Codes and Standards Enhancement (CASE) Initiative For PY2008: Title 20 Standards Development

Analysis of Standards Options for Linear Fluorescent Fixtures

Prepared for:
Pat Eilert
Gary Fernstrom
Ed Elliot

Pacific Gas and Electric Company

Prepared by:
Katie Ackerly and Steven Nadel
American Council for an Energy-Efficient Economy
Stan Walerczyk
Lighting Wizards
and
Energy Solutions

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1 Executive Summary

The Pacific Gas and Electric Company (PG&E) Codes and Standards Enhancement (CASE) Initiative Project seeks to address energy efficiency opportunities through development of new and updated Title 20 standards. Individual reports document information and data helpful to the California Energy Commission (CEC) and other stakeholders in the development of these new and updated standards. The objective of this project is to develop CASE Reports that provide comprehensive technical, economic, market, and infrastructure information on each of the potential appliance standards. This CASE report covers standards and options for linear fluorescent fixtures.

We analyze the option of setting fixture efficiency standards that are based on minimum ballast efficacy. Ballast efficiency requirements save energy, are simple to establish, and can also be used to eliminate inefficient lamps and ballasts from the new fixture market. In the current market, the vast majority of four-foot commercial fixtures use standard T8 lamp and electronic ballast systems. There is a growing share (~20%) of fixtures sold with extra-efficient "super" T8 lamp-ballast systems, but premiums placed on these products as well as the lead time required to obtain them have prevented wider adoption. The most recent federal ballast standard, which took effect in 2005, barred the use of magnetic ballasts for most new fixtures with high power factor (PF) ballasts (typical of commercial fixtures). Eight-foot standard output ("slimline") and high output fluorescent fixtures now predominantly come with T12s and electronic ballasts. In the residential sector, cheaper full-wattage T12 shop lights with magnetic ballasts are still the common, as these ballasts are low-power factor and exempt from the federal standard.

We recommend that California adopt minimum ballast efficacy factors (BEF) for new fixtures similar to those required under the High Performance T8 Specification published by the Consortium for Energy Efficiency (CEE) for new fluorescent fixtures. This spec applies only to four-foot, PF-corrected commercial fixtures and would restrict the use of standard-series T8 systems in commercial applications in favor of extra-efficient T8 systems. For eight-foot fixtures, which are not covered by the CEE specification, we propose minimum BEF levels that are in accordance with all but the lowest-efficacy eight-foot T8 products available from major ballast manufacturers.

A separate standard for residential fixtures (not PF-corrected) would need to be established to encourage the use of T8 technology in that sector. We propose setting minimum BEF requirements for these fixtures as well, at 2.80 BEF for four-foot, one-lamp fixtures and 1.55 BEF for four-foot, two-lamp fixtures.

Our analysis shows that the proposed standard would save over 2000 GWh of electricity and 560 MW of peak demand savings annually once the existing stock turns over, approximately a 9% savings.

In addition to this primary recommendation, we also explored a possible alternative standard that specifies a minimum Luminaire Efficacy Rating (LER) for fixtures. Use of LER is more complicated than BEF requirements, but provides more flexibility since it permits manufacturers to vary fixture, ballast and lamp efficiency in various ways to meet the minimum LER requirements.

2 Product Description

Fixtures[1] manufactured for fluorescent lamps are used to house the ballast, lamps, and structural features that are designed to distribute the light as desired. These features may include reflectors and diffusers, which are used to extend the reach of the lit area, and lenses or louvers, which reduce or control the glare created by the lighting system. Fixtures that include an "indirect" feature use the wall and ceiling to reflect and distribute either part or all of the light generated by the lamps.

Fixtures manufactured for linear fluorescent lamps include troffers, surface-mount and surface-suspended fixtures, wrap-arounds, indirect or direct/indirect light fixtures, striplights, and hooded industrials. (See Figure 1). Four-foot fixtures comprise the majority of fluorescent lighting used in commercial and industrial buildings, as well as a small portion of the residential lighting market. Two-lamp, four-foot fixtures (T8 or T12) are the most common in new construction, although one-, three-, and four-lamp fixtures are also widely available. Fixtures typically contain one ballast per fixture; some newer electronic ballasts can be wired in tandem to drive lamps in adjoining fixtures. When bi-level lighting is required (as in Title 24 for many applications), fixtures often contain two ballasts. Eight-foot fixtures, which typically house no more than two lamps, represent a small but significant portion of the market, used primarily in mass market retail, low-bay industrial, and some billboard applications. (DOE, 2002)

Fixture efficiency is generally defined as the percentage of light from the lamp(s) that leaves the fixture. However, this definition is not very useful to describe the effectiveness with which the system components use energy to maximize light output or how well the fixture optimizes light distribution in the space. Instead, the energy use of a fixture depends in most cases on the performance of the lamp-ballast system housed in the fixture. The ballast, which regulates the voltage and maintains the current supplied to the lamp, is generally built into the light fixture and used for many years. A standard ballast lasts roughly 15 years, which is a life of 50,000 hours (DOE, 2000) to be conservative (most electronic ballast manufacturers now offer 60,000-hour ballasts). Thus the type of ballast used has a dramatic impact on the fixture's overall energy use. Fixture design and construction then determines the temperature of the fixture and how it distributes light, which affects the number of fixtures needed to meet lighting needs in the space.

[1] Although we use the term "fixture" in this report, "luminaire" is the more technical term used by engineers.

a) two-lamp Lensed Recessed Troffer

b) 1-Lamp louvered surface-mount

c) 1-Lamp Surface-Suspended wrap-around

d) Direct/Indirect Fixture (www.finelite.com)

e) two-lamp striplight

f) Standard industrial two-lamp fixture

Figure 1. Common Fixture Types
Source unless noted: Lithonia Lighting
(www.lithonia.com)

Two ballast technologies, magnetic and electronic, are common in existing fluorescent fixtures. Both are designed to operate at either 120 or 277 volts and utilize standard 60 HZ input power. The magnetic ballast involves a steel transformer-type core and coil to regulate incoming power and send it to the lamp. This is the original ballasting technology designed for T12 fluorescent lamp systems, but magnetic ballasts are no longer available in new commercial T12 fixtures under new federal restrictions that took effect in 2005 (most residential fixtures are exempt).

High-frequency electronic ballasts use solid-state components to provide high-frequency controls that switch power supply circuits in order to transform incoming current into high-frequency power (20-40kHz). Advantages of electronic ballasts as compared to conventional magnetic ballasts include a 15–20% increase in system efficacy over efficient magnetic ballasts; reduced noise, weight, flickering and excess heat generation; and often increased control flexibility (Thorne and Nadel, 2003). Electronic ballasts are available in instant-start (IS), rapid-start (RS), and program-start (PS) (also known as programmed-rapid start) types. The relative advantages and disadvantages of each are summarized in Table 1. For T8 lamps, most ballasts are IS, but RS and PS are also used. However, RS electronic ballasts are being phased out in favor of PS ballasts. In contrast, T12 electronic ballasts are mostly RS, with the exception of two-pin "slimline" T12s that often use IS ballasts.

Extra-efficient or "Super T8" electronic ballasts, developed over the past 10 years, incorporate more advanced ballast components that substantially improve lamp system efficacy over generic types. IS extra-efficient ballasts, which are the most common, can reduce energy use by 10% compared to a generic IS ballast and 13% compared to a generic RS ballast (with T8 lamps). There are now also extra-efficient PS ballasts, which are almost as efficient as extra-efficient IS ballasts.

Table 1. Identifying Characteristics of Fluorescent Non-Dimming Ballast Types

Ballast Type	Lamp Start	Advantages	Disadvantages
Instant Start (IS)	High voltage spark, no heat to coil	Typically more efficient than PS of same generation because no cathode-heating	Shorter Lamp Life with more frequent cycling
Rapid Start (RS)	Heats lamp coil and provides voltage simultaneously	Longer Lamp Life	Lower Efficiency Series-Wired; if one lamp burns out, others my also fail.
Program Start (PS)	Heats lamp coil prior to high voltage spark		

Source: CEE, 2003; Ballast manufacturers

3 Manufacturing and Distribution Channel Overview

There are over 25 manufacturers who produce fixtures for linear fluorescent lamps in the U.S. (U.S. Census Bureau, 2001). These manufacturers depend on ballast components supplied by only a handful of manufacturers. As of 2005 there were 10 manufacturers of fluorescent lamp ballasts in the U.S. Major players include Advance Transformer (a subsidiary of Philips Lighting Company), General Electric, Osram-Sylvania, and Universal Lighting Technologies.

Most fluorescent fixtures are typically specified by architects, lighting designers, engineering firms or electrical contractors and purchased through a distributor. Commercial customers, including building managers and engineers, or other design and engineering professionals may also be responsible for the purchase of fluorescent fixtures. Residential and some commercial customers purchase a fair number of fixtures through retail channels, including home improvement centers, hardware chains, and other mass merchandisers. Retail sales to residential consumers account for roughly 6% of the annual distribution of fluorescent fixtures, based on U.S Census Bureau ballast sales, which doesn't take into account imports (Census Bureau, 2006). With imports, we estimate that perhaps 30% of the total fixture sales go to residential consumers (discussed further in Section 5.1).

4 Energy Usage

4.1 Test Methods

4.1.1 Current Test Methods

For reasons discussed in Section 4.4, the fixture standards options in this analysis involve ballast efficiency requirements. For the purpose of federal standards and rulemakings, the Ballast Efficacy Factor (BEF) has been used to quantify the efficiency of lamp-ballast systems for the past 20 years, and is expressed as follows:

BEF = BF x 100 / Ballast Input Power,

where BF (ballast factor) = Lamp Lumens on a Test Ballast / Rated Light Output (from catalog). The current law references federal test procedure 56 FR 18682 (April 24, 1991) for rating BEF.

4.1.2 Proposed Test Methods

We recommend using the BEF test procedure referenced under federal regulations for fluorescent ballasts. However, it should be noted that a major disadvantage of BEF is that it must be calculated for one-, two-, three- and four-lamp ballasts separately, and it assumes a standard lamp for each ballast, making it difficult to compare ballast efficiency unit-to-unit across different lamp-ballast configurations and lamp types. Comparing ballasts with reduced-wattage lamps (e.g., 25, 28, 30 and 32W F32T8s) is also cumbersome.

To correct for these shortcomings, California may at a later date consider the option of replacing BEF with Relative System Efficiency (RSE), an alternative metric for rating lamp-ballast efficiency that was recently developed by Francis Rubenstein at Lawrence Berkeley National Laboratory (LBNL). RSE is normalized for total rated lamp power, as shown below, providing a simpler, unit-less basis for comparing ballast performance regardless of the number of lamps in a system or the use of new, more efficient lamps.

RSE = BF x 100 / (Ballast Input Power / Total Rated Lamp Power), Where:

> Total Rated Lamp Power = the Number of Lamps per Ballast x Rated Lamp Power (from catalog).

Like BEF, RSE is based on information available from the ballast and lamp catalogs and thus is easy to incorporate into standards rulemakings. A third strategy that is being developed by manufacturers is ballast efficiency, which simply calculates the percentage of power that gets to the lamps and avoids calculating light output. Because RSE and ballast efficiency must both be further vetted with industry and other experts, we do not incorporate either into our proposal below, but rather highlight RSE as a promising option for discussion.

4.2 Baseline Energy Use Per Product

The energy consumption of a fluorescent fixture depends predominantly on lamp system wattage and daily operating hours. System wattage is determined by the rated wattage of the lamp, the number of lamps in the system, and the efficacy of the ballast (BEF). Ballast efficacy is in turn influenced by ballast type (e.g., magnetic or electronic), ballast construction and components (which control losses), and ballast factor (BF).

The ballast factor gives the ratio of lumens output provided by the ballast to those provided by a 1.0 reference ballast. In general, a ballast factor of less than one means the ballast is driving the lamp at a lower-than-rated power level. Ballasts are commonly available at three BF levels: low (<0.85), normal (0.85–1.00) and high (>1.01). There are also some extra-efficient PS ballasts available that operate at extra low and “super” low ballast factors of 0.71 and 0.60, respectively.

Our base case assumes two-lamp ballasts with normal ballast factors because they represent the majority of the market. The baseline commercial four-foot fixture is a typical 4’ x 2’ troffer with two T8 lamps and a generic instant-start T8 ballast with a ballast factor of 0.87–0.88. This ballast factor results in a lower system wattage than rated lamp wattage (58 W instead of 64 W). Our residential base case is a two-lamp T12 “shop light” with a magnetic ballast that has a low ballast factor (0.66–0.68). In the absence of better data, the wattage level for our base case residential fixture assumes that 80% of residential customers are using full-wattage 40W lamps, and the other 20% are using reduced-wattage 34W lamps.

One last parameter that affects losses is a ballast’s power factor (PF). Because lamp ballasts are not resistive AC circuits, the capacity of a ballast to perform its work (real power) is often lower than the power the utility supplies (apparent power = current x voltage), requiring higher currents to perform the work and increasing electricity loads. In order to avoid utility penalties, commercial ballasts must be corrected to have a high PF (>90%). In the residential sector, where the number of units and operating hours are minimal, cheaper, low-PF ballasts are allowed. Commercial and residential fixtures are thus indicated respectively as “PF Corrected” and “Not PF Corrected.”

Table 2. Baseline Energy Use Per Unit

Fixture Type	Rated Lamp Watts	System Watts	Annual Operating Hours [b]	Unit Electricity Consumption (kWh/yr)
Four-foot Fixtures				
PF Corrected (Commercial &Industrial) (2-lamp T8, electronic 0.87 BF ballast)	32	59	3,740	217
Not PF Corrected (Residential) (2-lamp T12, Magnetic 0.67 BF ballast) [a]	38	68	800	54.4
Eight-foot Fixtures (Virtually All PF Corrected)				
Standard output lamps (T12 mostly)	60	123	3,740	460
HO lamps (T12 mostly)	95	207	3,740	774

Source: Manufacturer catalogs and Stan Walerczyck.
[a]Base case residential T12 energy use is weighted average of 40W lamps (80% @ 70 system watts) and 34W (20% @ 60 system watts) lamps, a conservative characterization of the current market.
[b] Daily operating hours for fluorescent lamps from DOE, 2002.

4.3 Efficiency Measures

To improve the efficiency of a fixture, one can add thermal control, add higher reflective surfaces, and/or add clear or prismatic lenses. fficiency can be further improved by using fewer lamps with higher light output or by installing a more efficient ballast. As explained in Section 4.4, ballast efficiency is the simplest and probably the best strategy for regulating fixtures.

Extra-efficient electronic ballasts involve more advanced components and more carefully control current and voltage in order to respond to changes in lamp characteristics over time. Instant-start ballasts provide greater system efficacy on average compared to RS and PS ballasts, although there are some PS ballasts that do have similar efficiencies to IS ballasts. Moreover RS and PS ballast types are often more compatible with occupancy sensors and other control options that offer additional energy-saving possibilities.

Using extra-efficient electronic ballasts not only avoid power losses themselves but also promise additional energy savings through the use of high-lumen T8 lamps that are made to operate with these ballasts. Because lamps and ballasts can not be treated independently when estimating energy use, efficiency options in our analysis assume operation with high-lumen lamps.

4.4 Standards Options

4.4.1 *Description of Options*

For this CASE study we examined several standards options for new fixtures including ballast efficiency requirements, a prohibition on use of T12 lamps and ballasts, restrictions on use of 4-lamp fixtures, and required fixture efficiency (where fixture efficiency is a measure of the proportion of light produced that leaves the fixture). After considering these options we decided to concentrate on ballast efficiency requirements because they offer high savings potential and are based on a simple metric. Ballast efficiency requirements can save energy in their own right, and can also be used to eliminate T12 lamps and ballasts from the new fixture market. Although our proposal includes minimum ballast efficacy levels for one-, two-, three-, and four-lamp fixtures, our energy-use and savings analysis focuses on two-lamp fixtures because they comprise the majority (~60%) of fixtures in commercial buildings (Brook, 2006). Thus our ultimate savings estimates are conservative because they do not take into account the extra savings from three- and four-lamp fixtures (~30% of the market combined; Brook, 2006), which will yield greater reductions in system wattage under the standard than the two-lamp fixtures that we used in our analysis. One-lamp fixtures comprise another ~10% of the market, and will probably yield somewhat smaller reductions in system wattage under a fixture standard.

Because fixture efficiency varies as a function of numerous parameters, including type of fixture and number of lamps, previous attempts to develop fixture efficiency requirements by NEMA and ACEEE ultimately proved to be too complicated to be very workable.

For ballast efficiency requirements, there are several questions. First, there is the question of what efficiency metric to use. Ballast efficacy factor (BEF) has been widely used but suffers from the fact that BEF varies as a function of the number of lamps controlled. As noted in section 4.1, two alternative metrics, RSE and ballast efficiency, are being developed and vetted with industry and lighting experts. If either metric meets with broad approval, our proposed standard could be converted. In the meantime, we use the current metric – BEF.

The next consideration is where to set the efficiency requirement for the most common category – four-foot long commercial and industrial fixtures. These fixtures use power-factor corrected ballasts. Most new fixtures of this type use T8 lamps and generic electronic ballasts. The Consortium for Energy Efficiency (CEE) has developed a specification for extra-efficient lamps and ballasts that NEMA has adopted for their "Premium Ballast" label program. A state standard should adopt this specification with a few modifications. At a minimum, it must include placeholder requirements for one-lamp, high-BF ballasts, which currently are not available on the market and are listed as "N/A" in the CEE spec.

Secondly, the current breakpoint of 0.85 BF between normal and low BF categories opens a potential loophole for PS ballast manufacturers, who may choose to lower a normal BF only slighting (from 0.85 to 0.84) to meet a less stringent requirement. Because low-BF PS ballasts fall within the range of 0.71–0.73[2] rather than 0.74-0.85 for IS ballasts, a standard should better distinguish lower-efficiency, low-BF PS products from higher BF products. This could be accomplished either by changing the break-point

[2] Available "super-low" .60 BF ballasts (e.g., GE's Ultrastart ballast) would not meet CEE's requirements or our proposal, however these are typically used only in retrofit scenarios and not in new fixtures.

between low and standard BF categories, or adding a fourth BF category over the current gap in products (0.74–0.85 BF), which would have to comply with standard BF requirements rather than low BF (now "super-low") requirements.

Given changes in the market since CEE released its spec, a second standards option that tightens some of the proposed minimum BEF levels is also possible. As shown in Table 3, the BEF levels under "Option 2" are selected such that products from at least two manufacturers would comply now, and it is highly likely that more products will comply by the time the standard takes effect. The result of these changes would be to raise minimum efficiency of normal-BF PS ballasts and high-BF IS ballasts 3-6% from the CEE requirements. PS ballasts are often used in fixtures controlled by occupancy sensors. in the Southern California Edison service territory, installing a PS ballast is required to earn a rebate for installing an occupancy sensor. High-BF IS ballasts are used predominantly in warehouse and other high and low-bay applications. Table 9 gives a rough estimate of the statewide impact of tightening the BEF in these ballast categories.

Although this proposal is designed for 32-watt T8 lamps, lamp systems designed for high-efficiency reduced wattage (25W, 28W and 30W) lamps would all comply according to the new CEE spec for reduced-wattage T8 systems. The proposed standard would not, however, allow most T5HO and T5 ballasts; these ballasts should be exempted in order to allow these fixtures in appropriate applications. If the market share of T5 and T5HO fixtures increases substantially, the CEC should consider a similar standard for these products.

Table 3. Trial Ballast Performance Requirements for Four-Foot Fixtures
(Shading indicates a change from the current CEE High Performance T8 Specification)

BF	# Lamps	Modified CEE Specification	Option 2[a]
Instant Start			
≤ .85 (low)	1	≥ 3.08	≥ 3.08
	2	≥ 1.60	≥ 1.60
	3	≥ 1.04	≥ 1.04
	4	≥ 0.79	≥ 0.79
.85 – 1.00 (standard)	1	≥ 3.11	≥ 3.11
	2	≥ 1.58	≥ 1.58
	3	≥ 1.05	≥ 1.05
	4	≥ 0.80	≥ 0.80
≥ 1.01 (high)	1	≥ 3.03 [b]	≥ 3.03
	2	≥ 1.55	≥ 1.59
	3	≥ 1.04	≥ 1.07
	4	≥ 0.77	≥ 0.80
Program Start			
≤ .74 (super low)	1	≥ 2.84	≥ 2.84
	2	≥ 1.48	≥ 1.48
	3	≥ 0.97	≥ 0.97
	4	≥ 0.76	≥ 0.76
0.74 – 0.85 [b] (low)	1	≥ 2.84	≥ 2.94
	2	≥ 1.48	≥ 1.56
	3	≥ 0.97	≥ 1.06
	4	≥ 0.76	≥ 0.79
.85 – 1.00 (standard)	1	≥ 2.84	≥ 2.94
	2	≥ 1.47	≥ 1.56
	3	≥ 1.00	≥ 1.06
	4	≥ 0.75	≥ 0.79
≥ 1.01 (high)	1	≥ 2.84 [b]	≥ 2.84
	2	≥ 1.51	≥ 1.51
	3	≥ 1.00	≥ 1.00
	4	≥ 0.75	≥ 0.75

Source: CEE, 2006, manufacturer catalogs
[a] Option 2 is based on current availability of products by at least two manufacturers.
[b] Indicates values that are not currently in the CEE spec because products in this category do not exist in the market. For regulatory purposes, we suggest these gaps be filled in a standard.

Third, there is the question of where to set efficiency requirements for eight foot fixtures. As noted below in section 5.1, these fixtures are declining in use but still fairly common. CEE does not have a specification for these ballasts. Therefore, we compiled a database of products produced by five major manufacturers (Advance, GE, Howard, Osram Sylvania, and Universal) and selected BEF's that could be met by nearly all T8 ballasts now being produced. For eight foot lamps, only 1- and two-lamp ballasts are produced and there is a much narrower range of ballast factors, so much of the complexity of Table 3 can be eliminated. The proposed BEF values for eight-foot ballasts in new fixtures are provided in Table 4. The database used to develop these values can be found in Appendix B.

Table 4. Trial Ballast Performance Requirements for Eight-Foot Fixtures (BEF)

Lamps	Standard Output Lamps	High Output Lamps
1	≥ 1.50	≥ 1.04
2	≥ 0.77	≥ 0.54

Source: Manufacturer Catalogs (see appendix C)

Fourth, there is the question of what to do about residential fixtures, which are fixtures that are generally sold with ballasts that are not power factor corrected. Non-power factor corrected ballasts are not covered by federal ballast standards and thus these fixtures now primarily use T12 lamps and often use magnetic ballasts. Substantial energy can be saved by moving these sales to at least moderate efficiency T8 lamps and electronic ballasts (or other systems with similar performance). We identified two options for such a regulation. First, BEF requirements can be set, based on currently available residential-grade generic T8 electronic ballasts (Appendix C). Possible values are provided in Table 5. Second, total system watts can be capped, including lamp and ballast. Possible caps, based on generic T8 lamps and ballasts, are also provided in Table 5. The advantage of the first option is that it is very clear what passes and what does not and makes it difficult for loopholes to emerge. The advantage of the second option is that it provides more flexibility to manufacturers (e.g., would allow several low-BF T12 lamps and low wattage T12s) but at the risk of creating undesirable loopholes for less efficient T12 lamps. In order to be clear and to promote efficiency, we recommend the BEF option.

Table 5. Ballast Performance Requirements for Fixtures with Non-PF Corrected Ballasts

Lamps	Option #1– BEF	Option #2 – System Watts
1	≥ 2.80	≤ 32
2	≥ 1.55	≤ 56

4.4.2 Energy Use of Standard Options

The estimated energy use for the standards discussed above is summarized in Table 6.

Table 6. Energy Use for Standard Options (based on two-lamp T8 fixtures)

Type of Lamp and Ballast Used	Rated Lamp Watts	System Watts [a]	Annual Operating Hours[b]	Annual Energy Consumption (kWh/yr)
four-foot Fixtures				
Power factor corrected (primarily C&I)	32	54	3,740	202

Not power factor corrected (primarily residential)	32	56	800	45
eight-foot Fixtures (Virtually All PF-Corrected)				
Standard output lamps	59	102	3,740	408
HO lamps	86	160	3,740	599

Source: Manufacturer catalogs and Stan Walerczyck.
[a] Based on extra-efficient T8 ballast for power factor corrected and low-PF residential generic T8 . And generic residential T8 ballast for non-power factor corrected.
[b] Daily operating hours for fluorescent lamps from DOE, 2002.

5 Market Saturation and Sales

5.1 Current Market Situation

5.1.1 Baseline Case

The 2002 U.S. Lighting Market Characterization (DOE, 2002) estimates that fluorescent lamps comprise 77% of all lamps installed in commercial buildings and account for 60–70% of the total lighting electricity consumed in commercial and industrial facilities. Among these, two-lamp fixtures comprise 57% according to a recent survey of existing commercial buildings (Brook, 2006). Another 16% of fixtures are three-lamp fixtures, 15% four-lamp fixtures, and 12% one-lamp fixtures. According to data from the National Electrical Manufacturers Association (NEMA, 2006), sales of eight-foot lamps (predominantly T12) have declined in favor of four-foot T8s over the past six years.
No data are available to differentiate between four-foot and eight-foot fixture sales. For our analysis (Tables 7 and 8), we assume all fixture sales are for four-foot lamps. This modestly underestimates savings potential, since there are more energy savings possible with an eight-foot fixture than a four-foot fixture.

Based on 2005 ballast sales from the U.S. Census Bureau (2006), 83 million fluorescent ballasts are shipped each year nationwide and 72% are shipped to fixture manufacturers. Of the total ballasts shipped, 5 million of these (7%) are intended for use in the residential sector, not including imports (which are likely significant). We estimate that California represents 9.06% of this market, based on the percentage of national commercial floor area in the Pacific West census region (EIA, 2003) and the portion of the Pacific West population that resides in California (Census Bureau, 2002). For California’s share of residential fixture sales, we chose 10.9% based on population only. Assuming a 25-year life for most four-foot fluorescent fixtures, we derived existing stock estimates for commercial and residential fixtures, as shown in Table 7. By these assumptions we estimate that there are 5.1 million linear fluorescent fixtures sold each year in the California commercial building sector, excluding T5 fixtures, along with another 0.4 million fixtures sold in the residential market.

Over the past ten years, market share of magnetic ballasts have declined steadily in all sectors, but more notably in the commercial sector, according to total domestic shipments supplied by the U.S. Census Bureau (does not include imported ballasts). New T12 ballasts sold to the commercial sector have dropped by approximately 78%, and over 60% in the residential sector. Meanwhile, sales of electronic ballasts produced in the U.S. have increased 86%. Based on discussions with lighting experts, we assume the majority of imports are filling the void in demand for residential T12 fixtures, which are unregulated, while most U.S. fixture manufacturers are specializing in high-power factor commercial T8 fixtures. Our estimate of 2 million residential fixture sales for California (30% of total) is a rough estimate to account for these imports. It represents five times the number of magnetic (not-PF corrected) ballasts produced domestically[3].

5.1.2 High Efficiency Options

It is difficult to obtain detailed market share data for different ballast products, but it is clear from discussion with manufacturers that generic instant-start ballasts comprise the majority of the market, particularly since the 2005 ballast standard took affect. NEMA reports that about 20% of ballast sales from the five major ballast manufacturers meet CEE specifications (NEMA, 2007). This includes all ballast sales, and the share of extra-efficient ballasts in new fixtures alone may be much less. In the absence of better data we have elected to stay conservative.

Based on discussions with manufacturers and distributors and by visiting many retail stores in CA, we estimate that among residential four-foot fixtures, at least 80% come with full-wattage (40W) T12 lamps and magnetic ballast. The remaining 20% of systems achieve lower system wattage with a reduced-wattage “energy-saver” 34W lamp.

[3] We welcome more input on this assumption. It roughly corresponds to the number of residential fixtures suggested by the most recent U.S. Census Bureau Electric Lighting Fixtures Industrial Report (2001).

Table 7. California Statewide Baseline Sales, Stock and Energy Use

Design Options	Annual Sales [a]		California Stock [b]		System Watts [c]	Annual Operating Hours[d]	% On at Peak[e]	California Energy Use and Demand	
	U.S. (millions)	California (millions)	Units (millions)	Saturation (%)				MW	GWh/year
Commercial Fixtures (PF Corrected)	56.1	5.1	127	70%	59	3,740	78%	5,854	28,071
Residential Fixtures (Not PF-corrected)	19.7	2.1	54	30%	68	800	10%	365	2,921
Total	**75.9**	**7.2**	**181**	**100%**				**6,219**	**30,992**

[a] National sales from 2005 U.S. Census ballast shipments data. Fixture sales represent 72% of shipments and residential sales are inflated to account for imports. California sales estimated at 9.06% of U.S. commercial sales (see text).
[b] California existing stock derived by multiplying annual sales by a 25-year typical fixture lamp life (Gordon, et al., 1988).
[c] System watts for residential fixtures assumes 80% 40W T12 and 20% 34W T12 and the use of a 0.66-0.68 BF ballast.
[d] Daily operating hours averaged for T8 and T12 lamps in Commercial/Industrial and Residential sectors from DOE, 2002.
[e] Peak coincidence 78% for commercial sector (based on PG&E, 2000) and 10% on at peak in the residential sector (2.2 hrs/day (DOE, 2002) divided by 24 hours/day).

Table 8. California Statewide Energy Savings From Proposed Standards

Baseline Lamp	California Fixture Sales (millions)[a]	Percent Using Improved Fixtures Without New Standard [b]	Watts Saved per Fixture [c]	Percent on at Peak	For First-Year Sales		After Entire Stock Turnover	
					Coincident Peak Demand Reduction (MW)	Annual Electricity Savings (GWh/yr)	Coincident Peak Demand Reduction (MW)	Annual Electricity Savings (GWh)
Commercial Fixtures (PF Corrected)	5.1	35%	5	78%	20	62	496	1,546
Residential Fixtures (Not PF Corrected)	2.1	20%	12	10%	3	16	64	412
Total	**7.2**				**22**	**78**	**561**	**1,959**

[a] Sales data are derived in Table 7.
[b] See text for explanation of assumptions.
[c] PF-corrected savings based on a simple switch from IS ballast to extra-efficient IS ballast meeting CEE spec (savings slightly higher with Table 2, See Table 9; low-PF savings based on difference between T12 system with magnetic ballast (as shown in Table 7) and standard residential electronic T8 fixture.

Table 9. Estimate of Statewide Impact Under Different Design Options for Commercial 2-Lamp T8 Fixtures

Scenario	Appropriate Thermal and Fixture Efficiency Factor [a]	Effective Fixture Mean Lumens *(% change)*	Watts Saved	% Savings	**Savings For First Year Sales**		**Savings After Stock Turnover**	
					MW	GWh	MW	GWh
Base Case (Basic T8 with Generic IS Ballast)	0.80	3703	0	0	0	0	0	0
New Extra-Efficient Ballast Option 1 - Modified CEE (See Table 3)	0.83	3842 *(+ 4%)*	5	8%	20	62	496	1,546
New Extra-Efficient Ballast Option 2 – Tighter than CEE (See Table 3) [b]	0.84	3888 *(+ 5%)*	6	10%	22	69	556	1,734
Design Scenarios Using High-performance T8 Lamps With Extra-Efficient Instant-Start Ballast								
A. Full-wattage Lamps with Low, 0.77 BF	0.85	3855 *(+ 4%)*	11	19%	52	136	1,300	3,402
B. Fewer fixtures per square foot, 0.87 BF [c]	0.83	4253 *(+15%)*	13	22%	83	162	2,084	4,051
C. Reduced-wattage 28W T8 lamps; 0.77 BF	0.87	3500 *(- 5%)*	17	29%	44	210	1,091	5,257
D. One-lamp fixture in place of two-lamp fixture; 1.20 BF	0.99	3499 *(- 4%)*	21	36%	67	260	1,687	6,494

[a] This is an adjustment based on fixture design and operating temperature, both affecting "effective fixture mean lumens."

[b] Watts saved per fixture in this scenario is averaged across all fixtures, including those unaffected. This assumes an average 4.5% increase in efficiency per ballast and an estimated 25% of new fixtures to be affected. The latter percentage is a conservative guess in place of unknown market share of affected ballast types (high-BF IS ballasts are common in high- and low-bay applications, and PS ballasts are common in new commercial buildings where occupancy sensors are used).

[c] Watts saved in scenario B are based on reducing the number of fixtures by 15% to balance the 15% increase in effective fixture mean lumens as shown in preceding column.

5.2 Future Market Adoption of High Efficiency Options

Due to the growing market share of extra-efficient electronic ballasts in the commercial sector and aggressive promotion by California utilities, we estimate about 35% of the commercial new fixtures market will convert to extra-efficient electronic ballasts in the absence of a new standard over the next 25 years, up from the present 20% reported by NEMA. Future sales trends are more difficult to determine for the residential sector because of the lack of any data or current program promotions. As an estimate, we assume that 20% of total sales to the residential sector will adopt T8 lamp-ballast systems over the next 25 years without a standard. This includes the roughly 12% of lamps sold to new homes each year, which under Title 24 are increasingly efficient T8 systems[4]. The remaining 8% adoption rate without a standard is a conservative team estimate to account for a potential increase in T8 fixture sales to existing homes (up from virtually 0% market share today).

6 Savings Potential

6.1 Statewide California Energy Savings

Table 8 estimates statewide savings based on annual sales data for each base case fixture (Table 7) excluding a portion of sales to account for those that would adopt extra-efficient options without the standard, as explained in Section 5.2. Peak demand reduction is based on 78% coincidence in the commercial sector (PG&E, 2000; from an average of "commercial" and "all other" categories) and 10% coincidence in the residential sector based on 2.2 average daily operating hours as reported in DOE, 2002.

Used with a generic T8 lamp, an extra-efficient IS ballast would reduce power needed for a 2-lamp fixture by 5 watts (59W down to 54W), or 300 kWh saved per ballast over the course of its life. After the first year of implementation, the impact of the standard in commercial buildings alone would be 62 GWh delivered electricity savings. Across all sectors, annual state-wide savings after the stock turns over (25 years) would be 1,960 GWh and 561 MW of peak demand power.

Our savings estimates assume no change in ballast factor, number of lamps, or fixture spacing when switching to fixtures with extra-efficient ballasts. In reality however, electricity savings per fixture can increase from 5-9% to 17–20% if the new fixtures are used with high-performance T8 lamps and configured to achieve equivalent light output either by using a lower ballast factor or reduced-wattage replacement lamps. Even higher savings are possible with high-lumen lamps because they are likely to encourage fewer lamps per fixture (which would yield 30-35% savings and allow lamps to operate at a more optimal temperature), or the installation of fewer fixtures per square foot (a 20-35% savings). Educating lighting designers about the benefits of high-performance T8 lighting is critical to accelerating the application of these strategies. From a regulatory perspective, the combination of a separate lamp standard and a tighter Title 24 lighting

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[4] Our estimate of 12% sales to new homes is based on 4 lamps per home (HMG, 1999), 2 lamps per fixture, and housing completions data from the U.S. Census Bureau, taken as a percentage of our estimate of total residential fluorescent fixture sales.

power density requirement is the best way to harvest the higher levels of savings. Our rough estimates of the statewide impacts of high-performance T8 lighting strategies is summarized in Table 9.

As noted in a companion CASE report on fluorescent lamps, there is a federal rulemaking currently underway for fluorescent lamps and California would have to seek exemption from preemption if they want to go forward with a lamp standard. As an alternative, we recommend PG&E and CEC remain active in the federal rulemaking process and consider an education campaign to promote the use of more efficient T8s in new fixtures in California.

6.2 Other Benefits and Penalties

Many of the non-energy benefits associated with extra-efficient ballasts relate to their compatibility with extra-efficient, high-lumen lamps (even though only some fixtures come pre-lamped). High-lumen T8s generally have longer lives and higher lumen maintenance than standard series T8s and T12s, which reduces maintenance costs and occupant complaints because fewer replacements are required over the course of the fixture's life. The maintenance benefits of fewer replacement lamps also apply to both standard-output and HO eight-foot fixtures. Eight-foot standard and HO T8 lamps have 15,000-hour and 18,000-hour lives, respectively, relative to 12,000-hour T12 lamps.

Lower ballast losses also have the potential to reduce commercial sector air conditioning loads. Lighting is responsible for over 40% of total commercial buildings' cooling needs (DOE, 2007). For every 1.0 kWh saved in lighting energy, an additional 0.20 kWh are saved in air conditioning. In California, the heating season is not severe enough for more efficient ballasts to have the inverse impact on heating loads.

7 Economic Analysis

7.1 Incremental Cost

For new commercial fixtures, we calculate incremental costs based on the added cost of the higher BEF ballast (extra-efficient electronic ballast for four-foot fixtures and generic electronic ballasts for eight-foot fixtures) as well as any added costs associated with more expensive replacement lamps over the course of the fixture's 25-year life (1 additional ballast and 2-6 additional lamps depending on the lamp life). These cost estimates are based largely on discussions with lamp distributors assuming purchase by a medium commercial customer buying enough lamps per year to fulfill typical retrofit needs.

For four-foot fixtures, extra-efficient T8 ballasts carry an added cost of $1.00 each for the fixture manufacturer compared to generic electronic ballasts used with standard-series T8s. For eight-foot fixtures, we assume that the incremental cost of generic electronic ballast used with a T8 system as opposed to a T12 system will be minimal once production of T8 ballasts for these fixtures catches up with the existing production of T12 ballasts. Over the life of the fixture (25 years), T8 lamps add $32 for standard-output fixtures and $44 for HO fixtures. Note that the incremental unit cost per lamp ($2 for standard-output T8 lamps and $5 for HO T8 lamps) is partially offset by the reduced number of replacement lamps needed over the life of the ballast due to longer lamp life. These costs are based on current prices, and T8 prices would come down substantially with increased demand.

For residential fixtures, an incremental up-front cost for a new T8 fixture (including 2 lamps and a ballast) is $8.00 compared to a typical T12 two-lamp shoplight. This is based on the median incremental cost of a T8 fixture, relative to otherwise similar T12 fixtures, from a survey of retail stores that we conducted in the San Francisco Bay Area in late 2006 and early 2007 (individual data points range from $2–$14).

Table 10. Costs and Benefits Per Unit for Standards Options

Basecase Fixture (Lamp and Ballast)	Minimum Replacement Option under Standard	Watts Saved	Annual Energy Savings per unit (kWh)	Life (years)	Incremental Cost ($)[a]	Present Value of Lifetime Energy Savings ($)[b]	Lifecycle Benefit / Cost Ratio [c]	Net present Value per unit ($)[d]
four-foot Fixtures								
32W Std. T8 Generic Electronic IS Ballast (PF Corrected)	four-foot 32W Std. T8 EE Electronic IS Ballast	5	18.7	25	$2.00	$38.00	38	$37
40W/34W T12 Generic Magnetic RS ballast (Not PF Corrected)	four-foot 32W T8 Generic Electronic IS Ballast	27	21.5	25	$8.00	$43.47	5	$35
eight-foot Fixtures (Virtually All PF-Corrected)								
eight-foot 60W T12 std. output ES Electric IS ballast	eight-foot 59W Std. T8 EE Electronic IS Ballast	21	78.6	25	$32.00	$159.00	10	$127
eight-foot 90W T12 HO ES Electric RS Ballast	eight-foot 86W Std. T8 HO Generic Electronic IS Ballast	47	175.8	25	$44.00	$355.00	16	$311

[a] Incremental costs for commercial four-foot and eight-foot fixtures includes initial ballast and lamp costs and replacement lamps over the life of the fixture (2 50,000-hour ballasts), from a companion CASE study for fluorescent lamp standards. The incremental cost for the residential fixture is based on a retail store survey.
[b] Calculated using the CEC's average statewide present value statewide energy rates that assume a 3% discount rate (CEC 2004).
[c] Total present value benefits divided by total present value costs.
[d] Positive value indicates a reduced total cost of ownership over the life of the appliance

7.2 Design Life

The average fluorescent fixture lasts 25 years, according to a survey of experts in the field (Gordon, et al, 1988).

7.3 Lifecycle Cost / Net Benefit

Table 10 summarizes the projected life cycle cost savings based on incremental cost and present value of lifetime energy savings calculations. Net present value estimates are based on average statewide present value electricity and natural gas prices, supplied by the California Energy Commission.

8 Acceptance Issues

8.1 Infrastructure issues

As shown in Appendices A and B, complying ballasts for four-foot and eight-foot fixtures are widely available and should be readily accessible to fixture manufacturers. However, although some fixture manufacturers now have ordering codes for extra-efficient ballasts, this is not universal and ordering fixtures with extra efficient ballasts is not usually the easiest option. T8 residential fixtures are not as widely available, but changing from T12 to T8 fixtures would not pose a significant challenge to fixture manufacturers since T8 systems are already widely manufactured. Likewise, eight-foot T8 lamps and ballasts presently account for only a minority of the market (e.g., the California Commercial End Use Survey found that T8's account for about 13% of eight foot standard output fixtures and about 6.5% of eight foot HO fixtures in California commercial buildings in 2002/2003 (Brook, 2006)) but all major manufacturers produce them.

Currently there is often an added mark-up for extra-efficient ballasts by the contractor on top of those imposed by the manufacturer and distributor. Even though the fixture manufacturer only has to pay about $1 more per ballast for the technology, manufacturers (especially the large ones) often have to stop large product runs to make extra-efficient ballasts for specific orders. If California mandates the use of extra-efficient ballasts in various BFs, fixture manufacturers will get used to using extra-efficient ballasts, and costs to end customers would drop, making extra-efficient ballasts very cost-effective in new fixtures, even for relatively small quantities.

8.2 Application Issues

High efficiency fixtures, as defined in this CASE study, have no limitations we are aware of that prevent their use in any application. Initial costs are a little higher, but operating cost savings are substantial.

8.3 Existing Standards

8.3.1 Federal Standards

Fluorescent fixtures are unregulated by the federal government. There are existing minimum BEF requirements established for T12 fluorescent ballasts, which were first enacted in 1990 and revised again in 2000. The existing standard essentially restricts the use of magnetic ballasts with four-foot and eight-foot T12 lamps (T8s are not addressed). The standard applies to new fixtures for ballasts manufactured after July 1, 2005 and to replacement ballasts manufactured after July 1, 2010. Ballasts with dimming capabilities and residential-use ballasts with a power factor of less than 0.90 are exempt from the standard, as are replacement ballasts manufactured until 2010, which must comply with the older, less stringent 1990 standard.

Table 11. Federal Standard for Fluorescent Ballasts (Effective 2005)

Application of the Operation of	Ballast Input Voltage	Total nominal lamp watts	Ballast efficacy factor (BEF)
One F40T12 lamp	120 277	40 40	2.29 2.29
Two F40T12 lamps	120 277	80 80	1.17 1.17
Two F96T12 lamps	120 277	150 150	0.63 0.63
Two F96T12HO lamps	120 277	220 220	0.39 0.39

Source: U.S. Congress, 2005

In addition, the Energy Policy Act of 2005 (U.S. Congress 2005), set efficiency standards for ballasts marketed for reduced wattage T12 lamps, closing a loophole in the earlier ballast standard. This standard applies to ballasts in new fixtures manufactured after July 1, 2009 and is summarized in Table 12.

Table 12. Federal Standard for Fluorescent Ballasts for Reduced Wattage Lamps (Effective 2009)

Application of the Operation of	Ballast Input Voltage	Total nominal lamp watts	Ballast efficacy factor (BEF)
One F34T12 lamp	120 277	34 34	2.61 2.61
Two F34T12 lamps	120 277	68 68	1.35 1.35
Two F96T12/ES lamps	120 277	120 120	0.7 0.77
Two F96T12HO/ES lamps	120 277	190 190	0.42 0.42

Source: U.S. Congress, 2005

8.3.2 *Preemption*

Many fluorescent lamps and ballasts are regulated by the federal government. For these products, California is preempted from setting its own efficiency standards unless it files a petition for exemption from preemption, and DOE approves this petition. Such petitions must be based on a "compelling state interest" and must meet a variety of other requirements.

However, fluorescent fixtures are not regulated by the federal government and thus California is free to regulate them. Since individual ballasts that do not meet the federal standard can still be sold in California were this proposal to be adopted, preemption does not appear to be an issue. However, this approach could be interpreted to restrict sales of a covered product (ballasts), and if this proves to be an issue, we have developed an alternative regulatory approach in Appendix D.

8.3.3 *Interaction with Title 24 of California's Building Code*

The standards proposed here affect new fixtures in commercial and residential applications. Commercial applications are covered by Title 24, but from our inspections of many new buildings in California, and discussions with industry experts, it appears that the majority of new fixtures do not use the high performance ballasts proposed here and thus this proposed standard will save a substantial amount of energy beyond the energy saved by Title 24. Our savings estimates assume that 35% of fixtures will comply with the proposed Title 20 standard in the absence of such a standard, in large part due to the influence of Title 24.

Title 24 does require fluorescent fixtures in some residential applications but does not regulate their efficiency. Thus our proposed standards for residential fixtures do not overlap with Title 24.

8.4 Stakeholder Positions

It is the opinion of manufacturers that the proposed standard is pre-empted by federal regulations on commercial fluorescent ballasts because it is based on minimum ballast efficiency requirements. We contend that because our standard does not ban non-complying ballasts for retrofit applications, our proposed fixture standard is not pre-empted. With our proposal, ballasts with a lower BEF can still be sold.

Manufacturers strongly oppose any modifications to the BEF requirements established in the CEE High Performance T8 specification. Among cost and availability concerns, joint comments presented by NEMA pointed out that the proposed 3-6% increase under our Option 2" is within the margin of error for BEF measurements. This error has a lot to do with the difficulty of measuring light output for calculating the ballast factor; however, BEF should be sufficient to indicate the relative efficiency of one ballast to another.

NEMA also stated that the 0.85 BF breakpoint is institutionalized in ANSI standard C82.11-2002 and universally used by all manufacturers. The "loophole" we note in Section 4.4 would not impact energy savings enough to warrant changing CEE ballast classifications. We agree with this claim, and therefore for the purposes of standards enforcement we propose that the cleanest approach would be to create “low” and “super low” ballast categories for PS ballasts to cover products that do not currently exist between 0.74 and 0.85 BF.

Manufacturers questioned the accuracy of our incremental cost and watts saved estimates for non-power factor corrected (residential) fixtures. We have since adjusted our base case system wattage and incremental cost figures to reflect new retail survey data and low ballast factor ballasts.

One manufacturer commented that setting a standard based on BEF for residential fixtures may be problematic from an energy-savings standpoint because the T12 and T8 products currently available for the residential sector use a comparable amount of energy, even if T8 products are higher in light output and efficiency. There are numerous low (0.60–0.70) BF T12 lamp products available, while most residential T8 systems are standard-BF requiring roughly equivalent input power. Unless the standard is based on maximum wattage, the standard would drive some users to increase their wattage slightly. This is a valid concern for one-lamp systems only; however, even in the case of 1-lamp systems, we found that the *average* wattage of available 1-lamp T12 products and T8 products are equivalent, so we would not expect a significant increase in overall energy use. Additionally, should more low-BF (0.75–0.85 BF) T8 ballasts enter the market, T8 system wattage would drop substantially and BEF would clearly be the preferred option to achieve energy savings in the residential sector.

9 Recommendations

9.1 Recommended Standards Options

Based on the growing market share of extra-efficient T8 electronic ballasts for four-foot fixtures, a shift away from eight-foot T12 fixtures and the clear savings benefits of T8 lamp-ballast systems over T12 for both residential and eight-foot commercial fixtures, a standard that restricts the least efficient T8 ballasts in the commercial four-foot fixture market and T12 ballasts in the residential market is warranted. We recommend that California adopt a minimum BEF standard for four-foot PF-corrected (commercial) fixtures that exceeds the CEE High-Performance T8 Specification in certain ballast categories. We believe there are enough products available to warrant some more stringent “Option 2” modifications to the CEE levels, however, this proposal faces strong opposition from manufacturers. With either option, we recommend establishing requirements for one-lamp, high-BF fixtures and a fourth ballast category covering the existing gap in PS ballasts between 0.73 and 0.85 BF to eliminate opportunities for manufacturers to downgrade products. For now, we propose T5 and T5HO fixtures be exempted from this standard and we are looking into data to support separate BEF requirements for these products.

For residential fixtures with low-PF, we recommend opting for the first option of requiring a minimum 2.80 BEF for 1-lamp fixtures and 1.55 BEF for two-lamp fixtures

(Table 5). This eliminates potential loopholes that would allow some T12 lamps with low light output under a maximum watt requirement.

For eight-foot standard output and HO fixtures, we recommend setting the minimum BEF requirements for 1- and two-lamp fixtures as shown in Table 4. These would allow all but the lowest efficacy T8 lamp-ballast systems currently available from major manufacturers.

California should consider the benefits of converting BEF values to Relative System Efficiency (RSE) levels, particularly if adopted by CEE for their specification. Likewise, if manufacturers finish developing and vetting a proposal to use ballast efficiency, this should be considered as well.

9.2 Proposed Changes to the Title 20 Code Language

[To be prepared later]

10 References

Brook, Martha. 2006. Email "Re: CEUS Lighting Data". Nov. 26. Sacramento, Calif.: California Energy Commission.

[CEC] California Energy Commission. 2004. *Update of Appliance Efficiency Regulations*. CEC Publication # 400-04-007D; Appendix A, Table 22. July 2004 California Energy Commission.

[CEE] Consortium for Energy Efficiency. 2003. *An Assessment of High Performance Commercial Lighting Opportunities.* Boston, M.A.: Consortium for Energy Efficiency.

-------. 2005. High-Performance T8 Specification. http://www.cee1.org/com/com-lt/com-lt-specs.pdf. Washington, D.C.: Consortium for Energy Efficiency, Inc.

-------. 2002. *US Lighting Market Characterization. Volume I: National Lighting Inventory and Energy Consumption Estimate*. Washington, D.C.: Navigant Consulting, Inc.

[DOE] U.S. Department of Energy. 2007. *2007 Buildings Energy Databook*. Washington, D.C.: U.S. Department of Energy.

[EIA] Energy Information Administration. 2005. *Commercial Building Energy Consumption Survey.* Washington, D.C.: Department of Energy.

-------. 2003. *Residential Energy Consumption Survey.* Washington, D.C.: Department of Energy.

Gordon, et al. 1988. *Use of Commercial Energy Efficiency Measure Service Life Estimates in Program and Resource Planning*. In Proceedings of the 1988 ACEEE Summer Study in Energy Efficiency in Buildings. Washington, D.C.: American Council for an Energy-Efficient Economy.

[NEMA] National Electrical Manufacturers Association. 2007. *Special Statistical Report Bulletin for the Ballast Section (2-BL) and ACEEE – High Efficiency and Dimming Ballast Shipments meeting CEE Specification.* Rosslyn, V.A.: National Electrical Manufacturers Association.

-------. 2006. *Data Needed for Federal Rule Making on Fluorescent Incandescent Reflector and Incandescent A-Line Lamps.* Rossyln, V.A.: National Electrical Manufacturers Association.

[PG&E] Pacific Gas & Electric Company. 2000. *2001 Energy Efficiency Programs Application, Attachment K, Workpapers.* San Francisco, C.A.: Pacific Gas & Electric Company.

Thorne, J. and S. Nadel. 2003. *Commercial Lighting Retrofits: A Briefing Report for Program Implementers.* Report A032. Washington D.C.: American Council for an Energy-Efficient Economy.

U.S. Cenusus Bureau. 2003. Electric Lighting Fixtures: 2001. Current Industrial Reprots MA335(01)-1(RV). Washington, D.C.: U.S. Census Bureau.

U.S. Census Bureau. 2006. Fluorescent Lamp Ballasts: 2005. Current Industrial Reprots MQ335C(05)-5. Washington, D.C.: U.S. Census Bureau.

U.S. Congress. 2005. *Energy Policy Act of 2005, Conference Report.* Washington, DC: U.S. Government Printing Office.

Appendix A: Consortium for Energy Efficiency Qualifying products list for High-Performance four-foot T8 Ballasts

www.cee1.org/com/com-lt/347-ballasts.xls

Manufacturer	Product Name	Model Number	Voltage (V)	Ballast Start Type	Ballast Factor Range	Ballast Factor	Input Watts (W)	BEF
HP T8 Qualified Ballasts with 1 Lamp								
Advance Transformer Company	Optanium	IOP-2S32-SC	120/277	PS	Normal	0.9	29	3.10
		IOP-1P32-SC	120/277	IS	Normal	0.87	28	3.11
		IOP-1P32-LW-SC	120/277	IS	Low	0.77	25	3.08
		IOP-2S32-LW-SC	120/277	PS	Low	0.73	25	2.92
Dynamic Ballast	High Efficiency	DY 132 IS WV - HE	120/277	IS	Normal	0.88	28	3.14
General Electric	GE Ultramax	GE-132-MAX-N/Ultra	120/277	IS	Normal	0.88	28	3.11
		GE-132-MAX-N-DIY	120/277	IS	Normal	0.88	28	3.11
		GE-132-MAX-L/Ultra	120/277	IS	Low	0.77	25	3.08
Howard Industries	HEX Electronic	E1/32IS-120HEX	120	IS	Normal	0.87	28	3.11
		E1/32IS-277HEX	277	IS	Normal	0.87	28	3.11
Osram - Sylvania	Quicktronic	QHE1x32T8/UNV ISH-SC	120/277	IS	High	1.2	38	3.16
		QTP 1X32T8/UNIV PSN-TC	120/277	PS	Normal	0.88	31/30	2.84/ 2.93
		QHE 1X32T8/UNIV ISN-SC	120/277	IS	Normal	0.88	28	3.14
		QHE 1X32T8/UNIV ISL-SC	120/277	IS	Low	0.78	25	3.12
		QTP 1X32T8/UNIV PSX-TC	120/277	PS	Low	0.71	25	2.84
PQL	Superior Life	SL-1/32IS-120	120	IS	Normal	0.88	24	3.67
		SL-1/32IS-277	277	IS	Normal	0.88	24	3.67
Standard Products	Optistart	E232SPR120-277L	120/277	PS	Normal	0.88	29	3.03
Universal Lighting Technologies	Ballastar	B232PUS50-A	120/277	PS	Normal	0.88	29	3.03
	F32 T8	B232PUNVHP-A	120/277	PS	Normal	1	32	3.13
		B232IUNVEL-A	120/277	IS	Normal	0.95	30	3.17
		B132PUNVHP-A	120/277	PS	Normal	0.88	31/30	2.84/ 2.93
		B132IUNVHE-A	120/277	IS	Normal	0.87	28	3.11
		B132IUNVEL-A	120/277	IS	Low	0.77	25	3.08
HP T8 Qualified Ballasts with 2 Lamps								
Advance Transformer Company	Optanium	IOP-2P32-HL-SC	120/277	IS	High	1.18	74/72	1.59/ 1.64
		ROP-2P32-SC	120	IS	Normal	0.88	55	1.6
		VOP-2P32-SC	277	IS	Normal	0.88	55	1.6
		IOP-2S32-SC	120/277	PS	Normal	0.88	56	1.57
		IOP-2P32-SC @ 120V	120	IS	Normal	0.87	55	1.58
		IOP-2P32-SC @ 277V	277	IS	Normal	0.87	54	1.61
		ROP-2P32-LW-SC	120	IS	Low	0.78	48	1.63
		VOP-2P32-LW-SC	277	IS	Low	0.78	48	1.63
		IOP-2P32-LW-SC	120/277	IS	Low	0.77	48	1.6
		IOP-2S32-LW-SC	120/277	PS	Low	0.71	47	1.51
Dynamic Ballast	High Efficiency	DY 232 IS WV - HE	120/278	IS	Normal	0.88	55	1.60
General Electric Company	Proline	GE-232-MV-L	120/277	IS	High	1.18	76	1.55
	Ultrastart	GE-232-MV-PS-H	120/277	PS	High	1.15	75 / 74	1.53/ 1.55
		GE-232-MVPS-N	120/277	PS	Normal	0.89	58	1.53
		GE-232-MVPS-L	120/277	PS	Low	0.71	47	1.51
	Ultramax	GE-232-MAX-N+	120/277	IS	Normal	1.00	62	1.61
		GE-232-MAX-N-42T	120/277	IS	Normal	0.87	53	1.64
		GE-232-MAX-N-DIY	120/277	IS	Normal	0.87	53	1.64
		GE-232-MAX-N-CTR	120/277	IS	Normal	0.87	53	1.64
		GE-232-MAX-L-42T	120/277	IS	Low	0.77	48	1.60
		GE-232-MAX-H-42T	120/277	IS	High	1.15	73	1.58
		GE-232-MAX-L/Ultra	120/277	IS	Low	0.77	48	1.6
		GE-232-MAX-N/Ultra	120/277	IS	Normal	0.87	54 / 53	1.61/ 1.64
		GE-232-MAX-H/Ultra	120/277	IS	High	1.15	74 / 73	1.55/ 1.58
	Ultrastart	GE-232-120-PS-N	120	PS	Normal	0.89	57	1.56
		GE-232-277-PS-N	277	PS	Normal	0.89	57	1.56
Howard Industries	HEX Electronic	E2/32IS-120HEX	120	IS	Normal	0.87	55	1.58
		E2/32IS-277HEX	277	IS	Normal	0.87	55	1.58
		EP2/32IS/MV/SC/HE	120/277	IS	Normal	0.87	54/53	1.61/1.64
		EL2/32IS-277HEX	277	IS	Low	0.77	48	1.6
		EPL2/32IS/MV/SC/HE	120/277	IS	Low	0.77	48	1.6
	Anti-	SKEU322AS	120/277	IS	Normal	0.88	44	2

Maxlite	Striation High Efficiency Ballast	SKEU322HE	120/277	IS	Normal	0.88	56	1.57
		SKEU322HEL	120/277	IS	Low	0.77	48	1.6
Osram - Sylvania	Quicktronic	QHE 2X32T8/UNIV ISH-SC	120/277	IS	High	1.2	74	1.62
		QTP 2X32T8/UNIV PSN-TC	120/277	PS	Normal	0.88	60 / 58	1.47/ 1.52
		QHE 2X32T8/UNIV ISN-SC	120/277	IS	Normal	0.88	55	1.6
		QHE 2X32T8/UNIV ISL-SC	120/277	IS	Low	0.78	48	1.63
		QTP 2X32T8/UNIV PSX-TC	120/277	PS	Low	0.71	47 / 46	1.51/ 1.54
		QHE 3X32T8/UNIV ISN-SC	120/277	IS	Normal	0.99	63/62	1.57/1.60
		QHE 4X32T8/UNIV ISN-SC	120/277	IS	High	1.06	68	1.56
PQL	Superior Life	SL-2/32IS-120	120	IS	Normal	0.88	56	1.57
		SL-2/32IS-277	277	IS	Normal	0.88	56	1.57
Technical Consumer Products, Inc.	E32	E32IS32120H	120	IS	High	1.22	77	1.58
		E32IS32277H	277	IS	High	1.22	78	1.57
	E432	E432IS32120N	120	IS	Normal	0.89	60	1.59
		E432IS32277N	277	IS	Normal	0.99	63	1.58
		E432IS32120L	120	IS	Low	0.79	49	1.60
		E432IS32120U	120	IS	Low	0.72	44	1.62
Ultrasave Lighting Ltd.	n/a	UT232120MH	120-277	IS	High	1.18	75	1.57
Universal Lighting Technologies	Ballastar	B232PUS50-A	120-277	PS	Normal	0.88	57/56	1.54/1.57
	F32 T8 Ultim8	B332I277HE	277	IS	High	1.01	61	1.66
		B332PUNVHP-A	120/277	PS	Normal	0.99	64 / 63	1.55/1.57
		B232IUNVHP-B	277	IS	Normal	0.88	55	1.60
		B332I120HE	120	IS	Normal	0.96	60	1.60
		B332I120L-A	120	IS	Normal	0.92	58	1.59
		B332IUNVEL-A	277	IS	Normal	0.89	56	1.59
		B232PUNVHP-A	277	PS	Normal	0.88	60	1.47
		B232I120HE	120	IS	Normal	0.87	54	1.61
		B232I277HE	277	IS	Normal	0.87	53	1.64
		B232IUNVHE-A	120/277	IS	Normal	0.87	55 / 54	1.58/1.61
		B332I277EL	277	IS	Normal	0.87	55	1.58
		B332I120EL	120	IS	Normal	0.86	53	1.62
		B232I120EL	120	IS	Low	0.77	47	1.64
		B232I2770EL	277	IS	Low	0.77	47	1.64
		B232IUNVEL-A	120/277	IS	Low	0.77	48	1.60
		B232IUNVHEH-A	120/277	IS	High	1.18	74/73	1.59/1.61
HP T8 Qualified Ballasts with 3 Lamps								
Advance Transformer Company	Optanium	IOP-3P32-HL-90C-SC	120/277	IS	High	1.18	110/107	1.07/1.10
		ROP-3P32-SC	120	IS	Normal	0.88	83	1.06
		VOP-3P32-SC	277	IS	Normal	0.88	82	1.07
		IOP-3S32-SC	120/277	PS	Normal	0.88	83	1.06
		IOP-3P32-SC @ 120V	120	IS	Normal	0.87	82	1.06
		IOP-3P32-SC @ 277V	277	IS	Normal	0.87	80	1.09
		ROP-3P32-LW-SC	120	IS	Low	0.78	72	1.08
		VOP-3P32-LW-SC	277	IS	Low	0.78	71	1.1
		IOP-3P32-LW-SC @ 120V	120	IS	Low	0.77	73	1.05
		IOP-3P32-LW-SC @ 277V	277	IS	Low	0.77	71	1.08
		IOP-3S32-LW-SC	120/277	PS	Low	0.71	72	0.99
Dynamic Ballast	High Efficiency	DY 332 IS WV - HE	120/279	IS	Normal	0.88	83	1.06
Fulham	Workhorse	WHSG4-UNV-T8-IS	120	IS	Normal	1	93	1.08
		WHSG4-UNV-T8-IS	277	IS	Normal	0.99	93	1.07
		WHCG4-120-T8-IS	120	IS	Normal	0.99	91	1.09
General Electric Company	Proline	GE-332-MV-L	120/277	IS	Low	0.78	74	1.05
		GE-332-MV-N	120/277	IS	Normal	0.87	81	1.07
		GE-332-MV-H	120/277	IS	High	1.15	110	1.05
	Ultramax	GE-332-MAX-N+	120/277	IS	Normal	1.00	90	1.11
		GE-332-MAX-N-42T	120/277	IS	Normal	0.87	80	1.09
		GE-332-MAX-N-DIY	120/277	IS	Normal	0.87	80	1.09
		GE-332-MAX-N-CTR	120/277	IS	Normal	0.87	80	1.09
		GE-332-MAX-L-42T	120/277	IS	Low	0.77	72	1.07
		GE-332-MAX-H-42T	120/277	IS	High	1.15	109	1.06
		GE-332-MAX-H/Ultra	120/277	IS	High	1.15	111 / 109	1.04/1.06
		GE-332-MAX-L/Ultra	120/277	IS	Low	0.77	73 / 72	1.05/1.08
		GE-332-MAX-N/Ultra	120/277	IS	Normal	0.87	82 / 80	1.06/1.09
	Ultrastart	GE-332-MVPS-L	120/277	PS	Low	0.71	68	1.04
		GE-332-MVPS-N	120/277	PS	Normal	0.89	84	1.06

		GE-332-MV-PS-H	120/277	PS	High	1.15	110 / 108	1.04/1.06
		GE-332-120-PS-N	120	PS	Normal	0.89	84	1.06
		GE-332-277-PS-N	277	PS	Normal	0.89	85	1.05
Howard Industries	HEX Electronic	E3/32IS-277 HEX	277	IS	Normal	0.87	83	1.05
		E3/32IS-120 HEX	120	IS	Normal	0.87	83	1.05
		EP3/32IS/MV/SC/HE	120/277	IS	Normal	0.87	82/80	1.06/1.09
		EL3/32IS-120 HEX	120	IS	Low	0.77	73	1.05
		EL3/32IS/MV/SC/HE	277	IS	Low	0.75	71	1.06
		EL3/32IS-277 HEX	277	IS	Low	0.77	73	1.05
		EP4/32IS/MV/SC/HE	277	IS	Normal	0.92	88	1.05
		EPL4/32IS/MV/SC/HE	120/277	IS	Low	0.84	80 / 79	1.05/1.06
		EPL3/32IS/MV/SC/HE	120/277	IS	Low	0.77	77	1.07
Osram - Sylvania	Quicktronic	QHE 3X32T8/UNIV ISH-SC	120/277	IS	High	1.18	111	1.06
		QTP 3X32T8/UNIV PSN-TC	120/277	PS	Normal	0.88	88 / 85	1/1.04
		QTP 3X32T8/UNIV PSX-SC	120/277	PS	Low	0.71	73 / 71	0.97/1
		QHE 3X32T8/UNIV ISL-SC	120/277	IS	Low	0.78	73	1.07
		QHE 3X32T8/UNIV ISN-SC	120/277	IS	Normal	0.88	83 / 82	1.06/1.07
		QHE 4X32T8/UNIV ISL-SC	120/277	IS	Low	0.85	80	1.06
		QHE 4X32T8/UNIV ISN-SC	120/277	IS	Normal	0.96	90/89	1.07/1.08
PQL	Superior Life	SL-3/32IS-120	120	IS	Normal	0.88	80	1.10
		SL-3/32IS-277	277	IS	Normal	0.88	80	1.10
Standard Products	Optistart	E432PPR120-277	120/277	PS	Normal	0.94	89	1.06
		E432PPR120-277L	120/277	PS	Normal	0.87	78	1.12
	Gold Label	E432PI120G11	120	IS	Normal	0.97	88	1.1
Technical Consumer Products, Inc.	E32	E32IS32120H	120	IS	High	1.2	114	1.05
		E32IS32277H	277	IS	High	1.18	112	1.06
	E432	E432IS32120N	120	IS	Normal	0.87	80	1.08
		E432IS32277N	277	IS	Normal	0.95	89	1.07
		E432IS32120L	120	IS	Low	0.84	78	1.07
		E432IS32120U	120	IS	Low	0.77	72	1.07
		E432IS32277L	277	IS	Low	0.82	77	1.07
		E432IS32277U	277	IS	Low	0.77	71	1.08
Ultrasave Lighting Ltd.		UT332120	120	IS	Normal	0.89	83	1.07
		UT332120M	120-277	IS	Normal	0.89	83	1.07
		UT332120MH	120-277	IS	High	1.18	110	1.07
Universal Lighting Technologies	n/a	B332I120RHH	120	IS	High	1.18	113	1.04
		B332I277RHH	277	IS	High	1.18	113	1.04
		B332I277RHU-A	277	IS	High	1.08	102	1.06
		B432I277HEH	277	IS	High	1.28	119	1.08
		B332IUNVHP-A	277	IS	Normal	0.88	83	1.06
		B332I120HE	120	IS	Normal	0.87	80	1.09
		B332I277HE	277	IS	Normal	0.87	79	1.1
		B432I120HE	120	IS	Normal	0.96	88	1.09
		B432I277HE	277	IS	Normal	0.96	89	1.08
		B332IUNVHE-A	120/277	IS	Normal	0.87	83 / 81	1.05/1.07
		B432I120EL	120	IS	Normal	0.84	79	1.06
		B332IUNVHEH-A	120/277	IS	High	1.18	111/108	1.06/1.09
		B432PUNVHP-A	120	PS	Normal	0.93	90	1.03
		B432PUNVHP-A	277	PS	Normal	0.93	85	1.09
		B432IUNVHP-A	277	IS	Normal	0.94	89	1.06
		B432IUNVHE-A	120	IS	Normal	0.96	84	1.14
		B432IUNVHE-A	277	IS	Normal	0.96	82	1.17
		B432I277EL	277	IS	Normal	0.87	76	1.14
		B432I120EL	120	IS	Normal	0.85	73	1.16
		B332I120EL	120	IS	Low	0.77	70	1.1
		B332IUNVEL-A	120/277	IS	Low	0.77	74 / 73	1.04/1.05
HP T8 Qualified Ballasts with 4 Lamps								
Advance Transformer Company	Optanium	IOP-4P32-HL-90C-G	120/277	IS	High	1.18	148/144	0.80/0.82
		ROP-4P32-SC	120	IS	Normal	0.88	108	0.81
		VOP-4P32-SC	277	IS	Normal	0.88	107	0.82
		IOP-4S32-SC	120/277	PS	Normal	0.88	109	0.81
		IOP-4P32-SC @ 120V	120	IS	Normal	0.87	108	0.81
		IOP-4P32-SC @ 277V	277	IS	Normal	0.87	106	0.82
		ROP-4P32-LW-SC	120	IS	Low	0.78	95	0.82
		VOP-4P32-LW-SC	277	IS	Low	0.78	94	0.83
		IOP-4P32-LW-SC @120V	120	IS	Low	0.77	97	0.79
		IOP-4P32-LW-SC @277V	277	IS	Low	0.77	95	0.81
		IOP-4S32-LW-SC	120/277	PS	Low	0.71	92	0.77
Dynamic Ballast	High	DY 432 IS WV - HE	120/280	IS	Normal	0.88	106	0.83

Fulham	Efficiency Workhorse	WHSG4-UNV-T8-IS	120	IS	Normal	0.92	114	0.81
		WHSG4-UNV-T8-IS	277	IS	Normal	0.92	112	0.82
		WHCG4-277-T8-IS	277	IS	Normal	0.89	110	0.81
General Electric Company	Proline	GE-432-MV-L	120/277	IS	Low	0.8	100	0.80
		GE-432-MV-N	120/277	IS	Normal	0.88	110	0.80
		GE-432-MV-H	120/277	IS	High	1.15	144	0.80
	Ultramax	GE-432-MAX-H/Ultra	120/277	IS	High	1.15	147 / 151	0.78/0.76
		GE-432-MAX-N/Ultra	120/277	IS	Normal	0.87	109 / 107	0.8/0.81
		GE-432-MAX-L/Ultra	120/277	IS	Low	0.77	97 / 96	0.79/0.80
		GE-432-MAX-N+	120/277	IS	Normal	1.00	121	0.83
		GE-432-MAX-N-42T	120/277	IS	Normal	0.87	107	0.81
		GE-432-MAX-N-DIY	120/277	IS	Normal	0.87	107	0.81
		GE-432-MAX-N-CTR	120/277	IS	Normal	0.87	107	0.81
		GE-432-MAX-L-42T	120/277	IS	Low	0.77	96	0.80
		GE-432-MAX-H-42T	120/277	IS	High	1.15	147	0.78
	Ultrastart	GE-432-277-PS-N	277	PS	Normal	0.89	112	0.79
		GE-432-120-PS-N	120	PS	Normal	0.89	112	0.79
		GE-432-MVPS-N	120/277	PS	Normal	0.89	114	0.78
		GE-432-MVPS-L	120/277	PS	Low	0.71	88	0.81
		GE-432-MVPS-H	120/277	PS	High	1.16	144	0.81
Howard Industries	HEX Electronic	EP4/32IS/MV/SC/HE	120/277	IS	Normal	0.87	109/107	0.80/0.81
		E4/32IS-120HEX	120	IS	Normal	0.87	109	0.8
		E4/32IS/-277HEX	277	IS	Normal	0.87	109	0.8
		EL432IS/MV/SC/HE	277	IS	Low	0.75	94	0.8
		EL4/32IS-120 HEX	120	IS	Low	0.77	98	0.79
		EL4/32IS-277 HEX	277	IS	Low	0.77	96	0.8
		EPL4/32IS/MV/SC/HE	120/277	IS	Low	0.77	95 / 94	0.81 / 0.82
Maxlite	Anti-Striation	SKEU324AS	120/277	IS	Normal	0.88	88	1
	High Efficiency Ballast	SKEU324HE	120/277	IS	Normal	0.88	109	0.81
		SKEU324HEL	120/277	IS	Low	0.77	95	0.81
Osram - Sylvania	Quicktronic	QHE4x32T8/UNV ISH	120/277	IS	High	1.15	144/141	0.80/0.82
		QHE 4X32T8/UNIV ISN-SC	120/277	IS	Normal	0.88	108 / 107	0.81/0.82
		QTP 4X32T8/UNIV PSN-SC	120/277	PS	Normal	0.88	118 / 113	0.75/0.78
		QHE 4X32T8/UNIV ISL-SC	120/277	IS	Low	0.78	95	0.82
		QTP 4X32T8/UNIV PSX-SC	120/277	PS	Low	0.71	93 / 91	0.76/0.78
PQL	Superior Life	SL-4/32IS-120	120	IS	Normal	0.88	112	0/79
		SL-4/32IS-277	277	IS	Normal	0.88	112	0.79
Standard Products	Optistart	E432PPR120-277L	120/277	PS	Low	0.77	101	0.77
	Gold Label	E432PI120G11	120	IS	Normal	0.85	105	0.81
Technical Consumer Products, Inc.	E432	E432IS32120N	120	IS	Normal	0.87	107	0.81
		E432IS32277N	277	IS	Normal	0.88	108	0.82
		E432IS32120L	120	IS	Low	0.78	95	0.82
		E432IS32120U	120	IS	Low	0.72	84	0.85
		E432IS32277L	277	IS	Low	0.75	92	0.82
		E432IS32277U	277	IS	Low	0.70	85	0.82
Ultrasave Lighting Ltd	n/a	UT432120L	120	IS	Low	0.71	93	0.76
Universal Lighting Technologies	F32 T8	B432I277HEH	277	IS	High	1.18	145	0.81
		B432I120HE	120	IS	Normal	0.87	100	0.87
		B432PUNVHP-A	277	PS	Normal	0.88	115	0.77
		B432IUNV-D	277	IS	Normal	0.88	109	0.81
		B432I277RH-A	277	IS	Normal	0.88	110	0.80
		B432IUNVHP-A	277	IS	Normal	0.88	108	0.81
		B432I277HE	277	IS	Normal	0.87	105	0.83
		B432IUNVHE-A	120/277	IS	Normal	0.87	109/106	0.80/0.82
		B4231120HE	120	IS	Normal	0.87	106	0.82
		B432I277L-A	277	IS	Low	0.78	98	0.76
		B432I120EL	120	IS	Low	0.77	95	0.81
		B432I277EL	277	IS	Low	0.77	93	0.82
		B4321UNVEL-A	120/277	IS	Low	0.77	97/96	0.79/0.80

Appendix B: Available Eight-Foot Lamp Ballasts from Major Manufacturers

Note: Does not include products from other manufacturers that would qualify under our proposed standards options.

Manufacturer	Family	Lamps	Lamp Type	Input Volts	Input Power	BF	BEF
Standard Output							
GE	Electronic	1	F96T8/WM	277	53	0.87	1.64
Advance	Optanium	1	F96T8 ES	120	64	1.05	1.64
Advance	Standard	1	F96T8 ES	120	68	1.1	1.62
Advance	Standard	1	F96T8 ES	277	68	1.1	1.62
GE	Electronic	1	F96T8/WM	120	54	0.87	1.61
GE	Electronic	1	F96T8	277	55	0.87	1.58
Advance	Standard	1	F96T8 standard	120	70	1.1	1.57
Advance	Standard	1	F96T8 standard	277	70	1.1	1.57
Advance	Optanium	1	F96T8 standard	120	67	1.05	1.57
GE	Electronic	1	F96T8	120	56	0.87	1.55
Howard	Electronic	1	F96T8	120	73	1.13	1.55
Howard	Electronic	1	F96T8	277	73	1.13	1.55
GE	Electronic	1	F96T8	120	60	0.92	1.53
GE	Electronic	1	F96T8	277	60	0.92	1.53
Universal	Std Electronic	1	F96T8	120	58	0.88	1.52
Universal	Std Electronic	1	F96T8	277	58	0.88	1.52
Howard	Electronic	1	F96T8	120	58	0.87	1.50
Howard	Electronic	1	F96T8	277	58	0.87	1.50
GE	Electronic	1	F96T8	120	62	0.87	1.40
GE	Electronic	1	F96T8	277	62	0.87	1.40
Sylvania	Electronic	2	F096T8/XP(55W) ES	277	102	0.88	0.86
Sylvania	Electronic	2	F096T8/XP(55W) ES	120	102	0.88	0.86
Sylvania	Electronic	2	F096T8/XP(55W) ES	277	102	0.88	0.86
Sylvania	Electronic	2	F096T8/XP(55W) ES	347	102	0.88	0.86
Sylvania	Electronic	2	F096T8/XP(55W) ES	120	104	0.88	0.85
Advance	Optanium	2	F96T8 slim ES	120-277	103	0.87	0.84
GE	Electronic	2	F96T8/WM	277	105	0.87	0.83
Advance	Optanium	2	F96T8 slim standard	120-277	107	0.87	0.81
GE	Electronic	2	F96T8/WM	120	107	0.87	0.81
Universal	ULTim 8	2	F96T8	277	109	0.88	0.81
Advance	Standard	2	F96T8 slim ES	120	106	0.85	0.80
Advance	Standard	2	F96T8 slim ES	277	106	0.85	0.80
Universal	HP Electronic	2	F96T8	120-277	110	0.88	0.80
Sylvania	Electronic	2	F096T8/XP(59W) std	277	110	0.88	0.80
Sylvania	Electronic	2	F096T8/XP(59W) std	120	110	0.88	0.80
Sylvania	Electronic	2	F096T8/XP(59W) std	277	110	0.88	0.80
Sylvania	Electronic	2	F096T8/XP(59W) std	347	110	0.88	0.80
Universal	ULTim 8	2	F96T8	120	111	0.88	0.79
GE	Electronic	2	F96T8	277	110	0.87	0.79
Universal	High Light	2	F96T8	120	150	1.18	0.79
Universal	High Light	2	F96T8	277	150	1.18	0.79
GE	Electronic	2	F96T8	120	150	1.18	0.79
GE	Electronic	2	F96T8	277	150	1.18	0.79
Universal	Std Electronic	2	F96T8	120	112	0.88	0.79
Universal	Std Electronic	2	F96T8	277	112	0.88	0.79
Sylvania	Electronic	2	F096T8/XP(59W) std	120	112	0.88	0.79
Universal	HP Low Pwr	2	F96T8	120	100	0.78	0.78
Universal	HP Low Pwr	2	F96T8	277	100	0.78	0.78
GE	Electronic	2	F96T8	120	100	0.78	0.78
GE	Electronic	2	F96T8	277	100	0.78	0.78
Universal	HP Electronic	2	F96T8	120-277	113	0.88	0.78
Howard	Electronic	2	F96T8	120	112	0.87	0.78
Howard	Electronic	2	F96T8	277	112	0.87	0.78
GE	Electronic	2	F96T8	120	112	0.87	0.78
Advance	Standard	2	F96T8 slim standard	120	110	0.85	0.77
Advance	Standard	2	F96T8 slim standard	277	110	0.85	0.77

Sylvania	Electronic	2	F096T8/XP(55W) ES	120	141	0.88	0.62
Sylvania	Electronic	2	F096T8/XP(55W) ES	277	141	0.88	0.62
Sylvania	Electronic	2	F096T8/XP(59W) std	120	151	0.88	0.58
Sylvania	Electronic	2	F096T8/XP(59W) std	277	151	0.88	0.58
High Output							
Advance	Centium	1	F96T8/HO (PS)	120-277	100	1	1.00
Universal	Std Electronic	1	F96T8HO	277	87	0.93	1.07
GE	Electronic	1	F96T8HO	277	87	0.93	1.07
Universal	Std Electronic	1	F96T8HO	120	92	0.96	1.04
GE	Electronic	1	F96T8HO	120	92	0.96	1.04
Universal	Std Electronic	2	F96T8HO	277	144	0.81	0.56
GE	Electronic	2	F96T8HO	277	144	0.81	0.56
Advance	Standard	2	F96T8/HO	120	160	0.88	0.55
Advance	Standard	2	F96T8/HO	277	160	0.88	0.55
Universal	Std Electronic	2	F96T8HO	120	151	0.81	0.54
GE	Electronic	2	F96T8HO	120	151	0.81	0.54
Advance	Centium	2	F96T8/HO (PS)	120	185	0.95	0.51

Appendix C: Residential Four-Foot T12 and T8 Fluorescent Ballasts

Note: Only includes products by three major U.S. manufacturers.

Manufacturer	Family	# Lamps	Lamp Type	Input Volts	Line Current (Amps)	Input Power (w)	BF	BEF
T12								
Advance	Electromagnetic RS	1	F40T12 (430mA)	120	0.53	32	0.63	1.97
Universal	Electromagnetic RS	1	F40T12	120	0.53	36	0.61	1.69
Sylvania	Electromagnetic RS	1	F40T12	120	0.53	31	0.60	1.94
GE	Electromagnetic RS	1	F40T12	120	0.53	36	0.61	1.69
GE	Electromagnetic RS	1	F40T12 WM	120	0.61	33	0.68	2.06
Advance	Electromagnetic RS	2	F40T12 (430mA)	120	0.72	70	0.68	0.97
Advance	Electromagnetic RS	2	F34T12 (460mA)	120	0.61	60	0.66	1.10
32T8								
Advance	Ambistar (IS)	1	F32T8	120	0.48	33	1.00	3.03
Advance	Residential Class B EMI	1	F32T8	120	0.45	30	0.88	2.93
Sylvania	Quicktronic IS	1	F032/XP	120	0.56	34	0.87	2.56
Universal	Triad Electronic (IS)	1	F32T8	120	0.53	35	1.06	3.03
Universal	Triad Electronic (IS)	1	F32T8	120	0.53	36	1.06	2.94
Advance	Ambistar (IS)	2	F32T8	120	0.80	56	0.88	1.57
Advance	Residential Class B EMI	2	F32T8	120	0.75	55	0.81	1.47
Sylvania	Quicktronic IS	2	F032/XP	120	0.89	55	0.87	1.58
Universal	Triad Electronic (PAR IS)	2	F32T8	120	0.80	56	0.88	1.57
Universal	Triad Electronic (PAR IS)	2	F32T8	120	0.80	56	0.88	1.57
Advance	Ambistar (IS)	3	F32T8	120	1.36	80	0.84	1.05
Sylvania	Quicktronic IS	3	F032/XP	120	1.46	92	0.96	1.04
Universal	Triad Electronic (SER RS)	3	F32T8	120	1.20	92	0.96	1.04
Sylvania	Quicktronic IS	4	F032/XP	120	1.70	110	0.84	0.76
Universal	Triad Electronic (SER RS)	4	F32T8	120	1.40	109	0.87	0.80
25T8								
Sylvania	Quicktronic IS	1	F025/XP	120	0.56	34	1.03	3.03
Sylvania	Quicktronic IS	2	F025/XP	120	0.74	28	1.05	3.75
Sylvania	Quicktronic IS	3	F025/XP	120	1.18	72	1.00	1.39
Sylvania	Quicktronic IS	4	F025/XP	120	1.38	86	0.88	1.02
Advance	Residential Class B EMI	1	F25T8	120	0.25	24	0.9	3.75
Advance	Residential Class B EMI	2	F25T8	120	0.50	43	0.88	2.05

Appendix D: Alternate Proposal for Setting Fluorescent Fixture Standards Based on Luminaire Efficacy Ratio (LER)

D.1. Introduction and Background

This appendix document presents a concept for an alternate approach for setting linear fluorescent fixture efficiency standards based on “luminaire efficacy rating” (LER). LER is a measurement developed by the National Lighting Collaborative in response to a directive in the Energy Policy Act of 1992 to develop a metric that could be used to evaluate the efficiency of the whole fixture, including lamp, ballast, and design features. LER is defined as the ratio of total rated lamp lumens over input watts with adjustments for ballast factor and a “fixture efficiency” (FE) factor, which is total luminous flux emitted from the fixture compared to total rated lumens.

The efficiency of the lamp-ballast system often comprises a small majority of the fixture’s LER. Other components of the fixture that impact its ability to maximize useful light include shape, number and spacing of lamps, reflective materials, diffusers, and shielding components (lenses or louvers) that soften and scatter the light.

LER has not been used as the basis for regulation, but it has been used by the federal government to identify fixtures that are in the “top 25%” of the market under the Federal Energy Management Program’s (FEMP) procurement guidelines[5]. The FEMP specification distinguishes among six fixture types: recessed lensed, recessed louvered, plastic wraparound, strip lights, industrial, and 2x2 recessed for U-tube lamps. Suspended fixtures with “indirect” light distribution components are not included in the spec.

NEMA is working on a revised metric to succeed LER called “target efficiency rating” (TER), which accounts for the amount of light hitting the workplane or “target” rather than total light output. The benefit of TER as compared to LER is that it avoids creating unintended advantages for fixtures that are technically efficient (they allow a lot of light out of the fixture) but offer poor light distribution. Measuring a fixture’s TER involves making assumptions about the likely application for the fixture and is probably more problematic as a basis for regulation. The metric is still under development and it is not clear when it would come under comprehensive use in the industry.

The proposal outlined below is not intended for adoption but rather to demonstrate an approach for regulating fixture efficiency we feel is reasonable if the concept is further developed in coordination with industry and other stakeholders. To develop a full standards proposal, more comprehensive product, market and cost data are needed.

[5] The spec was last revised in 2001 and is currently under revision. http://www1.eere.energy.gov/femp/procurement/eep_fluor_lum.html

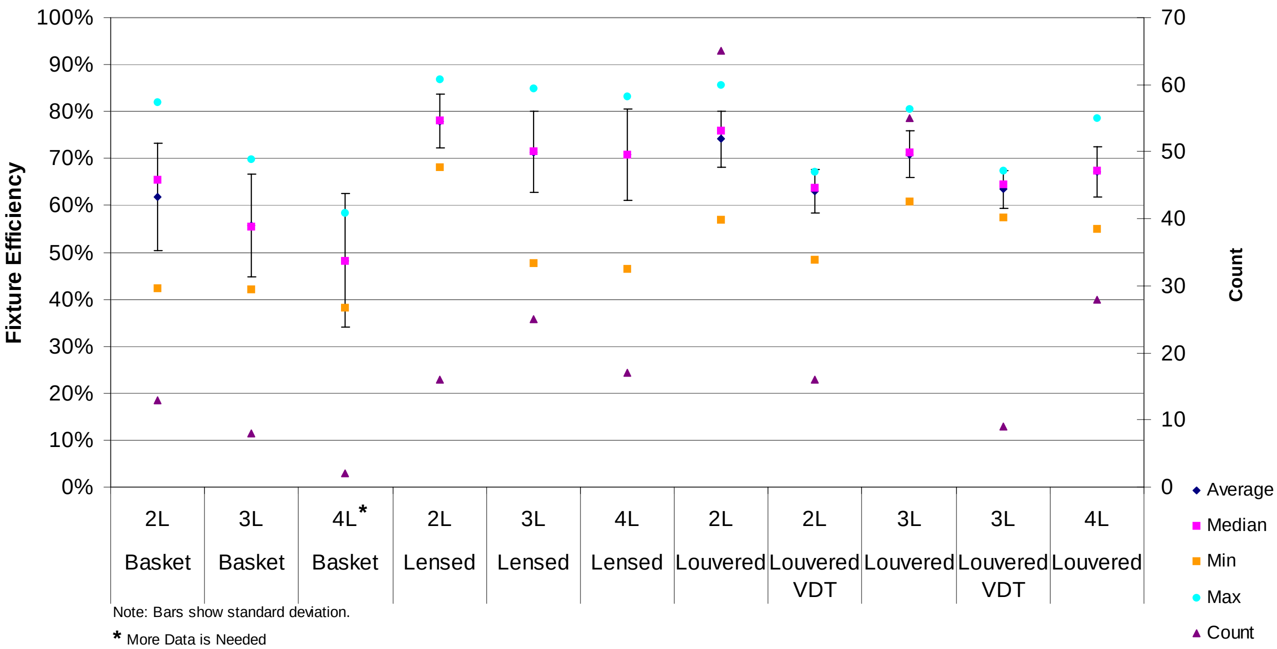
D.2. Approach

D.2.1 Methodology

Our investigation is based on an initial dataset of over 500 product records including published fixture efficiency data and design characteristics for major fluorescent fixture types, including suspended fixtures, strip lights, wrap-arounds, industrial high-bay, and recessed or surface-mounted box fixtures in 1x4, 2x2, 2x4 and 4x4 configurations. Our dataset contains predominantly Lithonia, DayBrite, and Cooper-Metalux products, as well as those from a few smaller manufacturers. We obtained product data from manufacturer and distributor online catalogs, brochures, and specification sheets with some phone contacts with company representatives.

To develop a concept for fluorescent fixture standards based on LER we focused on a more detailed evaluation of 2x4 fixtures (recessed and surface-mount box fixtures), which represent one of the largest segments of the commercial fluorescent lighting market and would be a high priority for efficiency regulation. This category also offers a large and varied selection of available products, allowing us to evaluate the range of fixture efficiencies available and investigate where threshold efficiency levels might be appropriately established.

Figure D.1. 2x4 Fixture Efficiency Data



Out of 250 records for 2x4 recessed and surface-mount fixtures, we examined fixture efficiency variation across different fixture types and identified three basic product classes – fixtures with wide-cell louvers, those with prismatic lenses, and those with basket diffusers (usually perforated metal). We further differentiated these into 11 total sub-categories based on number of lamps and glare control (fixtures labeled "preferred" for use with video display terminals [VDT]). At first cut, we feel these categories appropriately control for application- and design-based factors (i.e., distinct product utility) that may impact fixture efficiency.

D.2.2 Proposal

Using the fixture efficiency data shown in Figure D.1, we examined LER under three lamp-ballast scenarios to determine what minimum LER would offer valuable savings without limiting design flexibility or forcing the use of efficient lamps and ballasts. Table D.1 outlines the underlying assumptions used for evaluating LER.

Our base case fixture assumes standard 700-series T8s and generic instant-start ballasts because, although the federal government allows new T12 fixtures with electronic ballasts to be sold, the vast majority of fixtures sold are T8s. The fixtures with the highest LERs are those that use high-performance T8 systems, including 3100-lumen lamps and extra-efficient electronic ballasts. Because many fixtures are not shipped with lamps included, we also evaluated how a fixture's LER is impacted by the use of base lamps and an extra-efficient ballast only.

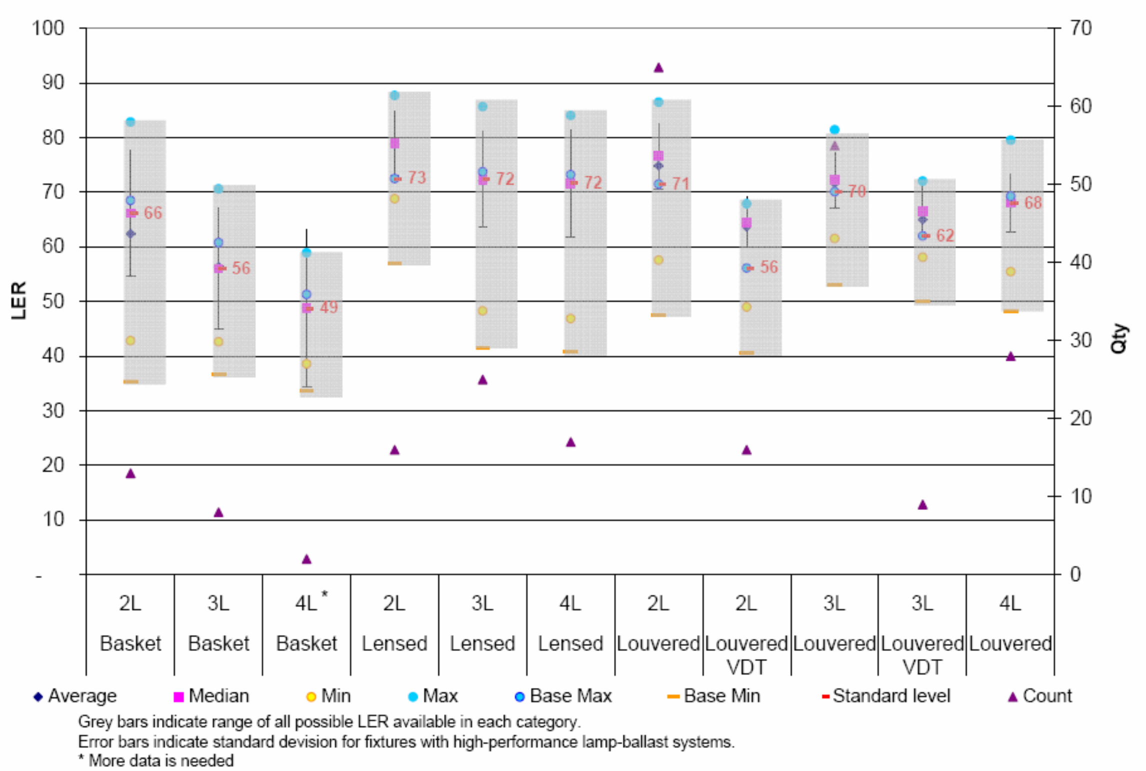
Table D.1. Assumptions Used to Model LER

Lamp-Ballast System	Lumens per Lamp	Ballast Factor	Watts	
"Base" Lamp and Ballast (700-series T8, generic instant-start electronic ballast)	2800	0.88	2 Lamps 3 Lamps 4 Lamps	59 85 112
Extra-Efficient Ballast (With 700-series T8)	2800	0.88	2 Lamps 3 Lamps 4 Lamps	54 81 108
High Performance System (High-lumen T8 and extra-efficient instant start ballast)	3100	0.88	2 Lamps 3 Lamps 4 Lamps	54 81 108

One option for a standard is to set minimum LER at the base maximum (fixture with "base lamp and ballast"). This allows only the most efficient fixtures to be used with a generic T8 system. In some fixture classes however, the base maximum LER falls above the median LER for fixtures using high-performance lamps and ballasts. In order for at least half of all available products to comply using efficient lamps and ballasts, we would propose a standard based on the *lower* of either the "base" maximum LER or the "high performance" median LER. This proposed standard level is shown in red in Figure D.2. For most lensed and louvered fixtures, the proposed minimum LER level would be around 70. For "basket" and "VDT" fixtures, lower LER's are recommended. For comparison, the minimum base LER is included in Figure D.2 to show the full range of possible LERs for each fixture groups.

According to our data, this approach would allow all but the very least efficient two-lamp fixtures using high-performance lamps and ballasts, and it would allow about half of 2-lamp fixtures using only the extra-efficient ballast. The proposal results in more stringent standards for 3- and 4-lamp fixtures, which carries the added benefit of encouraging the use of fixtures with fewer lamps. It has a similar affect on fixtures with basket diffusers, to encourage more efficient designs that incorporate direct and indirect light. It may be possible to simplify the standard by grouping lensed and louvered fixtures, making exceptions for those with glare control designs (VDT).

Figure D.2. LER Range for 2x4 Fixtures with High Performance Lamps and Ballast



D.3. Savings Analysis

D.3.1 Basecase

To illustrate our proposed approach we present our analysis for the 2x4 louvered recessed fixture category. For our analysis we assume a 3-lamp 2x4 recessed louvered fixture. The base case fixture has a fixture efficiency of 71%, equal to the median value for this category, and an LER of 62.

D.3.2 Efficiency Options

There are three means of improving the LER of a fixture: 1) improving the Fixture Efficiency so that more of the lamp output leaves the fixture 2) using a ballast with a higher ratio of ballast factor to system watts (Ballast Efficacy Factor) and 3) using a lamp with a higher ratio of lamp lumens to system watts.

To illustrate how LER improvements would achieve energy savings, we've modeled a few of the main permutations of options to achieve a target LER of 70 for our basecase fixture: improving the efficiency of the fixture and using a lower ballast-factor ballast; installing an extra-efficient ballast, installing higher-lumen lamps (with either a normal or low ballast factor); or selecting a combination thereof. The relative annual energy savings associated with these scenarios are illustrated in Table D.3. Note that, because we wish to compare the impact of modifying different fixture components all else being equal, the strategy of switching to a fixture with fewer lamps is not included in the example. As shown in Figure D.2, it is easier to meet a high LER with a two-lamp fixture than with a three-lamp fixture and this is likely to be one of the more cost-effective options.

Likewise, in a new construction scenario or gut-rehab with a redesign of the lighting layout, the choice of a wider spacing for fixtures is an additional source of savings. We anticipate the trend towards wider fixture spacing to increase as improvements to lamp lumen output and fixture efficiency result in more light output for fixtures at equal and lower energy consumption.

D.3.3 Market Adoption of Efficiency Options

For our savings analysis, we made assumptions about which methods would be used to meet a new LER standard. Our estimate was that 90% of new fixtures will utilize extra-efficient ballasts to improve LER, as this is a very low-cost option that requires merely a supply shift. We assume 10% of new fixtures will be installed with revised fixture spacing based on higher lumen lamps and higher efficiency fixtures, as a result of manufacturers' promotion of increased fixture spacing with new high-performance lighting. We also assume about one third of fixtures will use a ballast with a lower ballast factor to compensate for higher lumen lamps and/or higher efficiency fixtures.

We project the standard will shift about two thirds of lamps into higher-efficiency categories. Since 700-series T8 is the basecase, the improved category includes 800-series and high-lumen T8s, as well as reduced-wattage T8s[6]). Because not all fixtures are shipped with lamps installed, it is possible that manufacturers could claim higher LER from high-lumen lamps without ensuring they are used with the fixture. Although probably not a significant loophole since downgrading lamps would affect lighting design, a final standards proposal should address this issue.

Table D.2. Possible Impact of Fixture Standards on Market

Parameter		Current Share	Post-Standard Share
Ballast Efficiency	GEB	90 %	10 %
	Extra Eff	10%	90 %
Ballast Factor	Normal	87 %	70 %
	Reduced	13 %	30 %
Lamp Type	700-series	49 %	15 %
	800-series	45 %	20 %
	Reduced	1 %	15 %
	High-Lumen	5%	50%
Revised Spacing		0 %	10 %

Note: This is one possible outcome that we model for illustrative purposes.

[6] In our detailed analysis, reduced-wattage lamps were treated as a 30/70 blend of 25WT8 and 28WT8 lamps

Table D.3. Illustrative Efficiency Options for 2x4 Recessed Louvered 3-Lamp Fixtures

Design Options	LER	Fixture Efficiency	Rated Lumens per lamp	Ballast Factor	System Watts	Relative Light Output	Annual Operating Hours	Unit Electricity Consumption (kWh/yr)	% Savings
Base Case									
700 series T8 lamps Generic electronic IS ballast Normal ballast factor	62	71%	2800	0.88	85	100%	3,740	318	-
Efficiency Options									
Higher Fixture Efficiency	70	81%	2800	0.88	85	116%	3,740	318	0%
High-lumen lamps	70	74%	3100	0.88	85	116%	3,740	318	0%
High-lumen T8 lamps Extra-efficient electronic IS ballast	70	71%	3100	0.88	81	111%	3,740	304	4%
Extra-efficient electronic IS ballast	70	76%	2800	0.88	81	108%	3,740	304	4%
Higher Fixture Efficiency Low ballast factor[1]	70	82%	2800	0.77	76	104%	3,740	284	11%
High-lumen T8 lamps Low ballast factor[1]	70	74%	3100	0.77	74	104%	3,740	280	12%
High-lumen T8 lamps Extra-efficient electronic IS ballast Low ballast factor[1]	70	71%	3100	0.77	72	99%	3,740	269	15%

[1]An alternative to lowering the ballast factor is to use reduced wattage (25W, 28W, or 30W) T8s.

D.3.4 Estimated Savings

Based on a more detailed analysis of all possible lamp-ballast permutations and incorporating the adoption trends outlined above, we arrived at a weighted average savings of 11%, with a minor, 4% increase in light output for 2x4 3-lamp recessed/box louvered fixtures.

Statewide savings impact from the proposed LER standard, based on the 11% savings discussed in the previous section, is summarized in Table D.4. The calculations are highly generalized given that we only analyzed 3-lamp 2x4 recessed/box louvered fixtures. If this savings is representative of other fixture categories, the calculations below can be considered a reasonable, conservative state-wide estimate. The wattage reduction per fixture is based on applying the 11% wattage reduction to the weighted average baseline wattages for two *and* three-lamp fixtures, given commercial building inventory data (Brook 2006). This generalizes the fixture market by disregarding higher savings from four-lamp fixtures and eight-foot fixtures, but gives a conservative sense of the scope of savings possible from the standard. To avoid taking credit for market transformation already underway, we make a blind estimate of 20% adoption in the absence of a standard.

Table D.4. California Statewide Energy Savings From Proposed Standards

California Annual Sales (millions)	Average watts saved per fixture	Percent on at Peak	For First-Year Sales		After Entire Stock Turnover	
			Coincident Peak Demand Reduction (MW)	Annual Electricity Savings (GWh/yr)	Coincident Peak Demand Reduction (MW)	Annual Electricity Savings (GWh)
5.1	7	78%	27	103	669	2,567

Notes: For the source of sales data and peak coincidence assumption, see Table 7 in main body of the report.
Average watts saved per fixture is based on a 11% average reduction for 2-lamp and 3-lamp fixtures given market shares of 60% and 30%, respectively (Brook, 2006; no savings is assumed for 1-lamp fixtures). The 20% pre-standards compliance is factored in to the savings estimates.

D.4. Economic Analysis

D.4.1 Incremental Cost

Incremental costs for extra-efficient ballast, high-performance T8 lamps, and high-efficiency fixtures are included in our net present value analysis. Extra-efficient T8 ballasts carry an added cost of $1.00 each for the fixture manufacturer compared to generic electronic ballasts used with standard-series T8s (see page 17).

Incremental cost for high efficiency fixtures was calculated by comparing the retail cost of premium fixtures with very high fixture efficacies. Manufacturers have developed lensed and louvered fixtures with fixture efficiencies of 84-90%, well above the standard lensed and louvered fixtures with efficiencies between 67% and 78%. The average fixture efficiency improvement offsets the 12% reduction in light output due to selection of a reduced light output (0.78 BF) ballast rather than a normal light output (0.88 BF) ballast. This ballast change incurs no extra cost.

These high fixture efficiency products currently command a cost premium in the marketplace, but demonstrate the feasibility of fixture efficiency improvements. A preliminary retail survey suggests that these fixtures sell for $37 more than standard lensed or louvered fixture. This premium should fall in the case of a standard, so our cost assumption is conservative.

Incremental cost data for high performance T8 lamps comes from PG&E's 2006 Ballast Efficacy Table ($2 per lamp). Here, high performance refers to a 32 watt T8 lamp with 3100 initial lumens. The lamp lumen increase offsets the 12% reduction in light output due to the ballast factor.

D.4.2 Design Life

Ballast lifetimes will vary with annual operating hours. In this analysis we have focused on a standard office setting and 2x4 fixtures. Consistent with this focus, the calculations assume an industry minimum 50,000 hour ballast life and 3,740 annual operating hours. Lamp lifetimes are calculated using annual operating hours and 24,000 hours mean life for high performance T8 lamps. The average fluorescent fixture lasts 25 years, according to a survey of experts in the field (Gordon, et al, 1988).

D.4.3 Lifecycle Cost / Net Benefit

Table D.5 summarizes costs and benefits for different scenarios under the proposed LER standard. Entries in this table are shown only for measures or combinations of measures that include both wattage reductions and improvements in LER.

Table D.5. Costs and Benefits Per Unit for Standards Options

Efficiency Option under Standard	Watts Saved	Annual Energy Savings per unit (kWh)	Life (years)	Incremental Cost ($)[a]	Present Value of Lifetime Energy Savings ($)[b]	Lifecycle Benefit / Cost Ratio[c]	Net present Value per unit ($)[d]
Extra-Efficient Ballast	5	19	25	$2.00	$27	13.4	$25
High Efficiency Fixture & Generic Electronic Reduced Light Output Ballast	10	37	25	$37	$67	1.8	$31
High Efficiency Fixture & Extra Efficient Electronic Reduced Light Output Ballast	14	52	25	$43	$94	2.2	$51

High Performance T8 Generic Electronic Reduced Light Output Ballast	14	37	25	$61	$67	1.1	$7
High Performance T8 Lamps & Extra Efficient Electronic Reduced Light Output Ballast	14	52	25	$67	$94	1.4	$27

[a] Incremental costs for extra efficient ballasts, see Section 7 of the main report above; for HPT8 lamps from PG&E's 2006 Efficacy Table, for High Efficiency Fixtures from Distributor Survey 5/2008: Bell Electrical Supply, Santa Clara and www.Grainger.com, 5/12/08.
[b] Calculated using the CEC's average statewide present value statewide energy rates that assume a 3% discount rate (CEC 2004).
[c] Total present value benefits divided by total present value costs.
[d] Positive value indicates a reduced total cost of ownership over the life of the appliance

D.5. Summary

Our analysis of 2x4 recessed fixtures suggests that there are certain high-volume fixture categories for which a wide range of available fixture efficiencies exist and for which setting a minimum LER standard seems reasonable without limiting manufacturers' compliance options or eliminating substantive product features. A fixture efficiency standard based on LER would be more complex to develop, but has the potential to provide flexibility to manufacturers and to drive positive transformation in the lamp, ballast and fixture markets. Collaboration with manufacturers to collect comprehensive data would ensure fixture types are appropriately differentiated under minimum LER requirements and levels are appropriately set.

Our evaluation of 2x4 three-lamp recessed louvered fixtures suggests savings potential around 11% with this approach, mainly from ballast improvements in three-lamp fixtures. Moving forward, we would collect more detailed incremental cost data and additional market share data for a wider range of high-volume fixture categories to more accurately model the energy savings and market impacts of requiring minimum LER.