut-off	LED Panel Lighting	Daylighting	24	25	20	20
Linear Fluorescent	19%	Manual Switch	100%	Linear Fluorescent T-8 / Code Compliant T-12	Shut-off	LED Panel Lighting	Personal Tuning	24	32	20	28
Linear Fluorescent	19%	Manual Switch	100%	Linear Fluorescent T-8 / Code Compliant T-12	Shut-off	LED Panel Lighting	Institutional Tuning	24	33	20	29
Linear Fluorescent	19%	Manual Switch	100%	Linear Fluorescent T-8 / Code Compliant T-12	Shut-off	LED Panel Lighting	Multiple Measures	24	37	20	32
Linear Fluorescent	19%	Manual Switch	100%	Linear Fluorescent T-8 / Code Compliant T-12	Shut-off	High Efficiency Linear Fluorescent T-8/T-5	Occupancy	17	20	15	16
Linear Fluorescent	19%	Manual Switch	100%	Linear Fluorescent T-8 / Code Compliant T-12	Shut-off	High Efficiency Linear Fluorescent T-8/T-5	Daylighting	17	25	15	20
Linear Fluorescent	19%	Manual Switch	100%	Linear Fluorescent T-8 / Code Compliant T-12	Shut-off	High Efficiency Linear Fluorescent T-8/T-5	Personal Tuning	17	32	15	28
Linear Fluorescent	19%	Manual Switch	100%	Linear Fluorescent T-8 / Code Compliant T-12	Shut-off	High Efficiency Linear Fluorescent T-8/T-5	Institutional Tuning	17	33	15	29
Linear Fluorescent	19%	Manual Switch	100%	Linear Fluorescent T-8 / Code Compliant T-12	Shut-off	High Efficiency Linear Fluorescent T-8/T-5	Multiple Measures	17	37	15	32
CFL	14%	Manual Switch	98%	Halogen	Shut-off	LED Task Lights	Occupancy	16	15	16	11
CFL	14%	Manual Switch	98%	Halogen	Shut-off	LED Task Lights	Daylighting	16	18	16	15
CFL	14%	Manual Switch	98%	Halogen	Shut-off	LED Task Lights	Personal Tuning	16	23	16	20
CFL	14%	Manual Switch	98%	Halogen	Shut-off	LED Task Lights	Institutional Tuning	16	Not Applicable	16	Not Applicable
CFL	14%	Manual Switch	98%	Halogen	Shut-off	LED Task Lights	Multiple Measures	16	27	16	23

In the following sections, we describe the codes and standards we reviewed to determine compliant lighting and controls, along with the calculation methodology in the potential saving columns.

Minimum Codes and Standards Compliant Lighting

This column lists the minimum codes and standards-compliant lighting replacement technology for each existing installed/baseline lighting technology. Incandescent, incandescent reflector, and linear fluorescent lamps are technologies with wide application that have been affected recently by state and federal standards. We describe the codes and standards requirements applicable to these technologies in detail below.

Aside from incandescent, incandescent reflector, and linear fluorescent lamps, we have included minimum compliant technologies for applications such as exit signs and traffic signals,[11,12] for which requirements have been in place for the past 10 to 12 years.

We also reviewed the 2009 version of the California Appliance Efficiency Standards, briefly referred to as Title 20 2010, which requires pulse-start ballasts for metal halide luminaires. We have listed these as the minimum codes and standards-compliant technology in Workbook 2014 for applications that use metal halide lamps.

General Service Incandescent Lamps, EISA 2007, and California's Title 20 2010

EISA 2007 established efficiency standards for general service lamps (the common medium screw base lamp) sold in the United States. These standards became effective nationwide in 2012. But California adopted these standards one year ahead of the federal effective date by incorporating them in Title 20 2010. For example, Title 20 2010 requires that a former 100-watt lamp manufactured on or after January 1, 2011, and sold in California use 72 watts or less, while providing the same amount of light. The minimum efficacy standards apply to lamps with lower-rated lumens every year, through 2013 in California and 2014 nationwide.

The requirements of Title 20 2010 for general service lamps are provided in Table 4.

Table 4. Title 20 2010 Standards for General Service Incandescent Lamps

Rated Lumen Ranges	Maximum Rated Wattage	Minimum Rated Lifetime	California Effective Date
1490–2600 Lumens	72 watts	1,000 Hours	Jan 1, 2011
1050–1489 Lumens	53 watts	1,000 Hours	Jan 1, 2012
750–1049 Lumens	43 watts	1,000 Hours	Jan 1, 2013
310–749 Lumens	29 watts	1,000 Hours	Jan 1, 2013

While EISA 2007 and Title 20 2010 do not ban incandescent light bulbs, they have resulted in an industry

11 Energy Policy Act of 2005 (EPAct 2005) set minimum efficacy requirements that can only be met by LED signs.

12 Title 20 2002 set minimum efficacy requirements that can only be met by LED signals.

shift towards more efficient lighting technologies such as halogen, CFL, and LED lamps, with halogen lamps being the least efficient and the closest replacement for incandescent lamps. For any lighting application in Workbook 2014, where incandescent bulbs constitute a portion of the existing installed inventory, the Minimum C&S Compliant Lighting column now lists halogen lamps as the minimum compliant lighting technology.

DOE Rule 10 CFR Part 430 and Incandescent Reflector Lamps

Incandescent reflector lamps (IRLs) are cone-shaped lamps with a reflective coating inside to direct the light and are used for applications such as spotlights, floodlights, recessed downlights, and track lighting. As existing installed technologies are listed in the workbook, directional lamps are not distinguished from non-directional lamps. Therefore, “incandescent” in the workbook can refer to both the general purpose incandescent and the incandescent reflector lamps.

However, given the specific application for which the incandescent lamp is listed, the user can infer to which type of incandescent technology it refers. For example, the incandescent technology listed as being used in the recessed/common area lighting application under the hotel/motel, dorm, and assisted living building subsector refers to IRL. Since halogen is being listed as the minimum codes and standards-compliant technology for applications that use general service incandescent lamps, it was necessary for us to determine if the minimum codes and standards baseline for the IRL lamps should also be halogen.

The efficiency of certain IRL shapes and sizes was regulated through the Energy and Policy Act (EPAct) of 1992.[13] California adopted Title 20 2006, which had more stringent standards for IRLs than the federal standards. Subsequently EISA 2007 extended these standards nationwide.[14] EISA 2007 also required the U.S. Department of Energy (DOE) to extend the coverage of EPAct 1992 IRL standards to a broader set of lamp shapes and sizes.[15]

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13 EPAct 1992 applied to R and PAR shaped lamps that are over 2.75 inches in diameter.

14 The only exception to this were the BPAR lamps, which had not been part of the Title 20 2006 standards. EISA 2007 extended the federal efficiency standards to BR/ER/BPAR lamp types with over 2.75 inches in diameter starting January 1, 2008.

15 EISA required that DOE extend the EISA efficiency standards—as of June 17, 2008—to lamps ranging in size from 2.25 to 2.75 inches. Exceptions were:

- IRLs rated at 50 watts or less that are ER30, BR30, BR40, or ER40 lamps
- IRLs rated at 65 watts that are BR30, BR40, or ER40 lamps
- R20 IRLs rated 45 watts or less

DOE Rule 10 CFR Part 430, effective as of July 14, 2012, specified efficiency standards for all common IRLs (as shown in Table 5) that were more stringent than EISA 2007.[16] This federal rule regulates IRLs that are R, PAR, ER, BR, BPAR, or similar shape. Regulated bulbs have diameters that exceed 2.25 inches (grouped into those with diameters exceeding 2.5 and those with diameters equal to or less than 2.5 inches) and are rated between 40 and 205 watts. To be consistent with how the IOUs' codes and standards programs refer to this standard, we also refer to it as Federal Standard 6 (Fed 6). An update to Fed 6 is expected by the end of 2014.[17]

Table 5. Federal Energy Conservation Standards for Incandescent Reflector Lamps (Fed 6)

Lamp Wattage	Lamp Type	Diameter (inches)	Voltage	Minimum Lumens per Watt*
40W – 205W	Standard Spectrum	>2.5	≥125	$6.8\times P^{0.27}$
			<125	$5.9\times P^{0.27}$
		≤2.5	≥125	$5.7\times P^{0.27}$
			<125	$5.0\times P^{0.27}$
40W – 205W	Modified Spectrum	>2.5	≥125	$5.8\times P^{0.27}$
			<125	$5.0\times P^{0.27}$
		≤2.5	≥125	$4.9\times P^{0.27}$
			<125	$4.2\times P^{0.27}$

*P = rated lamp wattage, in watts

Fed 6 did not result in a technology shift away from incandescent technology, as did EISA 2007 and Title 20 2010. The Appliance Standards Awareness Project (ASAP) states that the DOE intentionally did not choose an efficiency tier that would rule out the incandescent technology due to concerns with the impact on manufacturers. However, most consumers and businesses are already choosing CFLs and other more efficient, non-incandescent reflectors such as LED and ceramic metal halide lamps. The next DOE rule will likely include efficacy requirements that will necessitate the use of technologies such as halogen Infrared lamps as the minimum-compliant technology.[18]

Since the industry response to these standards has been to shift to technologies other than incandescent general service lamps (see previous section: General Service Incandescent Lamps, EISA 2007, and California's Title 20 2010), and the federal standards are likely to require halogen reflector lamps as the minimum compliant technology in the near future, Cadmus decided to list halogen as the minimum codes and standards-compliant technology in all cases where the existing installed/baseline

16 Energy Conservation Program: Energy Conservation Standards and Test Procedures for General Service Fluorescent Lamps and Incandescent Reflector Lamps; Final Rule, 10 CFR Part 430, 2009.

17 DOE filed notice of rulemaking under 79 FR 24067 on April 29, 2014. Available online: http://www1.eere.energy.gov/buildings/appliance_standards/rulemaking.aspx/ruleid/24

18 ASAP, (n.d.), Factsheet: Efficiency Standards Question and Answers Fluorescent Tube and Incandescent Reflector Lamps, retrieved from: http://www.appliance-standards.org/sites/default/files/Fluorescent-tube-incandescent-reflector-lamp.pdf

lighting technology is incandescent, regardless of whether the application requires a directional lamp or not.

DOE Rule 10 CFR Part 430 and Linear Fluorescent Lamps

The efficiency of linear fluorescent lamps has been regulated since EPAct 1992. The DOE rule that regulated the efficacy of IRLs discussed in the previous section also includes minimum efficacy requirements for general service fluorescent lamps. This rule took effect on July 14, 2012, and to be consistent with how the IOUs' Codes & Standards programs refer to this standard, we refer to it as Federal Standard 7 (Fed 7).

The minimum efficacy requirements of Fed 7 are reflected in Table 6. An updated federal standard for linear fluorescent lamps is due in 2014, which is scheduled to take effect in 2017.[19]

Table 6. Performance Requirements of General Service Fluorescent Lamps (Fed 7)

Lamp Type	Correlated Color Temperature	New Standards (Lumens per Watt)
4-foot Medium Bi-Pin	<4500K >4500K and <7000K	89 88
2- foot U-Shaped	<4500K >4500K and <7000K	84 81
8-foot Slimline	<4500K >4500K and <7000K	97 93
8-foot High Output	<4500K >4500K and <7000K	92 88
4-foot Miniature Bi-Pin Standard Output	<4500K >4500K and <7000K	86 81
4-foot Miniature Bi-Pin High Output	<4500K >4500K and <7000K	76 72

According to an analysis released by the National Electrical Manufacturers Association (NEMA), most T12 4-foot and 2-foot U-shaped lamps with medium bi-pin bases in the market in 2012 failed to comply with the rule (only a few very high lumen rare earth phosphor lamps complied, and lamps with CRI>87 were exempted from the rule).[20] However, several manufacturers have started to offer code-compliant 34 and 40 watt T12s in recent months.

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[19] DOE filed notice of rulemaking under 79 FR 24067 on April 29, 2014. Available online: http://www1.eere.energy.gov/buildings/appliance_standards/rulemaking.aspx/ruleid/24

[20] NEMA. *Summary: New 2012 Standards for General Service Fluorescent Lamps (GSFL).* May 23, 2012. Retrieved from: https://assets.sylvania.com/assets/Documents/New%202012%20Standards%20for%20General%20Service%20Flr%20Lps%20NEMA%20v2%20_2_.96439846-e6b0-4188-b823-5a93df679bde.pdf

On the other hand, all T8 and T5 lamps on the market passed the standard, except for the 700 line T8 products, which were granted a waiver by DOE for two years from July 14, 2012, until July 14, 2014.[21, 22] The 700 line T8 products are 32-watt lamps, and the more efficient and expensive 800 line T8 products are typically 28-watt lamps.[23]

According to Cadmus research, literature review, and conversations with industry representatives, the primary impact of Fed 7 in California has been the retrofit of 4-foot linear and 2-foot U-shaped T12 lamps (typically 40 watts) to T8 lamps.[24] This trend is likely to continue as a result of strong IOU efficiency programs that offer incentives for T8 technology.

Where linear fluorescent lamps are listed under the Existing Installed / Baseline Technology column, Cadmus has listed T8 / code-compliant T12 lamps as the minimum codes and standards-compliant lighting technology. This entry accounts for the retrofit trend in California but also acknowledges the fact that some T12s comply (and are still the least efficient linear fluorescent product based on nominal lamp wattage).

Minimum Codes and Standards Compliant Controls

This column lists the control strategies that are required by California Title 24 2013. Cadmus reviewed the Title 24 2013 requirements, included the requirements in this column, and provided a reference table in the Workbook 2014 worksheet dedicated to codes and standards. The Title 24 2013 lighting control requirements are extensive and detailed. We will briefly describe a few of the requirements that have broad application in the workbook and are new to the Title 24 2013 code here. For identification of which requirements are new to this edition of the codes and standards, we have relied on an infosheet from the California Lighting Technology Center.[25,26]

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21 NEMA. *Summary: New 2012 Standards for General Service Fluorescent Lamps (GSFL).* May 23, 2012. Retrieved from: https://assets.sylvania.com/assets/Documents/New%202012%20Standards%20for%20General%20Service%20Flr%20Lps%20NEMA%20v2%20_2_.96439846-e6b0-4188-b823-5a93df679bde.pdf

22 U.S. Department of Energy Office of Energy Efficiency and Renewable Energy. General Service Fluorescent Lamps (Waivers, Exceptions, and Exemptions). (n.d.). Retrieved from: http://www1.eere.energy.gov/buildings/appliance_standards/product.aspx/productid/70

23 Appliance Standards Awareness Project (ASAP). General Service Fluorescent Lamps. (n.d.) Retrieved from: http://www.appliance-standards.org/node/6802

24 Cadmus. Memo to CPUC Codes & Standards Management Team re: Potential Energy Savings and Compliance: General Service Fluorescent Lamps. October 15, 2013.

25 California Energy Commission (CEC). *2013 Building Energy Efficiency Standards for Residential and Nonresidential Buildings*. May 2012.

26 California Lighting Technology Center. *What's New in the Title 24 2013 Code?* November 2013.

Nonresidential Multilevel Control Requirements

Multilevel controls requirements are new to the Title 24 2013 building code and call for the ability to control lighting levels in response to the following signals:

- Manual dimming
- Lumen maintenance
- Tuning
- Daylighting
- Demand response

Section 130.1(b) of the Title 24 2013 code requires that a minimum number of control steps associated with particular lighting technologies are incorporated. The multilevel control requirements apply to luminaires installed in nonresidential spaces larger than 100 square feet except for classrooms. Classrooms with a connected general lighting load of 0.7 watts per square foot or less[27] must have at least one control step between 30% and 70% of full rated power.

Nonresidential Occupant Sensing Control Requirements

Occupant sensing requirements are not new to Title 24 2013.[28] However, indoor parking areas (including parking garages) and secondary spaces are new additions to the 2013 standards. Also new to the 2013 standards are bi-level occupant sensing requirements for corridor and stairwells, warehouse aisles and open areas, and library book stack aisles in section 130.1(c). Note that occupant sensing controls are different from the shutoff requirements, which can be achieved through occupant sensing, but also through automatic time-switch, signal from another building system, or other controls that are capable of automatically shutting off all of the lighting when the space is typically unoccupied.

Exterior Occupant-Sensing and Daylighting Requirements

In parking garages, other indoor parking areas, and loading and unloading areas, bi-level occupant-sensing controls are required for general lighting (Section 130.1[c]). In a parking garage area with a combined total of 36 square feet or more of glazing or opening, luminaires in the daylit zones must be controlled independently by automatic photocontrols.

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[27] There seems to be an error in the Title 24 2013 code. The classroom exception should apply to 0.7 watts per square foot or more, not 0.7 watts per square feet or less.

[28] Effective in January 2010, Title 24 2008 required occupancy sensing controls that automatically turn off all lighting in offices less than 250 square feet, conference rooms of any size, multipurpose rooms less than 1000 square feet, and classrooms of any size during vacant periods.

In addition to the photocontrols and automatic scheduling or astronomical time-switch controls that are required for all outdoor luminaires, those mounted less than 24 feet above ground are required to have bi-level occupant sensing controls (Section 130.2[c]).[29]

Residential Lighting Control Requirements

The Title 24 2013 code includes clear criteria for luminaires that qualify as high-efficacy luminaires, and these luminaires must be certified to the CEC. Luminaires that can accept low-efficacy lamps (typical medium screw base lamps) and LED luminaires that have not been certified do not qualify as high efficacy. Low-efficacy luminaires require occupant dimming or occupant-sensing controls in the residential application.

Potential (Codes and Standards Compliant to Efficient) Lighting and Controls Savings

To provide the IOUs an assessment of how savings from lighting programs are affected by the rising baseline in codes and standards—and in addition to preparing technical potential calculations from existing to efficient technologies—Workbook 2014 provides technical potential calculations from the codes and standards baseline to efficient technologies.

These technical saving potential values show how much energy can be saved—in aggregate across the IOU service areas—per year from the use of efficient lighting or control technology over the codes and standards baseline. These potential savings are calculated separately for lighting and controls. Note that the actual savings resulting from the simultaneous replacement of lighting and controls will be less than the sum of the technical potential savings calculated in the workbook for lighting and controls that are installed separately.

These potential saving calculations follow the same formula as existing-to-efficient potential calculations:[30]

Potential (C&S compliant to efficient) Lighting Savings
= Application Energy Consumption x Baseline Lighting Technology Saturation x Applicability x Percent Saving (C&S compliant to efficient)

[29] The following exceptions apply to these bi-level occupant-sensing control requirement:

- Pole-mounted luminaires with a maximum rated wattage of 75 watts
- Non-pole-mounted luminaires with a maximum rated wattage of 30 watts
- Linear lighting with a maximum wattage of 4 watts per linear foot of luminaire
- Outdoor sales: frontage, lots and canopies

[30] Cadmus. *Development of a Lighting Solutions Workbook for the LMT Program, Final Report.* CALMAC id: SCE0308. January 2012. p 21.

Potential (C&S compliant to efficient) Control Savings
= Application Energy Consumption x Baseline Lighting Technology Saturation x Baseline Controls Saturation X Applicability x Percent Saving (C&S compliant to efficient)

Application Energy Consumption is the portion of the IOU service area's annual energy consumed in the lighting application (for example, 4,282 gigawatt hours [Gwh] per year for area lighting in Figure 3).

Baseline Lighting Technology Saturation is the portion of the energy consumed by the baseline lighting technology in the lighting application (for example, 98% for linear fluorescent baseline lighting technology in Figure 4).

Baseline Controls Saturation is the portion of the lighting application energy consumption that is not controlled (that is, has either manual controls or is on a 24 hours a day, 7 days a week operation schedule) and is, therefore, available for the applicable control savings (for example, 79% of linear fluorescent baseline lighting technology does not have any automatic controls in Figure 3). This value is either based on the 2013 CSS, 2012 CLASS, the 2010 Lighting Market Characterization survey (referenced and discussed in the Literature Review and Workbook 2014 Data section of this report[31]) or is estimated based on Cadmus' professional judgment.

Applicability is a factor contained in a supporting worksheet and is currently set at 80% to account for the fact that not all of the technical potential is attainable due to physical constraints or other barriers.[32]

Percent Saving is an overall annual energy-saving factor for going from a baseline technology to an efficient replacement technology. The percent saving is often based on comparison of the wattage between baseline and replacement technologies (assuming that the hours of use remain the same when a baseline technology is replaced with a more efficient technology). It varies for each technology pairing, and all associated calculations are laid out in a supporting worksheet in the workbook. Workbook 2014 includes percent saving for codes and standards baseline-to-efficient technology pairings as well. Two examples for percent saving calculations are:

- Percent Saving from Linear Fluorescent T-8 / Code Compliant T-12 (compliant baseline) to High Efficiency Linear Fluorescent T-8 / T-5 (efficient replacement technology):

  The percent saving here is based on a comparison of lamp and ballast system-rated wattage, going from a two-lamp four foot 32-watt T-8 with an electronic ballast fixture (with a rated

31 This section of the interim report was included in Cadmus memo no. 2 dated May 2, 2014.

32 Ibid.

wattage of 60 based on Massachusetts Device Codes and Rated Lighting System Wattage Table[33] and Xcel Energy Lighting Retrofit Input Wattage[34]) to a two-lamp four-foot 28-watt T-8 with an electronic ballast (with a rated wattage of 48). The percent saving is calculated as (60W - 48W)/60W = 20%.

- Percent Saving from Shutoff and Multilevel Controls (compliant baseline) to Occupancy (efficient replacement technology):

  There is a limit to the total control savings in lighting applications. In other words, the lights have to remain on at least part of the time at the designed lumen output. On the other hand, documented controls savings in demonstration studies and simulations are often based on a baseline of no controls. We do not have documented savings resulting from the replacement of one control strategy (daylighting, for example) with another (occupancy, for example). We decided that the best approach for producing saving estimates resulting from the replacement of one control strategy with another is to compare the documented savings percentages.

  In this case, the percent saving is calculated based on the difference between controls savings resulting from occupancy controls (24% based on Williams et al.[35]) and those resulting from shutoff and multilevel controls (estimated through Cadmus' professional judgment based on other sources to be 20%[36]). The difference is 24% - 20% = 4%.

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33 Mass Save. Massachusetts Device Codes and Rated Lighting System Wattage Table for Massachusetts Customers, 2011 Retrofit Program. January 1, 2011. Available at: http://www.nstar.com/docs3/application_forms/retro-codes.pdf

34 Xcel Energy. Lighting Efficiency (input wattage guide). November 2013. Available at: https://www.xcelenergy.com/staticfiles/xe/Marketing/MN-Bus-Lighting-Input-Wattage-Guide.pdf

35 Refer to the Lighting Controls Updates section of this report (submitted in a memo dated May 2, 2014) for a complete discussion of this reference and the saving value for occupancy controls.

36 According to Cadmus professional judgment, the savings possible from shutoff controls is 5%. We have added this to the minimum savings possible from multilevel controls in Title 24, 2013. The minimum savings possible from multilevel controls (15%) has been obtained from this reference:
Southern California Edison. *Requirements for Controllable Lighting.* 2013 California Building Energy Efficiency Standards, Codes and Standards Enhancement Initiative. Prepared by Avery D., Benya, J., Neils, M., Rubinstein, F., Neils, D. March 2011.
Both of these values, the references, and the methodology are recorded in a supporting worksheet in Workbook 2014.

Baseline Lighting Technology and Controls Saturation Updates

The final results of three large California lighting market surveys became available in the third quarter of 2014. These surveys were:

1. **2011-2013 Commercial Saturation Survey (CSS):** The CSS is a survey of current installed equipment and baseline efficiencies for several end uses in the commercial sector. These end uses include lighting, televisions, office equipment, refrigeration, HVAC, energy management systems, and distributed generation systems. The survey involved on-site data collection, as well as a review of the utility customer information systems, billing data, and program tracking data. The study occurred in 2011-2013 and involved 1,439 on-site visits.[37]

2. **Commercial Market Share Tracking (CMST):** The CMST is a survey of market shares for various types and efficiencies of linear fluorescent lighting, televisions, and small packaged HVAC units from 2011-2013 in California. The CMST involved a telephone survey of 7,890 businesses, on-site data collection on purchases of linear fluorescents, televisions, and new HVAC systems from 500, 400, and 200 businesses respectively, and a telephone survey on the efficiency of linear fluorescents and commercial HVAC systems sold with 95 and 123 installers, respectively. While the CSS provides existing saturations of linear fluorescent lamps installed in the commercial sector, the CMST provides detailed information on the sales of various types and efficiencies of linear fluorescents.[38]

3. **2012 California Lighting and Appliance Saturation Survey (CLASS):** The 2012 CLASS followed up on the 2005 CLASS (the results of which were incorporated in Workbook 2012) and the 2000 Statewide Lighting and Appliance Efficiency Saturation Study. The 2012 CLASS helps the CPUC and the California IOUs estimate current levels of equipment and lighting saturation and efficiencies in the existing residential sector, based on an on-site survey of 2,000 single-family, multifamily, and mobile home residences in the service territories of the IOUs. The draft CLASS 2012 report also includes a comparison of the saturations and efficiencies between the 2012 CLASS data and previous CLASS studies.[39]

Cadmus prepared data requests for the CPUC, which managed all three surveys, and obtained lighting and controls saturations for the residential sector, the nonresidential commercial subsector (with the exception of hotel/lodging, hospitals, colleges and universities, which were not included in the CSS and

[37] Itron, California Commercial Saturation Survey, Final report. Prepared for the CPUC, August 2014.

[38] Itron, California Commercial Market Share Tracking Study, Final report. Prepared for the CPUC, July 2014.

[39] DNV GL, WO21: Residential On-Site Study: California Lighting and Appliance Saturation Study (CLASS 2012) – Draft Final Report. Prepared for the CPUC, 2014.

CMST surveys[40]), and exterior sector (with the exception of roadways not included in the CSS). Cadmus updated the existing installed/baseline lighting and controls technology types, with their saturations based on the responses received to the data requests.

In the interest of brevity, linear fluorescent lamp types are not broken out in either the existing installed/baseline lighting technologies or the efficient replacement technologies listed in the workbook. CSS provided the baseline saturation of all linear fluorescent lamps in the commercial buildings subsectors. However, we used the CMST saturation of linear fluorescent lamp types and efficiencies in the estimated saving percentage calculations for going from linear fluorescent as a baseline technology to more efficient lighting technologies (for more explanation see **percent saving** in the previous section of this report, *Potential (Codes and Standards Compliant to Efficient) Lighting and Controls Savings*).

The incorporation of recent saturation surveys in Workbook 2014 is a significant improvement in the accuracy of the saving potential calculations; the previous saturations were based on older California saturation surveys (such as 2005 CLASS and 2006 California Commercial End-Use Survey [CEUS]), national market studies, Northwest commercial building stock assessment, and Cadmus' engineering judgments. Additionally, Workbook 2014 now presents a more accurate picture of the existing building stock in California and the saturation of baseline and efficient technologies.

Changes to Building Subsector and Lighting Application Categories

The Workbook 2012 building subsectors and lighting applications were developed based on IOU needs, the 2006 CEUS, and the limited saturation data available in 2010-2012, when the workbook was created. In order to incorporate the baseline lighting saturation survey results from the 2011-2013 CSS in the workbook, the IOUs asked Cadmus to align the commercial building subsectors and lighting applications in the workbook with those used in the CSS. Table 7 shows the building sectors, subsectors, and lighting applications in Workbook 2014 as aligned with the 2011-2013 CSS.

The residential sector of the workbook includes single-family, mobile homes, high-rise and low-rise multifamily buildings. At the request of the LMT program, these subsectors are not broken out. However, in order to provide more granularity to the market saturation information, technical potential, and codes and standards baseline requirements in this subsector, two lighting applications have been defined for the residential sector:

- Living spaces include kitchen, bedroom, living room, dining room, office, play room, etc.
- Support spaces include hallway, corridor, bathroom, closet, garage, storage, utility room, storage, basement, etc.

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40 These excluded building types are discussed in the following section of this report on Changes to Building Subsector and Lighting Application Categories.

Table 7. Building Sectors, Subsectors, and Lighting Applications in Workbook 2014
(categories highlighted in red are nonresidential building subsectors that were not included in the 2011-2013 CSS)

Building Sectors	Building Subsectors	Lighting Applications
Residential (Interior and Exterior)	None	Exterior
		Interior Support Spaces
		Interior Living Spaces
Nonresidential Interior	Food and Liquor Stores	Each building subsector includes the following lighting applications as applicable: Area (low/medium bay) Area (high bay) Task Track Exit Display and Advertising
	Health and Medical Clinics	
	Office	
	Retail	
	Restaurant	
	Warehouse	
	School	
	Miscellaneous	
	Hotel/lodging	
	Health and Medical Hospitals	
	Colleges and Universities	
	Industrial	
	Agricultural	
Nonresidential Exterior	Outdoor	Parking Lot
		Parking Garage
		Façade, Landscape, Service Canopies
	Roadways	Streetlights
		Traffic Signals
		Signs and Billboards

Changes to the Workbook Structure and Summary Sheets

The main worksheet in Workbook 2014 is called Market Solutions, which includes application energy consumption, existing installed lighting technologies, efficient replacement lighting and control technologies, and the potential energy savings resulting from the replacement of existing technologies with efficient ones. The Market Solutions worksheet covers the most significant lighting applications across the residential and nonresidential interior and exterior subsectors and, therefore, is quite expansive.

In Workbook 2012, the Market Solutions worksheet had a branching structure that made it easier to digest at a glance. The addition of five distinct control strategies (occupancy, daylighting, personal tuning, institutional tuning, and multiple controls) to Workbook 2014 meant there would now be four or five new rows for each row in Workbook 2012. As a result, the Market Solutions work sheet in Workbook 2014 has 450 rows and 29 columns. The sheer size of the Market Solutions data has rendered the branching structure unfeasible in the 2014 update. The 2014 Workbook's Market Solutions worksheet, albeit not easy to digest in one glance, more closely resembles a database structure and, therefore, handles sorting and filtering better. It also supports long-term development of the Workbook, which is bound to become more extensive as it reflects the complexity of the lighting market.

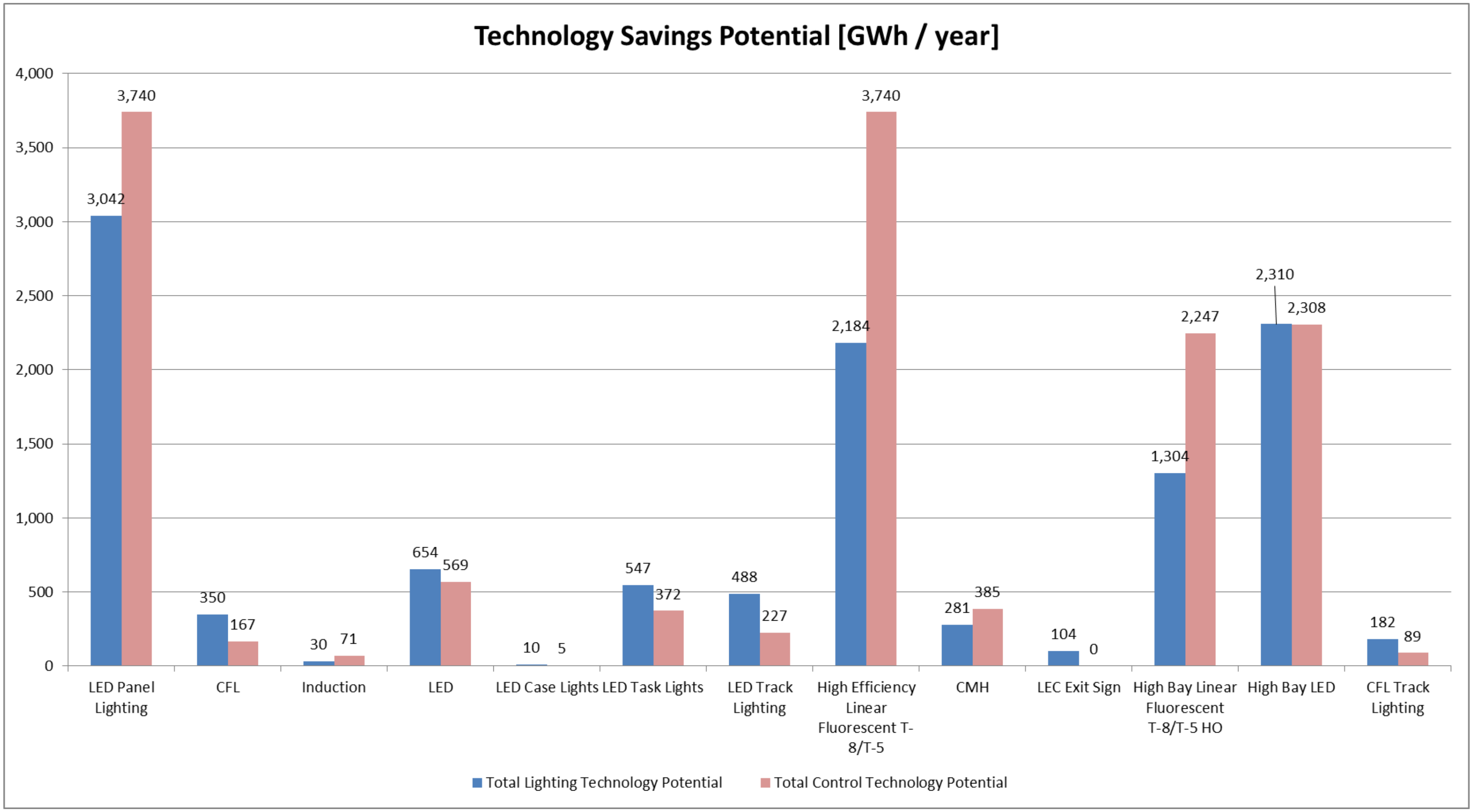
To provide the LMT program team with a high-level overview of the data contained in Market Solutions, Cadmus has created three new summary worksheets by sector and one user-customizable sheet; these are Summary-Residential, Summary-Nonresidential Interior, Summary-Nonresidential Exterior, and Summary-Custom. These summary sheets contain high-level charts and graphs that convey the sector-level information contained in the Market Solutions worksheet.

The tables underlying the charts on all summary sheets are locked, except for the Summary-Custom worksheet. This worksheet is open to the user to create and modify tables and charts based on a particular area of interest. There are two charts in each summary worksheet:

- Saving Potential by Efficient Technology
- Saving Potential by Application

The nonresidential summary charts derived from preliminary data are provided in Figure 5 and Figure 6. Figure 5 shows the technical saving potential of each efficient lighting replacement technology in Workbook 2014 across applications and building subsectors in the nonresidential interior sector. Based on the preliminary data shown in Figure 5, high efficiency linear fluorescent T-8 / T-5 and LED panel lighting technologies have the largest technical potential (due to the efficiency of the technology, but also their wide application in various building sub-sectors). Note that the potential savings shown in this figure cannot be added, since often more than one efficient replacement technology has been proposed for a single baseline technology. For example, both high efficiency linear fluorescent and LED panel lighting are proposed in the workbook as efficient replacement alternatives for baseline linear fluorescent technology.

Figure 5. Nonresidential Interior Sector Technical Saving Potential for Efficient Lighting and Control Technologies in Workbook 2014



Note: CMH stands for Ceramic Metal Halide lamps.

Figure 5 also shows the total control savings possible for each efficient replacement technology in the nonresidential interior sector. Since Workbook 2014 provides saving potential for multiple control strategies (i.e., occupancy, daylighting, personal tuning, institutional tuning, multiple controls), the total control saving potential shown here is the summation result of savings from control strategies with the highest saving potential in each application. For example, if *occupancy* was the strategy with the highest potential in a certain application using LED panel lighting, and *multiple controls* was the strategy with the highest saving potential in all other application, the control saving potential shown alongside LED panel lighting in Figure 5 is the sum of the savings resulting from those strategies.

Figure 6 shows the technical potential savings possible in each application in Workbook 2014, across building subsectors in the nonresidential interior sector. Figure 6 shows that general lighting and high-bay lighting are applications with the highest potential for lighting and control energy saving, followed by general lighting in lobbies and corridors, and low/medium bay lighting.

Similar summary charts for residential and nonresidential exterior have been provided in Figure 7, Figure 8, Figure 9, and Figure 10.

Figure 6. Nonresidential Interior Sector Technical Saving Potential in Major Lighting Applications in Workbook 2014

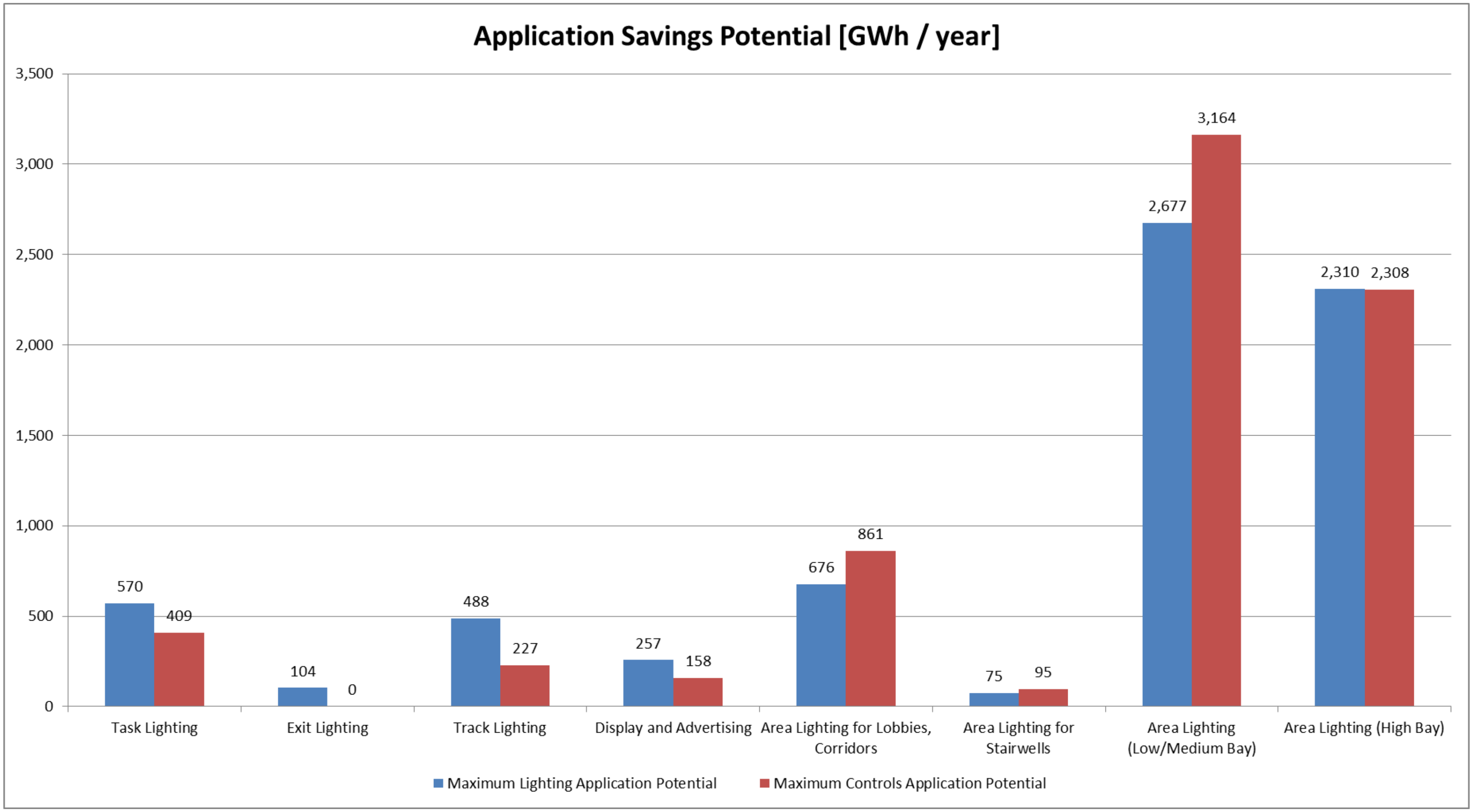


Figure 7. Residential Sector Technical Saving Potential for Lighting and Control Technologies in Workbook 2014

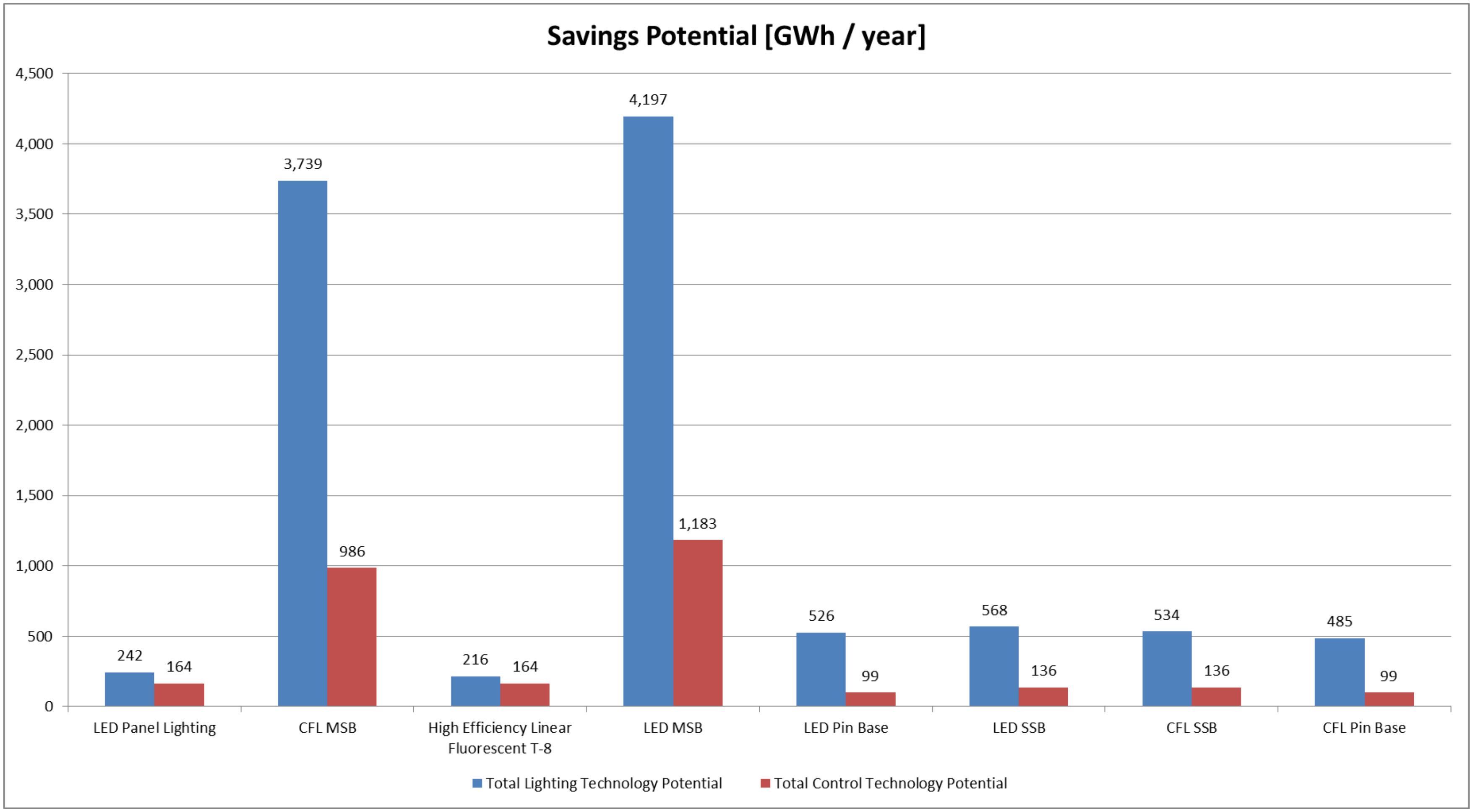


Figure 8. Residential Sector Technical Saving Potential for Lighting Applications in Workbook 2014

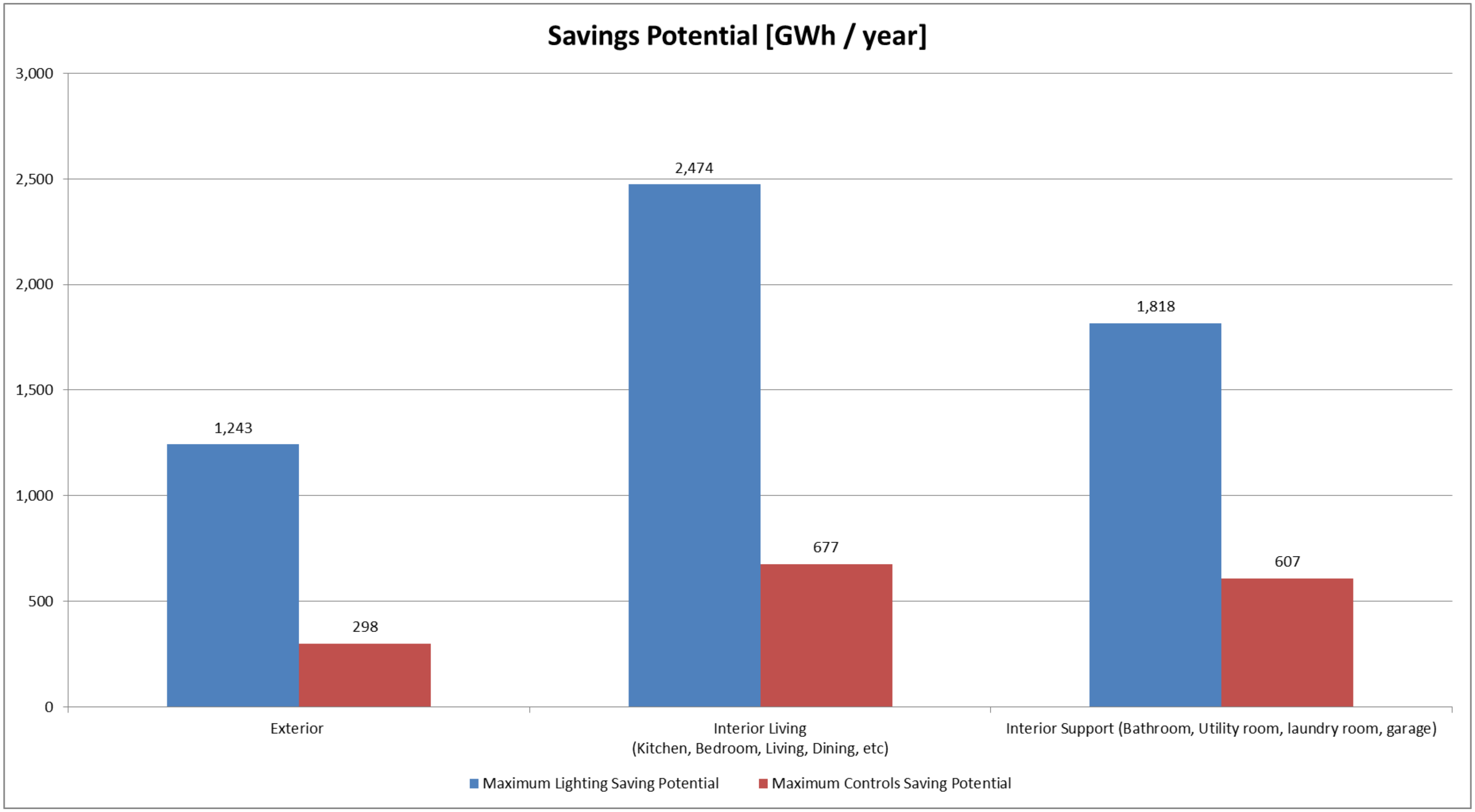


Figure 9. Nonresidential Exterior Sector Technical Saving Potential for Lighting and Control Technologies in Workbook 2014

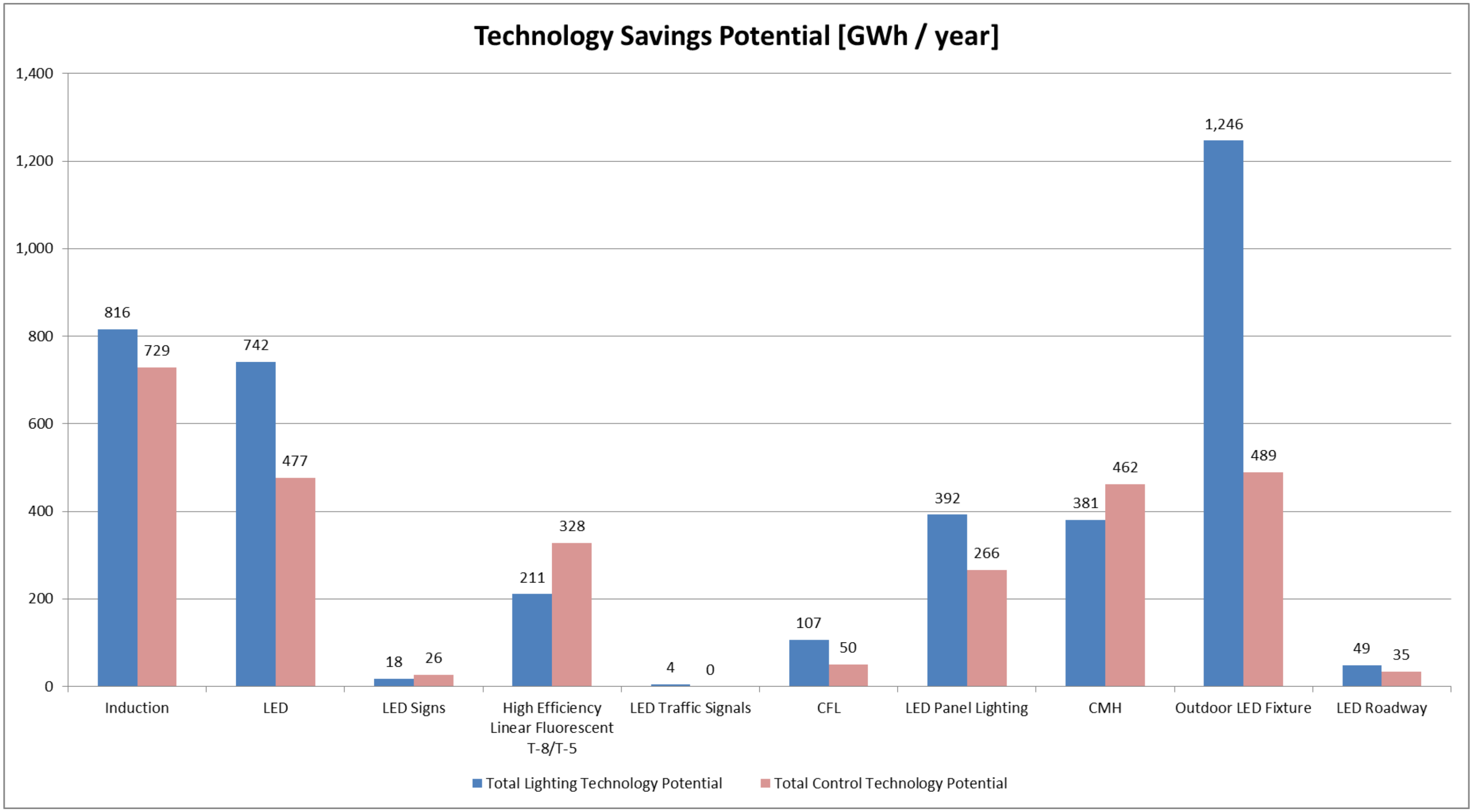
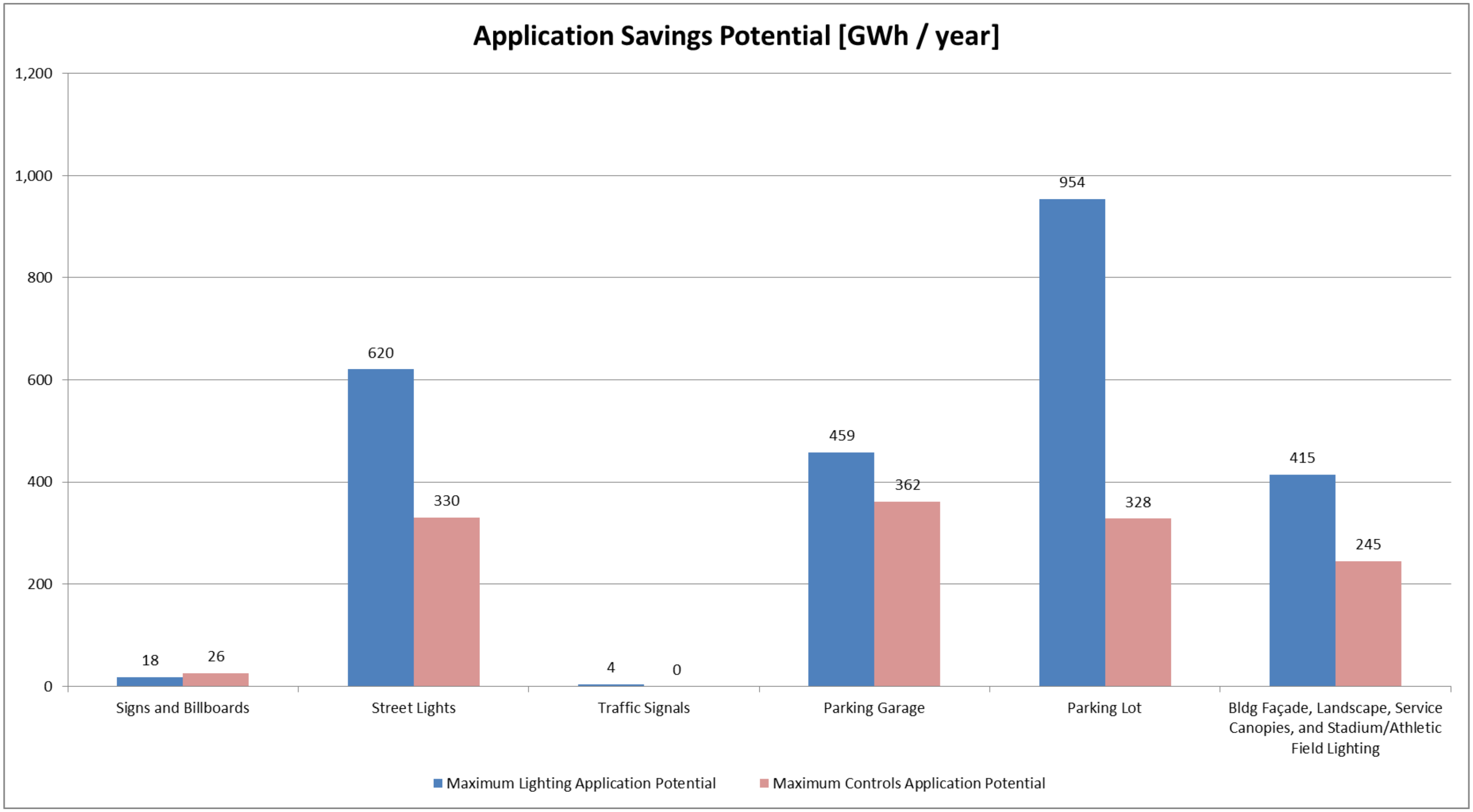


Figure 10. Nonresidential Exterior Sector Technical Saving Potential for Lighting Applications in Workbook 2014



Data Validation

The workbook is a planning tool that is meant to achieve an order of magnitude accuracy in estimating the potential for various lighting technologies statewide in order to assist the LMT team in prioritizing competing efficient technologies for market transformation strategy development. This section includes rough calculations to validate the technical potential savings estimates in Workbook 2014. Cadmus referred to the results of the 2013 California Energy Efficiency Potential and Goals Study (briefly referred to in this section as the 2013 CA Potential Study) to validate the technical potential saving estimates.[41]

The results of the validation tests are described below for residential and nonresidential lighting technical saving potentials. It is important to point out that the workbook and the 2013 CA Potential Study follow two different methodologies to arrive at the technical potential estimates. Additionally, there are many more estimates built into the workbook than in the potential study. Still, the potential study provides a good benchmark to validate the order of magnitude accuracy of the numbers calculated in Workbook 2014.

In both validation tests described below, the 2013 CA Potential Study technical savings were 1.3-1.8 times larger than those in the 2014 Workbook and within the order of magnitude. The difference between the two values could be due to the fact that the workbook incorporates the results of the three large California lighting saturation surveys (CSS, CMST, and CLASS) that became available after the 2013 CA Potential Study was published. The workbook therefore more accurately reflects the baseline lighting saturations in the existing building stock and the advancement that the state has made in reducing the technical potential by moving towards more efficient lighting technologies.

California Residential Lighting Technical Saving Potential Estimate in 2015

Workbook 2014 shows that the total residential sector technical saving potential estimate in the state (IOU territories) in 2015 is 7,117 GWh (refer to Figure 8). This includes the savings that would be achieved through upgrading noncompliant technologies to meet existing codes and standards. A simple calculation in the residential sector shows that excluding the savings associated with codes and standards would reduce the technical potential by 23%. Therefore, the total residential sector technical savings potential, excluding codes and standards in California, is 5,480 GWh.

In the 2013 CA Potential Study, Figure 5-1 (titled California Residential Gross Technical, Economic, and Cumulative Market Energy Savings Potential for 2012-2024) shows that the total residential technical saving potential in the state (across IOU territories) in 2015 is about 17,500 GWh. This includes lighting and all other end uses. In the same study, Figure 5-6 (titled California Breakdown of Consumption and 2014 Savings Potential by End Use) shows that, for year 2014, 42% of the technical potential savings are associated with the lighting end use. Therefore, Cadmus concluded that the 2013 CA Potential Study

41 Navigant, 2013 California Energy Efficiency Potential and Goals Study, Revised Draft Report, Prepared for CPUC, November 2013.

provides 7,350 GWh (17,500 GWh x 42%) as the estimate of technical saving potential for residential lighting in 2015. This number is 1.34 times larger and within the same order of magnitude as the 5,480 GWh technical saving potential estimated in Workbook 2014.

California Nonresidential Lighting Technical Saving Potential Estimate in 2015

Workbook 2014 shows that the total nonresidential interior and exterior sectors' technical saving potential estimate in the state (IOU territories) in 2015 is 18,140 GWh (refer to Figure 6 and Figure 10 in this report). This number includes the savings associated with both lighting and controls in commercial and industrial buildings.[42]

It also includes the savings that would be achieved through upgrading existing noncompliant technologies to comply with codes and standards technologies. A simple calculation in the workbook shows that excluding the codes and standards savings would reduce the technical potential by 35%. The industrial lighting technical saving potential is estimated as 1,679 GWh.

Therefore, the statewide (IOU territories) total nonresidential interior and exterior sector technical savings potential, excluding codes and standards and the industrial sector, is 10,700 GWh, which is calculated as (18,140 - 1,679) x 65%.

The 2013 CA Potential Study Figure 6-1 (titled California Commercial Gross Technical, Economic, and Cumulative Market Energy Savings Potential for 2012-2024) shows that the total commercial technical saving potential in the state (across IOU territories) in 2015 is about 32,500 GWh. This includes lighting as well as all other end uses. In the same study, Figure 6-6 (titled California Breakdown of Commercial EUIs and 2014 Savings Potential by End Use) shows that, for year 2014, 57% of the technical potential savings are associated with the lighting end use.

Therefore, Cadmus concluded that the 2013 CA Potential Study provides 18,525 GWh (32,500 GWh x 57%) as the estimate of technical saving potential for commercial building lighting in 2015. This number is 1.73 times larger and within the same order of magnitude as the 10,700 GWh technical saving potential estimated in Workbook 2014.

42 Agricultural buildings are also included in the nonresidential interior sector, but due to missing existing saturation values, the associate technical saving potential is calculates as zero in the workbook.

California Lighting Market Indicators

Cadmus performed the California Lighting Market Indicator analysis to assist the LMT program in tracking the changes in the California lighting market over time. Early in the analysis, Cadmus and the LMT program team agreed that useful market indicators will be:

- Based on readily available data
- Specific to California
- Tracked (consistently) over time

The indicators should also provide:

- A high level snapshot of market activity
- A useful understanding of changes in the market

In reviewing available data on the California market, Cadmus found multiple data sources that met the above criteria for the residential lighting market sector, but none for the nonresidential lighting market sector. As a proxy, Cadmus has used nonresidential utility program participation data. Cadmus has also referred to the results of three large California market surveys (CSS, CMST, and CLASS) and the reports prepared for the CPUC for a comparison of lighting technology saturations found over consecutive surveys.

Data Sources

Cadmus relied on three sources of data that met the agreed upon criteria for California lighting market indicators.

Residential

- Lighting point-of-sale (POS) data including sales price and volume from large grocery, drug, mass merchandise, and dollar stores retail outlets. This dataset does not include independent businesses (mom and pop shops), hardware and home improvement chains, or Costco. Cadmus purchased this data for 2010, 2011, and 2012, from a market research firm.
- Lighting shelf surveys conducted by DNV GL. Retail outlets included in this data are: discount, drug, grocery, hardware, home improvement, mass merchandise, and membership club. The aggregated data (weighted by retail outlet) may be accessed via: http://www.bulbstockdata.com/. DNV GL conducted retail stocking studies in 2009, 2011, 2012, and 2013.

Nonresidential

- California IOU nonresidential lighting program measure participation data for program years 2010-2012 (and preliminary numbers for 2013) from PG&E, SCE, and SDG&E.

Residential Market Indicators

Using the data sources listed above, Cadmus developed the following residential market indicators:

- Retail pricing
- Share of retail sales
- Retail shelf stocking by technology (incandescent, halogen, fluorescent, CFL, LED)

Given the limitations of the data sources used, we note that these indicators are not a perfect measure of the lighting market. The main limitation of the POS data is that it does not include home improvement retail outlets or membership clubs as reporting channels. A limitation of the shelf survey data is that it is not available for 2010, and the data collection methods vary slightly from year to year. Although we provide a side-by-side comparison of the shelf stocking and sales data in this report, the relationship between shelf stocking and sales deserves a separate, more thorough investigation.

Retail Pricing by Light Technology

Cadmus used POS data to determine average price per general purpose lamps sold through POS retail outlets. To conduct the analysis, we determined the weighted average price for a sample of seven to 10 models in each lighting technology category. The models we chose were those that had the highest sales volume. In order to identify lamps that would be most likely to be general purpose models, we excluded appliance and specialty lamps, non-screw base lamps, and lamps that were not equivalent to a 60 to 100 watt incandescent lamp. Results are shown in Table 8.

Table 8. Pricing Market Indicators

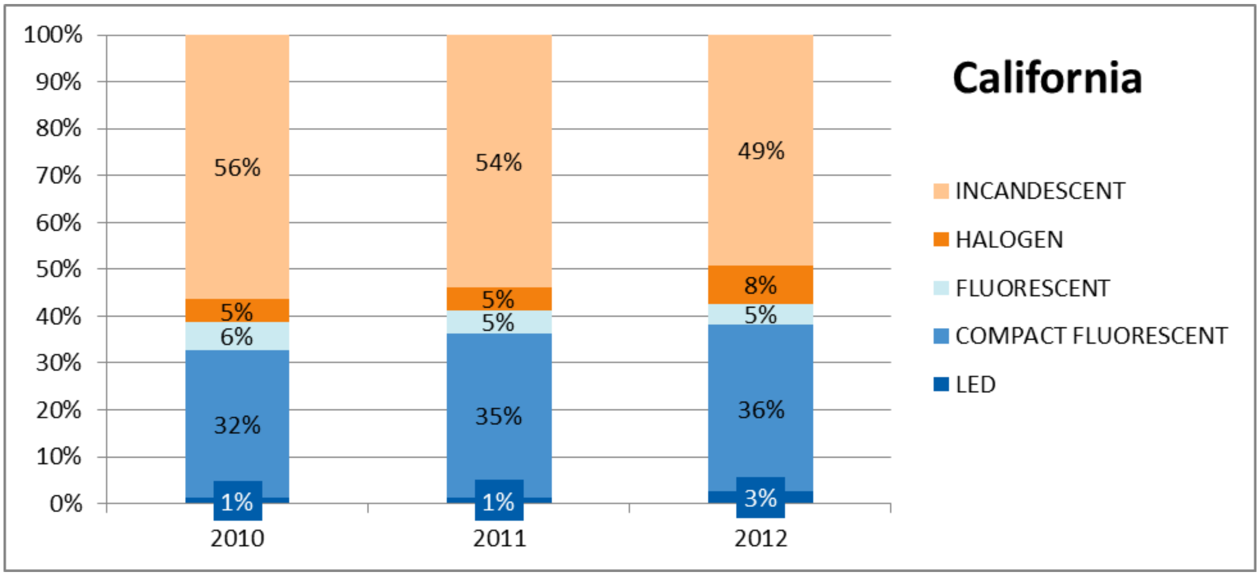
Light Technology	Price per General Purpose Bulb		
	2010	2011	2012
LED	N/A	N/A	$24.90
Compact Fluorescent	$0.75	$0.87	$1.71
Halogen	$3.63	$4.15	$4.19
Incandescent	$0.80	$0.84	$0.94

We found no LED lamps greater than 10 watts sold through the POS dataset outlets prior to 2012. This is not surprising since home improvement/hardware stores, which have the greatest selection of lamps, are not included in the POS data. With the exception of LED lamps, unit prices appear to be increasing year-over-year, possibly due to program subsidized lamp volume, increased quality, inflation, or cost to manufacture. The price differences between lighting technologies are consistent with our expectations (e.g., LEDs are the most expensive and incandescent are the least). Cadmus expects that repeating this analysis with POS data for 2013 and beyond, will provide further indication of how the price of LED lamps is changing in response to market interventions, increasing consumer awareness, and improvements in the technology.

Share of Retail Sales

The POS data allows us to track the sales volume of various lamp technologies through the reporting channels. We conducted this analysis for the three major metro areas of California (Los Angeles, San Diego, and the San Francisco Bay Area), but did not find significant differences between regions. Figure 11 shows the statewide results.

Figure 11. Share of Sales by Lighting Technology (Grocery, Drug, Mass Merchandise, and Dollar Store Outlets)

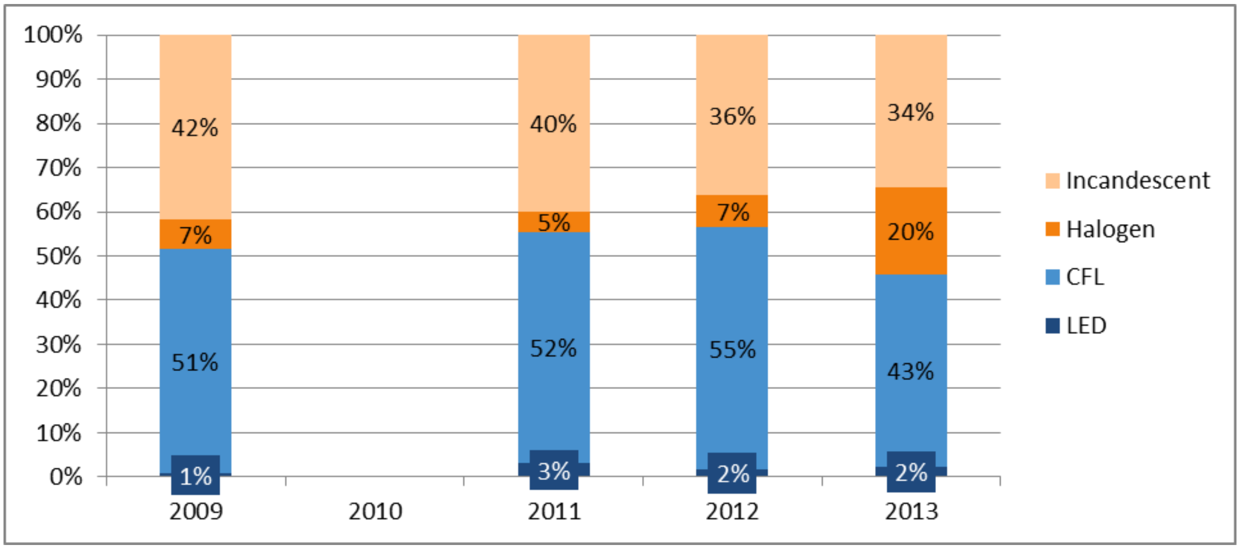


Halogen lamps and CFLs appear to be growing at the expense of incandescent lamps in 2012. LEDs may be showing growth in 2012, although their share of sales through the POS outlets is still very low.

Retail Shelf Stocking

Cadmus downloaded data from the DNV GL shelf stocking online database. We chose CFL, halogen, incandescent, and LED lamps with medium screw base and elected to use the channel weighted results. Figure 12 shows the results for the years where data are available.

Figure 12. Share of Retail Shelf Stock (Discount, Drug, Grocery, Hardware, Home Improvement, Mass Merchandise, and Membership Club Outlets)



We see an increase in halogen lamp stocking (possibly due to the EISA), and a decrease in traditional incandescent lamp stocking. LED stocking does not appear to have changed much between 2011 and 2013.

Cadmus further explored the relationship between retail shelf stocking and sales, by removing non-reporting channels from the shelf stocking data, in order to have a consistent set of reporting channels in both data sets. The results are described in the next section.

Comparison of Retail Shelf Stocking and POS Results

Figure 13 and Figure 14 show a comparison between sales and shelf stocking between 2009 and 2013. The shelf stocking data shown in Figure 14 contain results from discount, drug, grocery, and mass merchandise outlets, which are the outlets included in the POS data. The two data sources show the following changes between 2011 and 2012:

- LED and halogen lamps', and CFLs' share of sales and shelf stocking increased
- Incandescent lamps' share of sales and shelf stocking decreased

Figure 13. Share of Sales by Lamp Type

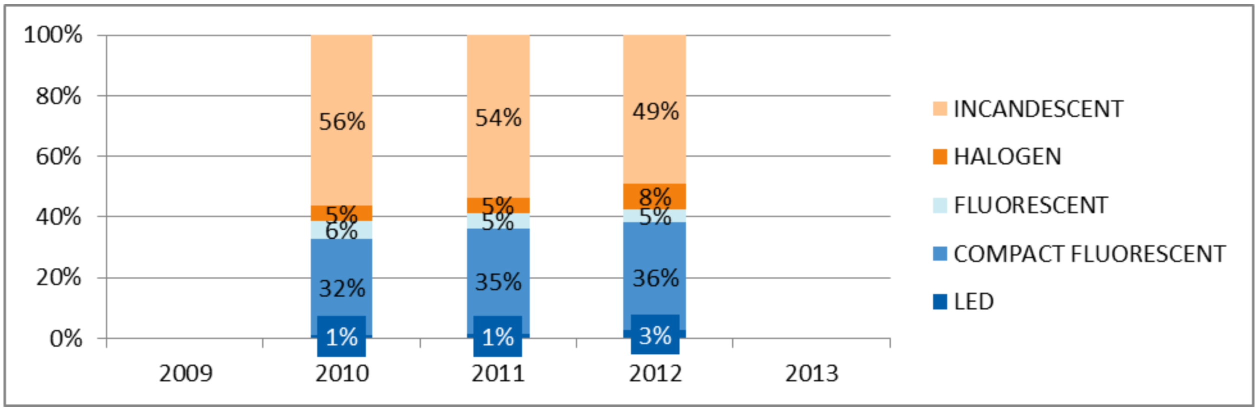
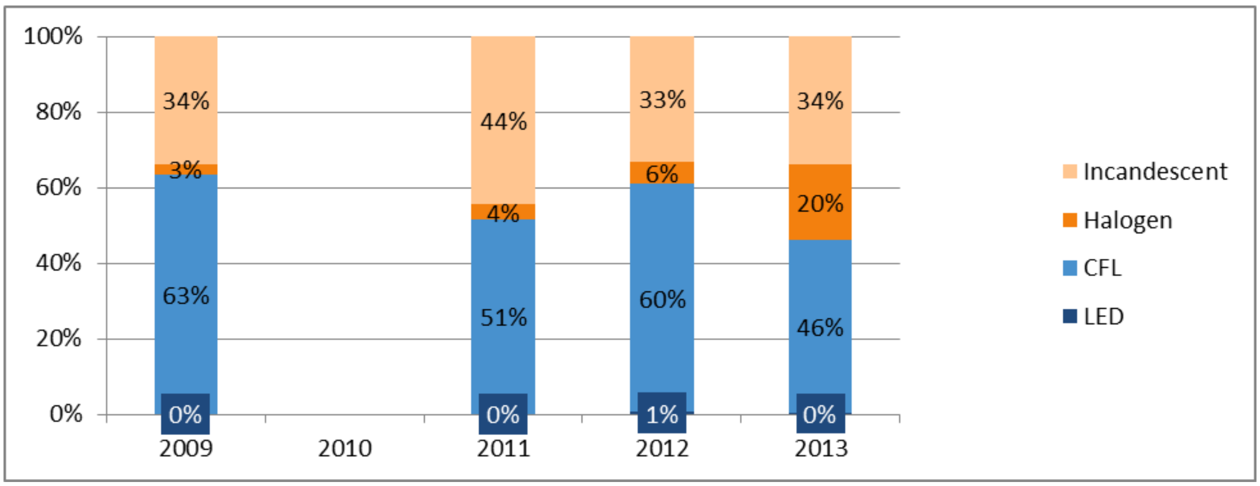


Figure 14. Share of Shelf Stock (Discount, Drug, Grocery, Mass Merchandise Outlets)



Residential Lighting Installed Lighting Saturation

Assuming that a residential lighting saturation survey will be performed periodically in the state, installed lighting technology saturation is a useful lighting market indicator. In order to successfully track installed lighting saturation as a market indicator across multiple saturation surveys, it is important for the survey results to be comparable in terms of technology categories, weighting methods, and building types included.

The draft report available based on the results of 2012 CLASS includes a section on comparing the results of the 2012 CLASS survey with the results of the 2006-2008 Upstream Lighting Evaluation.[43, 44]

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43 DNV GL. *WO21: Residential On-Site Study: California Lighting and Appliance Saturation Study (CLASS 2012) – Draft Final Report.* Prepared for the CPUC. 2014.

44 DNV GL. *Final Evaluation Report: Upstream Lighting Program, Volume 1*. Prepared for CPUC. February 2010.

The results of lamp type comparisons has been reproduced in Table 9. The authors note that in general the saturation of incandescent lamps decreased, while the saturation of CFL lamps increased. The installed share of LED lighting was relatively small in both studies. This is expected since LED lighting started gaining market traction in 2012 as a results of price reduction (with IOU incentives) and increased availability.

Performing a large scale survey such as CLASS is far more expensive than obtaining lighting sales data. Therefore, although annual tracking of market indicators based on lighting sales data may be possible, tracking of installed lighting saturation in the state may only be possible once every few years.

Table 9. Lighting Technology Saturations Comparison in the 2012 CLASS and the 2006-2008 California Upstream Lighting Study (based on the Number of Sockets Occupied)

Lamp Type	Upstream Lighting Metering Study	2012 CLASS
Incandescent	53%	49%
CFL	22%	28%
Fluorescent	12%	11%
Halogen	8%	9%
Socket Empty	4%	2%
LED	-	1%
Unknown	1%	-
Overall	100%	100%

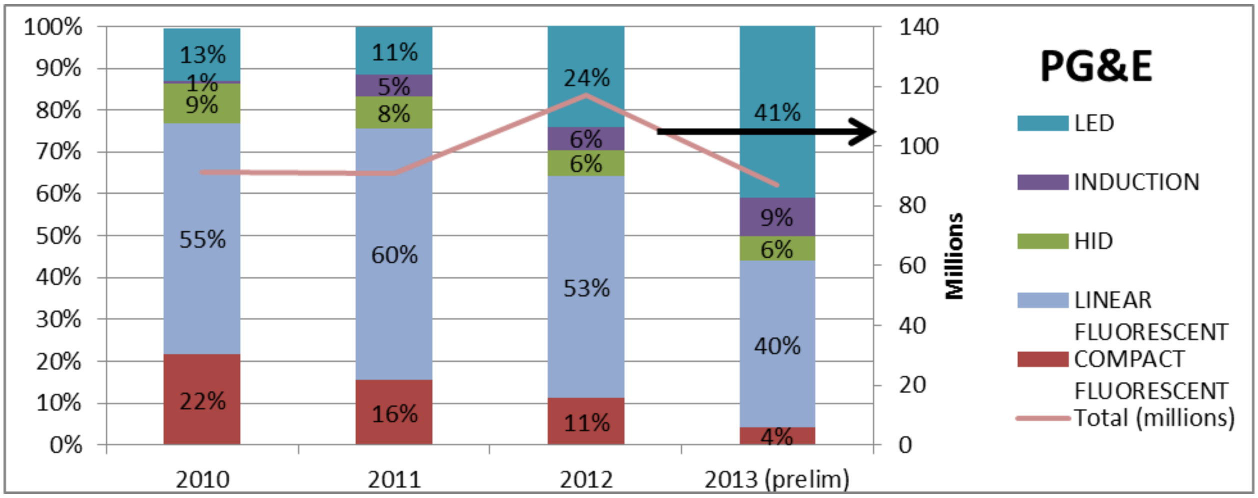
Nonresidential Market Indicators

Program Participation

Cadmus reviewed lighting measure participation data from the IOUs for program years 2010 through 2012 (and preliminary numbers for 2013). Upon review of the program participation data provided by the IOUs, Cadmus found a number of discrepancies. First, we saw PG&E measure participation was two to three orders of magnitude larger than the other IOUs. PG&E indicated the dataset provided included custom (calculated) and non-core programs (partnerships and third party). In contrast, SCE provided only core deemed program participation. SCE and SDG&E datasets allowed us to filter participation by program type; however, this was not an option for PG&E. Thus, we analyzed each utility’s lamp data separately.

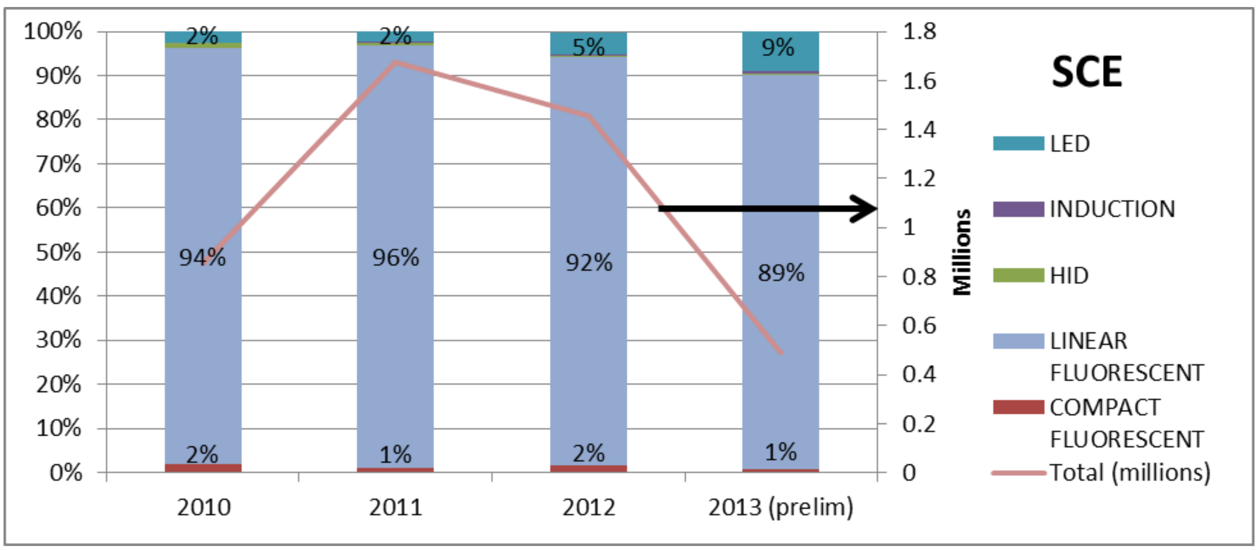
PG&E (Figure 15) programs experienced steady growth in LED and induction lighting and a decrease in linear fluorescents and CFLs.

Figure 15. PG&E Lighting Participation (all nonresidential)



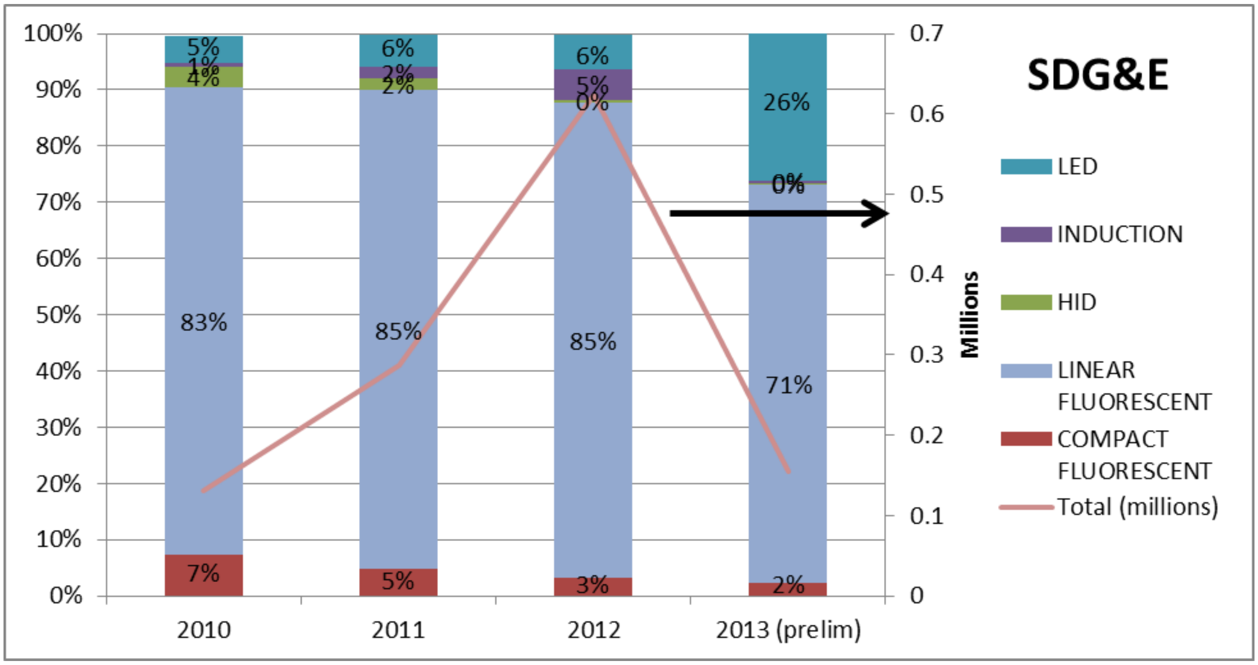
SCE (Figure 16) shows less aggressive growth in LEDs, with the majority of deemed participation in linear fluorescents. The preliminary data from 2013 suggests that participation in linear fluorescent incentives is slowly decreasing.

Figure 16. SCE Lighting Participation (nonresidential deemed)



SDG&E's preliminary 2013 data (Figure 17) shows significant growth in LED participation at the expense of linear fluorescents. For the three years prior, participation in induction lamp incentives increased while CFL participation decreased.

Figure 17. SDG&E Lighting Participation (nonresidential deemed)

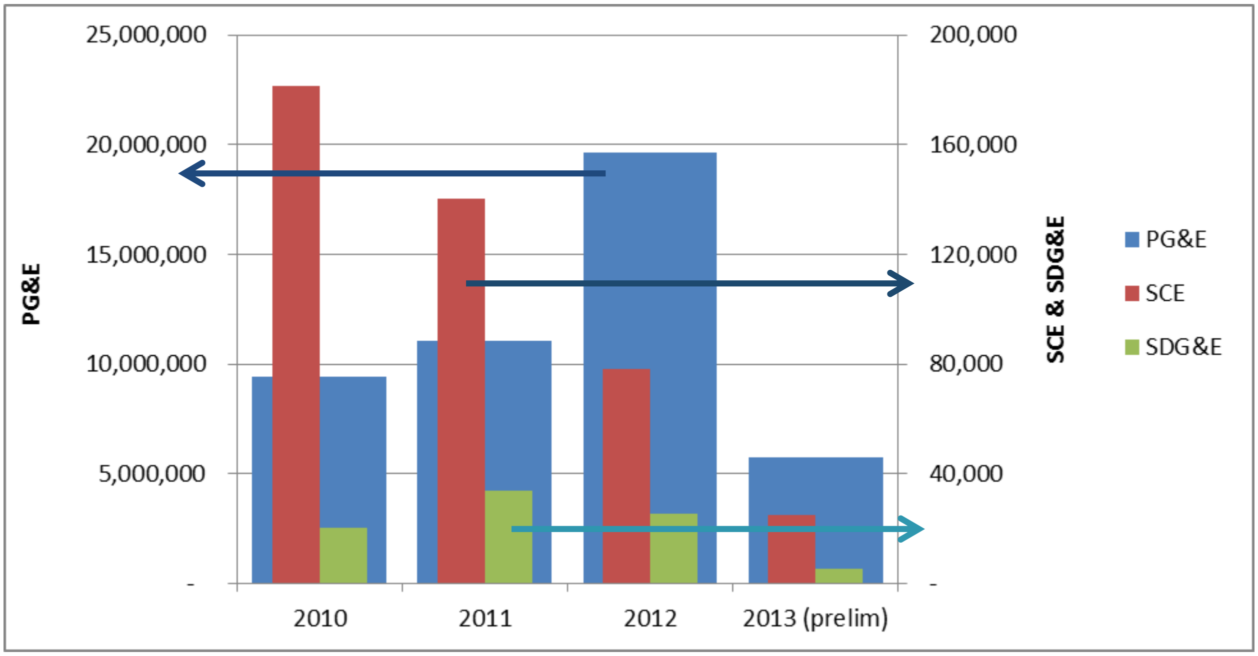


The results for all three utilities show a notable increase in use of LEDs and a decline in fluorescent technologies, particularly linear fluorescents and CFLs. Although program participation is not a representative market indicator, this data provides indication of increased market penetration for the more advanced technologies and declining popularity for the fluorescent technologies.

Figure 18 shows each IOU's participation over time for controls/sensors. PG&E's participation increased through 2012, while SCE's participation decreased year over year[45]. The participation numbers for 2013 were preliminary. Therefore, Cadmus can only tentatively point to a decline in SDG&E's participation in controls/sensors.

[45] Given the increasing importance of controls in lighting energy efficiency programs, Cadmus will highlight this trend and explore ways to change it as part of the LMT pipeline plan development effort.

Figure 18. Controls/Sensors Participation



Nonresidential Interior Installed Lighting Saturation

A more detailed set of data for the nonresidential sector has become available as a result of the 2013 CMST and the 2011-2013 CSS surveys. The final report available based on the results of the 2011-2013 CSS,[46] includes comparisons between the results of the 2011-2013 CSS with the 2006 CEUS. The report notes that the results of the two surveys are not exactly comparable: the building subsectors are not the same across the two surveys, and the results of each are weighted differently.

However, the CSS final report provides the following comparisons.

Share of T12 and T8 linear fluorescent lighting. Table 10 shows the comparison provided in the 2014 CSS final report between the CSS and the 2006 CEUS. T12s in the 2006 CEUS dataset are directly comparable to T12s in the 2011-2013 CSS. However, T8s in CEUS are comparable to the base efficiency T8 category in the 2011-2013 CSS, since high efficiency T8 technology was introduced to the market after the 2006 CEUS took place. As seen in the table, the installed share of T12 linear fluorescents has decreased across all building types included in the CSS, except for health/medical building subsector. The table also shows the saturation of T8s (base and high-efficiency), T5s, and linear LEDs increasing at the expense of T12s.

[46] Itron. *California Commercial Saturation Survey, Final report*. Prepared for the CPUC. August 2014.

Table 10. 2011-2013 CSS and 2006 CEUS Linear Fluorescent Lamp Efficiency Distribution by Business Type – Indoor Lighting

2011-2013 CSS	Food/ Liquor	Health/ Medical – Clinic	Misc.	Office	Restaurant	Retail	School	Warehouse
4-foot T12	4.5%	27%	14%	9%	30%	8%	8%	17%
4-foot T8 Unknown Efficiency	4.1%	1.5%	5%	4.2%	3.3%	10%	2.6%	4%
4-foot T8 Base Efficiency	70%	56%	60%	76%	52%	47%	71%	36%
4-foot T8 High Efficiency	21%	16%	18%	10%	14%	28%	17%	29%
4-foot T5	0.5%	0.3%	2.8%	1.4%	0.5%	8%	1.1%	13%
4-foot Other	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
4-foot LED	0.4%	<0.1%	0.1%	<0.1%	<0.1%	0.1%	<0.1%	<0.1%
Total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Note: The CSS results presented above have been weighted by site weight.

2006 CEUS	Food/ Liquor	Health/ Medical – includes Hospitals	Misc.	Office – Large and Small	Restaurant	Retail	School	Warehouse – Ref and Others
4-foot T12	22%	26%	44%	29%	62%	21%	22%	40%
4-foot T8	78%	74%	56%	71%	38%	79%	78%	60%
Total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Note: The CEUS results are kWh-weighted.

Share of Incandescent lamps and CFLs. Table 11 shows the comparison provided in the 2014 CSS final report between the CSS and the 2006 CEUS for installed share of incandescent lamps and CFLs. The table shows that the installed share of incandescent lamps has decreased across all CSS building subsectors, with the highest reduction in the warehouse and food/liquor building subsectors.

The CMST, which focuses on a study of market share as opposed to installed share, was the first of its kind performed in California. There are no prior surveys to track lighting technology market shares over time. However, if a survey similar to CMST is conducted periodically, sales (or market share) tracking of lighting and controls technologies will be a valuable lighting market indicator in the nonresidential market.

Table 11. 2011-2013 CSS and 2006 CEUS Incandescent and CFL Lamp Distribution by Business Type – Indoor Lighting

2011-2013 CSS	Food/ Liquor	Health/ Medical – Clinic	Misc.	Office	Restaurant	Retail	School	Warehouse
Incandescents	32%	29%	28%	25%	47%	46%	17%	11%
CFLs	68%	71%	72%	75%	53%	54%	83%	89%
Total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Note: The results above have been weighted by site weight.

2006 CEUS	Food/ Liquor	Health/ Medical – includes Hospitals	Misc.	Office – Large and Small	Restaurant	Retail	School	Warehouse – Ref and Others
Incandescents	71%	46%	61%	39%	78%	66%	46%	73%
CFLs	29%	54%	39%	61%	22%	34%	54%	27%
Total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Note: The results above are weighted by site weight.

Recommendations for Future Tracking of Lighting Market Indicators

For the residential market, Cadmus recommends the following future market indicator research activities:

- Purchase POS data for 2013 and continue annual tracking of market indicators based on pricing and sales.
- Ensure comparability and track installed lighting saturation as a lighting market indicator using the results of periodic (once every three to five years) CLASS surveys.

For the nonresidential market sectors interior and exterior, Cadmus recommends the following future market indicator research activities:

- Ensure comparability and track sales market share of various lighting technologies through periodic surveys similar to the CMST perhaps once every two to three years.
- Ensure comparability and track the installed lighting saturation of various lighting technologies through periodic surveys similar to the 2011-2013 CSS perhaps once every three to five years.
- Improve consistency in reporting program participation data by the IOUs so that data can be aggregated to be used for market indicator analysis.

Future Improvements to the Workbook

Cadmus recommends regular updates to the forecasted lighting consumption and saturation numbers in the workbook to keep its projections in sync with the rapid changes in the lighting market. Aside from these regular updates, Cadmus recommends two sets of improvements for the workbook. The first set enhances robustness, accuracy, and relevancy of the workbook to LMT program planning, and the second set improves the usability of the workbook.

In order to enhance the robustness, accuracy, and relevancy of the workbook, Cadmus has identified the following future improvement areas:

- Cadmus has not found reliable sources for the lighting and controls saturations in the agricultural building subsector and therefore these fields are missing. Additionally, the sources estimating the industrial building subsector saturations are about 14 years old. Further saturation surveys in these subsectors will aid Cadmus in completing or replacing the data in the next version of the workbook.
- Although the 2011-2013 CSS provided recent lighting and controls saturations for most building subsectors in the workbook, a few building types were not included in the 2011-2013 CSS. Therefore the saturations for these building subsectors are still based on estimates or old national data sources. These building subsectors are Hotels and Lodging, Health and Medical Hospitals, and Colleges and Universities. Further saturation surveys in these building subsectors will aid Cadmus in replacing the old data in the next version of the workbook.
- The LMT program team would like to either refine the current lighting control saving factor for multiple control approaches or add a new lighting control regime to characterize the potential for advanced lighting controls in the workbook. Further studies and work papers on advanced lighting controls will aid Cadmus in characterizing the savings possible for advanced lighting controls in the next version of the workbook.
- The potential saving estimates in the workbook are currently calculated for lighting and controls separately. This is because the control saving factors used in the potential calculations are based on studies that characterize the control retrofit savings independently from lighting retrofit savings. In application, however, most control retrofits are combined with lighting retrofits. The IOUs would like to use the workbook to estimate the potential savings from combined lighting and control retrofits. Cadmus anticipates that further review of new or upcoming studies in this area will help us identify the most appropriate methodology for combining the lighting and controls savings in the next version of the workbook.
- The IOUs would like to get a more detailed picture of the market penetration of new technologies and potentials in the residential sector. In the next version of the workbook, Cadmus will plan to break the residential sector into single-family, multifamily, and mobile homes subsectors and will provide applicable baseline consumption, existing saturations (based on 2012 CLASS), and saving potentials.

In order to enhance the usability of the workbook, Cadmus recommends exploring the option of turning the Excel-based workbook into a database that can be the foundation for a web application. Applications such as Shiny,[47] a data visualization software product, allow users to adjust scales and checkboxes and dynamically change resulting graphs. This would allow program managers (and potentially the public who will have access to the workbook) to run various scenarios and program-offering combinations and to visualize the resulting technical savings potential that are possible.

[47] A sample gallery of interactive visualizations prepared using Shiny can be found here: http://shiny.rstudio.com/gallery/.

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