Codes and Standards Enhancement Initiative
For PY2004: Title 20 Standards Development

Analysis of Standards Options for Metal Halide Lamps and Fixtures

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1 Introduction

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 metal halide (MH) lamps, ballasts and fixtures.

2 Product Description

Metal Halide Lamps

MH lamps were introduced in the 1960s. The lamps consist of a quartz or ceramic arc tube (or discharge tube) containing a starter gas, mercury, and metal halide salts. An outer envelope or bulb contains the arc tube, which operates at high temperature and pressure. The metal halide salts in the arc tube require a high voltage (higher than the voltage supplied by building electrical systems) to start the lamp. As a result, a ballast is required to supply the correct starting voltage and to regulate the starting and operating current. As the temperature and pressure within the lamp increase, the compounds in the arc tube vaporize to emit light. The glass outer envelope encapsulating the arc tube provides an inert atmosphere to prevent high temperature oxidation of the arc tube components and limits the amount of ultraviolet radiation emitted from the lamp.

MH lamps are available with either probe-start or pulse-start technology. Probe-start lamps are started when a discharge is created across the small gap between the starter electrode (or starting probe electrode) and one of two operating electrodes causing electrons to jump across the arc tube to the second operating electrode. A bi-metal switch removes the starting electrode from the circuit once the lamp is started.

Pulse-start MH lamps rely on a high-voltage ignitor in place of the starter electrode. The ignitor and ballast start the lamp through a series of high-voltage pulses. By eliminating the starting probe electrode, the seal area at the base of the arc tube is reduced in pulse-start lamps, and in turn heat loss is reduced. In addition, the ignitor heats the electrodes faster than the starter electrode, reducing the build up of tungsten that blackens the arc tube and reduces lamp performance in probe-start units.

Traditionally, probe-start lamps have been more common except for medium-base MH lamps, where pulse-start is used because of size limitations that will not accommodate the starter electrode required in probe-start lamps.

Ceramic MH lamps, which also utilize pulse-start technology, use ceramic rather than quartz arc tubes. Ceramic arc tubes can tolerate a higher temperature, resulting in improved color rendering and color temperature, and in some cases better efficacy. The improvements in color performance make ceramic MH particularly attractive in retail and other color-sensitive environments. Ceramic MH lamps use the same ballasts as pulse-start MH lamps.

Pulse-start MH lamps are available with rated lamp power ranging from 35W to 1000W. At this time, ceramic MH lamps of 39W to 400W are available (although the majority of lamps currently on the market are below 150W). This CASE report focuses on mid- to high-wattage MH lamps (i.e., probe-start lamps of 175W and higher and equivalent pulse-start lamps of 150W and higher).

In this size range, pulse-start technology yields a number of benefits relative to probe-start:

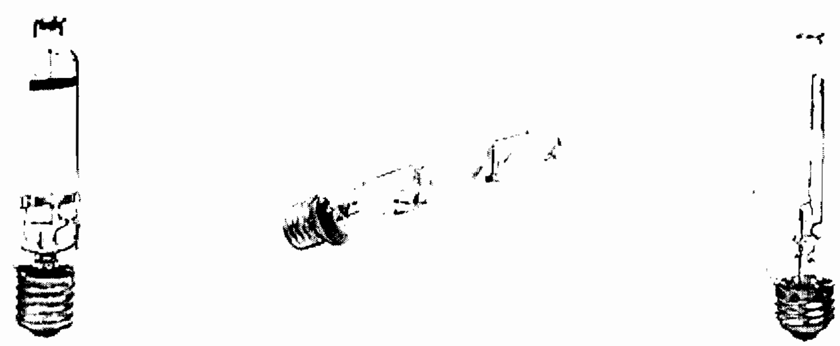
- *Higher efficacy.* Pulse-start MH lamps of 150W and higher have efficacies ranging from 51 to 96 lumens per watt (lpw), while the range for similar probe-start lamps is 37 to 97. In general, efficacy increases as wattage increases. When operated with electronic ballasts, even higher efficacy is possible—lamp input power can be reduced by 8% and ballast losses are reduced by as much as 50% (NLPIP 2003). Higher initial lumens from pulse-start lamps allow specifiers to use lower wattage lamps or to reduce the overall number of luminaires in the space.
- *Better lumen maintenance.* Pulse-start lamps have a reported mean lumen depreciation of 20% (at 40% of rated lamp life) compared to depreciation of 35% at 40% of life for probe-start lamps. At end of life, probe-start lamps can lose up to 45% of initial lumens. For pulse start, electronic ballasts can allow much improved lumen maintenance relative to magnetic ballasts.
- *Longer lamp life.* The rated life for most pulse-start MH lamps ranges from 15,000 to 25,000 hours. Typical design life for a 10-hour burn cycle is 20,000 hours for 300 to 450W lamps. Probe-start lamps typically have a rated life of 10,000 to 20,000 hours; 400W lamps have the highest rated life, while higher and lower wattage lamps have lower rated life. For both lamp types, lamp life is longest in the vertical base-up position.
- *Shorter warm-up and faster restrike times.* Pulse-start MH lamps have a warm-up time of 1 to 4 minutes and a restrike time of 2 to 8 minutes, both shorter than the times for probe-start—2 to 15 minutes and 5 to 20 minutes, respectively. Warm-up and restrike times are usually shorter with electronic than magnetic ballasts. It should be noted that ceramic MH lamps have a longer restrike time than other pulse-start MH lamps.
- *More consistent color temperature and less color shift.* All MH lamps experience color variations from lamp-to-lamp and over the life of an individual lamp. Manufacturers report less variation in correlated color temperature (CCT) among pulse-start MH lamps, which typically translates to fewer blue and pink tints, which can be very important in retail and other applications. In addition, pulse-start lamps maintain a more consistent CCT over their life with a typical color shift of less than 200K compared to the 600K shift common in probe-start MH lamps. Studies demonstrate that electronic ballasts can further reduce color shift.
- *Dimming capability.* Pulse-start MH lamps can be operated with electronic ballasts allowing for dimming down to 33% of full lamp output and the potential for greater energy savings. While probe-start and pulse-start lamps operating on magnetic ballasts can be dimmed, lamp dimming is usually limited to high and low settings;

furthermore the dimming is not linear (e.g., dimming to 50% of light levels requires 65% of maximum wattage). Dimming with electronic ballasts is much more linear, yielding greater energy savings.

- *Improved color rendering.* Ceramic MH lamps have a color rendering index (CRI) of up to 96, significantly better than the 65-70 CRI for probe-start and quartz pulse-start MH lamps. At these high levels, ceramic MH has better CRI than fluorescents, making it an excellent alternative for high end retail and other color-sensitive applications.

It should be noted that metal halide lamps come in three major configurations – lamps designed for vertical base up operation, lamps designed for horizontal operation, and "universal" position lamps (that can be operated in any orientation). Lamps designed for vertical and horizontal operation are optimized for these positions and have better efficacy than universal position lamps operating in these same positions. Pulse-start metal halide lamps are widely available for vertical operation, but availability of horizontal and universal pulse-start products is more limited at present, although several manufacturers report off-the-record that they are now developing fuller lines of pulse-start products.

Figure 1: Metal Halide Lamps



Probe-start MH lamp   Pulse-start MH lamp   Ceramic MH lamp

Ballasts for Metal Halide Lamps

A range of ballasts are available for use with MH lamps. Probe-start MH lamps typically use magnetic ballasts; the most common for lamps of 175W and higher is the constant-wattage autotransformer (CWA). Other types of probe-start ballast are high-reactance autotransformer (HX-HPF) and constant-wattage isolated transformer (CWI). CWA ballasts (also known as lead ballasts) provide good power regulation yielding a high power factor (0.90) and the ability to handle supply voltage variations of 10% and higher. On the downside, CWA ballasts are heavier, larger, and more expensive than HX-HPF ballasts; and their higher current crest factor negatively affects lamp lumen depreciation and lamp life. Compared to CWA ballasts, HX-HPF ballasts have a lower current crest factor, but cannot handle supply voltage variations greater than 5%. CWI ballasts use a design similar to CWA ballasts, but are larger and less efficient than most CWA styles. CWI ballasts are very common in Canada, but less popular in the U.S. market.

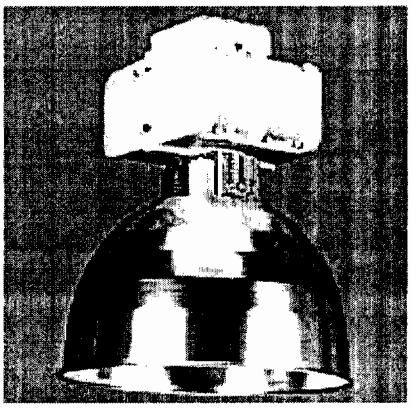
Both magnetic and electronic ballasts are available for pulse-start MH lamps, however electronic ballasts currently account for only an estimated 2% of of pulse-start ballasts. Magnetic pulse-start ballast systems include super constant-wattage autotransformer (SCWA), linear reactor, and regulated lag. SCWA are lead-style ballasts for pulse-start lamps, comparable to the CWA ballasts common in probe-start systems. Like CWA ballasts, SCWA technology offers good power regulation with modest ballast losses, handling voltage variations of up to 45%. These ballasts may also extend lamp life, improve lumen maintenance, and reduce ballast losses by 5-10 watts relative to CWA ballasts. Linear reactors (or "reactor" ballasts) are lag-style ballasts, offering improved lamp performance and life relative to SCWA but less power regulation. Reactor ballasts are only available in 277 volts and are suited for areas with very little variation in line voltage. Compared to CWA ballasts, reactor ballasts can reduce power input by 35 watts, however their sensitivity to power quality and specific voltage requirements limit their applicability. Regulated lag ballasts have the most sophisticated design of the magnetic pulse-start ballasts providing good power regulation as well as strong performance in terms of lamp life and lumen maintenance. Drawbacks of this design are a large physical size, lower efficiency, and higher cost compared to SCWA and linear reactor ballasts.

Electronic ballasts for MH lamps offer several advantages over magnetic ballasts, but their high cost and limited availability has limited their use. Benefits of electronic ballasts include reduced size, higher power factor, reduced ballasts losses (greater efficiency), cooler operation, improved lumen maintenance, better color stability, longer lamp life, and improved dimming capability. Although electronic ballasts currently account for a tiny fraction of pulse-start ballasts, recent developments bode well for further adoption of electronic ballast systems. For example, GE has extended the warranty on its MH lamps to include products operated with certain electronic ballasts. Furthermore, several manufacturers have announced their intention to introduce lower-cost, non-dimming electronic ballasts with a much lower price premium over magnetic ballasts as compared to dimming electronic ballasts available to date. Lamp manufacturers are also introducing pulse-start lamps optimized for use with electronic ballasts. In our discussions with manufacturers, it became apparent that most current MH research and development is focused on pulse-start lamps (including ceramic MH lamps) and electronic ballasts. Improvements in these systems are needed to help MH better compete with the latest T5 and high-output T8 lighting systems.

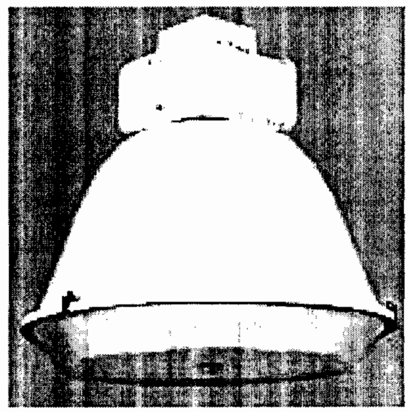
Fixtures for Metal Halide (and other HID) Lamps

Metal halide and other HID lamps are used in a variety of fixtures including recessed fixtures (particularly for lamps of less than 150 Watts), wall-mounted fixtures (often called "Wall-paks"), streetlights and pole-mounted fixtures, sports-lighting luminaires, and interior industrial-type fixtures. These latter fixtures are particularly common in such applications as warehouses, manufacturing, malls and "big box" retail, and gymnasiums. Industrial-type fixtures generally come in *high-bay* and *low-bay* types, where high-bay fixtures are designed for installation 20-25 feet or more above floor level and low-bay for lower mounting heights. Low-bay fixtures generally have special drop lenses to distribute light over a wider distribution angle, a consideration that is much less important for high-bay fixtures due to their higher mounting height. High-bay fixtures are generally made out of spun-aluminum but products are also available with more reflective surfaces or with prismatic outer shells. Conventional spun aluminum high-bay fixtures typically have a *luminaire efficiency* of about 75%, meaning about 75% of the light from the lamp exits the fixture and the remaining 25% becomes trapped in the fixture and ultimately converted from light to heat. Fixtures with more reflective surfaces or prismatic fixtures (whose outer shell is transparent or translucent, permitting some light to escape upwards to illuminate the ceiling) typically have efficiencies of 90% or more. Clear and translucent fixtures partially illuminate the ceiling, reducing the "cave effect" (making a room look like a cave), reduce glare, and improve contrast ratios.

Figure 2: Typical high-bay and low-bay MH fixtures



High-bay: Open die-cast aluminum



Low-bay: Enclosed die-cast aluminum

3 Market Status

3.1 Market Penetration

The 2002 U.S. Lighting Market Characterization (DOE 2002) estimates that there are a total of 34.8 million MH lamps operating in commercial, industrial, and outdoor stationary applications, accounting for 33% of the installed base of high intensity discharge (HID) luminaires. This translates into an existing stock of 3.1 million MH lamps in operation in California since the state accounts for about 9% of the U.S. commercial building floor area (CEC 2003, EIA 2002). MH lamps are the most common HID source in the commercial and industrial sectors, accounting for 63% and 71% of installed luminaires, respectively. MH lamps make up a smaller portion of outdoor stationary HID, accounting for only 9% of the installed HID base which is predominately high pressure sodium (67%). Mercury vapor makes up the remaining 24%, but its overall market share has been declining steadily since 1990. The 1999 Commercial Buildings Energy Consumption Survey (EIA 1999) reports that 24% of the lit commercial building floor space in the 13 states of the West Census Region includes some use of HID lighting, lower than HID use in other regions.[1]

3.2 Sales Volume

According to the National Electrical Manufacturers Association (NEMA), annual U.S. shipments of MH lamps totaled 18.6 million in 2001 and 19.2 million in 2002 (DOE 2003). If California also accounts for 9% of U.S. MH lamp sales, California sales totaled 1.67 million MH lamps in 2001 and 1.73 million MH lamps in 2002 (U.S. Census Bureau 2002). Shipments of MH lamps have increased every year since 1992. In contrast, shipments of high pressure sodium lamps have leveled off since the late 1990s and shipments of mercury vapor have steadily declined since the early 1990s.

HID fixture sales in 2000 and 2001, as compiled by the U.S. Census Bureau, total 12.6 million and 11.7 million, respectively. These numbers include fixtures used for all HID sources and not just MH. Sales are greater in 2000 than in 2001 due primarily to the recession that took hold in 2001. As noted in the paragraph above, California accounts for about 9% of U.S. fixture sales or roughly 1.1 million HID fixtures sold in 2001 including approximately 363,000 MH fixtures.

Good data on the relative proportion of high-bay versus low-bay fixtures are not available, but based on discussions with several lighting distributors, of industrial-type fixtures, 90% are high-bay and 10% low-bay. Low-bay sales have declined in recent years due to the growing popularity of high-output fluorescent lighting systems for low-bay applications.

3.3 Market Penetration of High Efficiency Options

Improved MH technology has been introduced over the past decade and continued improvements are anticipated. As a result, pulse-start MH lamps can compete directly as a replacement for probe-start MH, high pressure sodium and mercury vapor. These improvements include more widespread availability of pulse-start lamps and the introduction of electronic ballasts. While high performance in horizontal and vertical base down positions continues to present some challenges, manufacturers are addressing these issues and continue to make progress in correcting performance deficits. Pulse-start MH lamps are manufactured by EYE, General Electric, OSRAM Sylvania, Philips Lighting, Venture Lighting, and others. Ballasts for pulse-start MH lamps are manufactured by Advance Transformer (electronic and magnetic), Delta Power Supply (electronic), General Electric (electronic and magnetic), Holophane (electronic), Metrolight (electronic), Universal Ballast (magnetic), and Venture Lighting (magnetic); others are developing electronic ballasts.

[1] Low pressure sodium (LPS) lamps do not meet the definition of HID lamps developed by DOE based on existing definitions used by the American National Standards Institute and the Illuminating Engineering Society of North America. Although the lighting industry often classifies LPS lamps along with HID sources due to their common construction, application, and operation, for our purposes LPS is not included here.

According to one major lamp manufacturer (Nelson 2003), the vast majority of new construction and large-scale renovation incorporates pulse-start MH technology; however penetration rates remain much lower in the retrofit market. Standard fixture replacements and smaller-scale retrofits continue to utilize probe-start MH systems as evidenced by the continued dominance of probe-start lamps noted in the previous section. One fixture manufacturer reports that 29% of their high- and low-bay fixtures sold in California incorporate pulse-start ballasts; another reports that nationwide 25% of their fixture sales ship with pulse-start ballasts, but notes that sales of pulse-start fixtures are probably higher in California. Another lamp manufacturer reports that overall 80% of their shipments of MH lamps over 150W are probe-start, the remaining 20% are pulse-start. Several issues influence the adoption of pulse-start MH in retrofit applications. First, MH faces competition from other lighting technologies. In many retrofits, building owners interested in investing in new technology are replacing their HID systems with high-output T5 fluorescent lighting, T8 fluorescents, CFLs, and induction lighting rather than upgrading to pulse-start MH. These technologies have advantages over MH in applications where occupancy sensors can yield substantial savings. Even with electronic ballasting, the restrike time for pulse-start MH is too long to allow occupancy sensors to completely turn the MH lamp and ballast off. In contrast, fluorescent and induction lighting have instant-on capability allowing sensors to completely turn lights off in unoccupied spaces, saving additional electricity.

Current limitations of pulse-start MH in horizontal burning positions present an additional challenge. At this time, most existing pulse-start MH lamps are designated for the vertical, base up burning position—the typical burning position for common high-bay type applications. Most shoebox, wallpack, and pole-mounted shoebox fixtures require horizontal mounted lamps. Manufacturers have somewhat limited offerings of horizontal or universal position lamps; but offerings are increasing and one manufacturer has a fairly comprehensive line. Horizontal pulse-start MH lamps available today typically have a 5,000 hour shorter life than vertical lamps, making them less attractive in hard-to-reach applications. However, the manufacturers are addressing this issue and at least one anticipates that horizontal lamps with the same rated life as vertical lamps will be available in the next one to two years. In addition, recent experience shows that dimming of pulse-start MH lamps can extend lamp life substantially.

In terms of ballasts, experts estimate that about 2% of pulse-start ballasts are electronic. As for fixtures, data on fixture sales by efficiency level are not compiled. However, it is estimated that 20-25% of current high-bay fixture sales have a luminaire efficiency of 85% or more.

4 Savings Potential

4.1 Baseline Energy Use

Baseline energy consumption varies with the specific lamp/ballast/fixture combination and the application. Table 1 summarizes energy use for an average "base case" probe-start MH lamp. The average installed system wattage and operating hours are based on weighted averages for commercial, industrial, and outdoor stationary applications.[2]

Table 1: Typical MH Energy Use Estimate

Typical MH lamp	400 watts
Typical system wattage	460 watts
Typical operating hours	12 hours/day
Annual energy use	2,015 kWh
Typical cost	$0.12
Annual electricity cost	$242

Source: DOE 2002; EIA 2003

The installed base of MH lamps consumes an estimated 41% of national HID lighting electricity or 53 TWh per year (DOE 2002). In California, this amounts to about 6 TWh per year.

4.2 Proposed Test Method

A widely used test method for MH and other HID lamps is LM-51-00 published by the Illuminating Engineering Society of North America (IESNA). This standard is titled *Electrical and Photometic Measurements of High Intensity Discharge Lamps*. It is regularly updated, with most recent version published in 2000. The American National Standards Institute (ANSI) publishes a test method for ballasts, ANSI C82.6-1985 (R1996) *Ballasts for High Intensity Discharge Lamps – Method of Measurement*. This document was last revised in 1996 and another revision is pending. Under the standards proposed in Section 4, only this latter test method needs to be referenced in the CEC regulations.

4.3 Efficiency Measures

The efficiency of mid- to high-wattage MH lamp systems can be increased with the use of pulse-start lamp technology with magnetic pulse-start ballasts. As noted above, pulse-start MH lamps of 150W and higher offer improved efficacy relative to probe-start lamps (51 to 96 lpw vs. 37 to 97 lpw), although the differences in efficiency narrow substantially in higher wattage lamps (e.g. greater than 500W). The most common magnetic ballast, the constant-wattage autotransformer (CWA) ballast, runs on different voltages but is less efficient than some other ballast types. In applications with a single line voltage and good power quality, dedicated 277 voltage linear reactor ballasts can

[2] According to data in the *U.S. Lighting Market Characterization* (DOE 2002), the weighted average system wattage for MH is 437W. For this analysis, the closest sized typical MH system was selected (i.e., 400W lamp with magnetic ballast). It is also worth noting that with MH lamps, as the lamps age, resistance goes up and system wattage also goes up. With a brand new lamp, the wattage may be 450 and with a very old lamp, the wattage could be 470.

reduce power consumption by 10W to 15W per fixture. Additional energy savings can be realized through the use of electronic ballasts and improved fixtures. Electronic ballasts can reduce lamp input power by 8% and ballast losses by up to 50% (NLPIP 2003). Installation of better fixtures also saves energy; for example it is possible to save wattage through elimination of spun-aluminum fixtures (about 75% luminaire efficiency) in favor of fixtures with 85% luminaire efficiency or higher. These latter fixtures permit use of lower wattage lamps while maintaining desired light levels.

4.4 Standards Options

Pulse-start MH lamps are manufactured by all of the leading lamp manufacturers as well as some smaller manufacturers. This technology is becoming more widely available and enjoys an increasing market share. Pulse-start lamps with magnetic pulse-start ballasts represent a sensible and achievable near-term level for minimum efficiency standards for vertical-position MH lamps. Rapid progress is also being made to increase the number of horizontal and universal position pulse-start lamps and to increase the number and availability of quality moderate-cost electronic ballasts for pulse start lamps. Therefore, standards are also achievable for these products, but with a few extra years provided before standards take effect in order to provide manufacturers adequate time to prepare. Although higher efficiency fixtures offer additional energy savings, a number of technical issues make establishment of a fixture standard unadvisable at this time.

When setting standards, we recommend that they apply to 150-500 Watt metal halide lamps. This size range accounts for a significant majority of the MH lamp sold each year. Furthermore, above 500 Watts efficiency differences are much smaller between pulse- and probe-start lamps and energy savings will be very limited. Virtually all MH lamps below 150 Watts are already pulse-start. .

Two options are available for setting standards for 150-500 Watt products. First, standards can be set on lamps and ballasts, permitting only passing products to be sold. Such standards would result in more immediate energy savings since existing probe-start products will generally have to be replaced with pulse-start products as they burn out. However, such a standard will require facility managers to replace ballasts (and sometimes even fixtures) when lamps burn-out. While such change-outs are generally cost-effective, they represent significant capital costs to facilities. In addition, mixing probe-start and pulse-start lamps within a space could result in uneven lighting (due to differences in lamp lumens, lamp lumen depreciation, and color shifts over time) and makes facility management more challenging, as many lamp replacements are no longer simple. Also, pulse-start lamps sometimes require a new socket and that socket can be much more difficult to install than the new ballast.

Second, efficiency standards can be applied to new fixtures, so that lamps, ballasts and fixtures can all be changed at the same time. Such a standard is lower-cost and easier for facilities to manage. The disadvantage is that savings will be achieved over a longer period of time, since it will be roughly 20 years before most existing fixtures will have to be replaced. However, some fixtures would be replaced within 5 or 10 years due to new construction and gut rehabs. Overall, the ease of implementation for a fixture-based standard is compelling and therefore we propose that California take this route.

In particular, we propose a two-tiered standard that would take effect in two stages. The initial standard would apply only to fixtures designed and sold for use with vertical-burning position MH lamps. Two years later, the second stage of the standard would take effect, adding fixtures for horizontal and universal lamps. In addition, the proposed second tier of the standard would require electronic ballasts (or equivalent efficiency) for interior fixtures using lamps in the 150 to 500 W range. We limit this proposed standard to a maximum of 500 W because the volume of ballast sales over 500 W is relatively small, the ballasts would be considerably more expensive, and the efficiency differences between pulse- and probe-start lamps are smaller at these higher wattages. Similarly, electronic (or equivalent efficiency) ballasts are not required for fixtures operating at 480V due to technical challenges and high cost. Electronic ballasts are not recommended for exterior fixtures located in direct-sunlight in hot regions of the state at this time due to the negative impact of excessive temperatures on ballast life. Direct sunlight on hot days can result in temperatures in the ballast case above 50 degrees C. Therefore, we propose to exclude from the second-tier standard luminares rated for use in wet locations (as defined in the National Electrical Code) that contain ballasts rated for operation above 50 degrees C. We focus on wet location ratings as a proxy for outdoor fixtures, since "outdoor" is difficult to define and most outdoor fixtures are rated for wet locations. Quite a few (but far from all) pulse-start magnetic ballasts are rated for use above 50 C. Presently, only a few electronic ballasts are rated at 50 C, but based on discussions with manufacturers, we expect that many more electronic ballasts will be introduced in the next few years that operate at temperatures above 50 C.[3]

4.5 Energy Savings

Table 2 provides savings estimates per lamp relative to the base case probe-start MH lamp with magnetic ballast as described in Table 1. A pulse-start MH lamp of the same wattage as the base case and operated by a magnetic ballast will provide additional light, but energy savings are negligible. Substituting a lower wattage pulse-start lamp (e.g., 350W for 400W) will maintain roughly the same light level, lower power input by 70W and reduce energy consumption by approximately 300 kWh or 15%. Replacing the magnetic ballast with an electronic ballast will lower power input relative to the base case by 120W and increase energy savings to approximately 525 kWh or 26%.

Using the data from Table 2 on savings per lamp, combined with information on lamp and fixture sales, lamp and fixture life and current market share of pulse-start lamps and electronic ballasts, savings can be estimated on a statewide basis. Savings from the first year of the standard (Tier 1) are estimated at 58 GWh. First year savings for Tier 2 are

[3] Examples of current electronic ballasts rated for high temperature operation are the Advance Dynavision and the Metrolight eHID ballast lines.

larger, an estimated 76 GWh.[4] Estimated savings once the entire stock of MH fixtures has turned over are provided in Table 3.

Table 2: Savings Estimates for Efficient MH Options

Pulse-start MH lamp w/magnetic ballast	
Lamp wattage	350 watts
System watts	390 watts
Annual electricity use	1,708 kWh
Annual electricity savings vs. base case	307 kWh
Annual energy cost savings vs. base case	$37
Coincident peak savings	61.6 Watts
Pulse-start MH lamp w/electronic ballast	
Lamp wattage	320 watts
System watts	340 watts
Annual electricity use	1,489 kWh
Annual electricity savings vs. base case	526 kWh
Annual energy cost savings vs. base case	$63
Coincident peak savings	105.6 Watts

Notes: Assumes operation 12 hrs/day (DOE 2002), electricity cost $0.12/kWh (EIA 2003), and coincident peak factor of 0.88 (average of Warehouse and Assembly Industrial categories from PG&E 2000).

Table 3. Estimated Statewide Savings for Proposed Standards

Standard	Per Unit Annual Savings			Statewide Savings When Stock Turns Over	
	KWh	Coincident Watts	Percent	GWh	MW
Pulse-start, magnetic ballasts	307	61.6	15%	827	166
Additional savings with electronic ballasts	219	44.0	11%	557	112
TOTAL	526	105.6	26%	1,384	278

Notes: Based on 2002 lamp sales and 2000 fixture sales in California and data in Tables 1 and 2. Assumes existing lamps have a 3-year life (~15,000 hours) and that 65% of MH lamps sold are 150-500 Watt. Assumes that fixtures have an average 20-year life (Skumatz and Hickman 1994). Does not include savings from the ~20% of lamp sales that are now pulse-start and the ~2% of ballast sales that are now electronic. Does not include gradual growth in MH lamp and HID fixture sales.

[4] First year savings for Tier 1 are based on 2001 fixture sales and assumption that 65% of MH fixture sales are for 150-500W lamps with vertical lamp positions. First year savings for Tier 2 are based on 2001 fixture sales and an estimate that 60% of MH fixture sales are interior fixtures from 150-500 W.

5 Economic Analysis

5.1 Incremental Cost

Pulse-start MH lamps and ballasts are moderately more expensive than probe-start systems, although the price has dropped considerably in recent years. Typical incremental costs for 400W pulse-start MH lamps and ballasts are approaching 15% relative to probe-start. This translates to less than $5 per lamp and $15 per magnetic ballast in many applications (Nelson 2003). Until recently, electronic ballasts have had a higher cost premium, with incremental costs of approximately $60 to as high as $150. However, several major manufacturers have indicated that they will be introducing new electronic ballasts and the competition between manufacturers is likely to drive prices down. For example, a product due out in the fourth quarter of 2004 from a major manufacturer will be priced at about $70, which is only about $30 more than a typical pulse-start magnetic ballast.

5.2 Design Life

The rated lamp life for pulse-start MH lamps typically ranges from 15,000 to 25,000 hours. MH ballasts have a longer life, generally around 60,000 hours. Ten hours is the daily burn time used in the test procedure. This is for a typical application; ballast life is also affected by temperature, with high temperatures reducing ballast life. For this analysis, we have assumed a lamp design life of 20,000 hours or 4.5 years with an average burn time of 12 hours per day. In most applications, typical burn time is 12 hours per day. Using these same assumptions, a 60,000-hour ballast will have a life of 13.5 years. As noted above, the typical fixture will have a life of 20 years but to make the calculations much easier, we use even multiples of lamp and ballast life and thus assume an average fixture life of only 13.5 years.

5.3 Life Cycle Cost

Table 4 summarizes projected life cycle cost savings from pulse-start MH for magnetic and electronic ballasts and also for high-efficiency industrial-type high-bay fixtures.

Table 4: Projected Pulse-Start MH Life Cycle Savings

Option	Fixture Life (years)	Energy Savings (kWh/year)	Incremental Cost	Net Present Value Savings
Pulse-start w/magnetic ballast	13.5	307	$ 30	$247
Increment for electronic ballast	13.5	219	30	168
All of the above	13.5	526	$ 60	$415

Notes: Analysis covers 13.5 years including one ballast, initial lamp, and two replacement lamps after 4.5 and 9 years (to be conservative, we ignore the fact that most pulse-start lamps have about a 3-year life and will need to be replaced 1.5 extra times during this analysis period). Incremental costs based on information in Section 5.1.

6 Acceptance Issues

6.1 Infrastructure Issues

Pulse-start MH is capturing a significant and growing share of the MH market in new construction and major renovations, but relatively little uptake in the retrofit market. The technology is competing with high-output fluorescent systems in both new construction and retrofit. One issue that may pose a hurdle to pulse-start technology in the near-term is limited availability of lamps suitable for horizontal and universal burning positions. At this time, three out of four major manufacturers have horizontal pulse-start MH lamps of 320W and in the 680W to 750W range. As noted above, one manufacturer has a much more comprehensive line and anticipates that remaining problems with reduced life in horizontal lamps will be resolved in the next one to two years. A standard for pulse-start MH could first focus on vertical position lamps and incorporate a two-year lag in the effective date for horizontal and universal lamps in order to allow sufficient time for multiple manufacturers to introduce a full line of products.

Similarly, as noted above, many major ballast manufacturers are just now introducing full-lines of electronic pulse-start ballasts. In order to permit manufacturers to bring a full line of these ballasts to market, two additional years would be useful before a standard took effect.

Finally, one other issue we researched is how electronic ballasts might work in pole-mounted luminaries in which the ballast is located in the base. First, many of these luminaires will be exempted since they are rated for wet locations and often contain ballasts rated for high-temperature operation. Second, some electronic ballasts can operate at distances of up to 50 feet from the lamp. Third, for other remote-ballast applications, a modest-cost remote starter can be used to start lamps. Thus, we conclude that this issue will not present an obstacle to our proposed standard.

6.2 Existing Standards

Although the U.S. Department of Energy (DOE) identifies HID lamps (including mercury vapor, high-pressure sodium, and MH) as a product class for which standards could be developed, it has not set minimum efficiency standards for this class of products. On June 20, 2003, DOE released the *Draft Framework for Determination Analysis of Energy Conservation Standards for High Intensity Discharge Lamps* for public comment. This framework document presents the framework for DOE's planned analysis of standards for HID lamps. Comments on the framework were due on September 5, 2003. DOE anticipates completion of its determination analysis by the end of 2004 and completion of a possible rulemaking by 2008 resulting in an effective standard date of 2011. According to the draft framework, DOE is considering a standard that would effectively phase-out mercury vapor lamps by establishing a minimum efficacy for HID lamps that exceeds that achievable with mercury vapor technology. The DOE document does not propose to consider a standard that would impact MH lamps.

DOE also has a standard that essentially requires use of electronic ballasts in new fluorescent fixtures as of 2005. This standard applies to replacement ballasts for use in existing fixtures as of 2010. This standard does not cover other types of ballasts or fixtures, including MH and other HID ballasts.

7 Recommendations

Based on our analysis, a standard for mid- to high-wattage metal halide systems is warranted based on the cost-effective energy savings achievable. Standards requiring electronic ballasts are also cost-effective and achievable and are therefore also recommended. As discussed above, the preferred path is to apply such a standard to new mid- to high-wattage metal halide luminaires. The initial standard would apply to fixtures designed and sold for use of vertical burning position metal halide lamps. After a two year lag, horizontal and universal lamps would be phased into the standard and the standard upgraded to require use of electronic (or equivalent efficiency) ballasts in appropriate applications (i.e., 150 to 500 W lamps).

In order to develop a specific proposed standard level for pulse-start MH lamp/ballast systems, we assembled a database with information on more than 50 pulse-start MH ballasts (magnetic and electronic) designed for operation with 150 to 500W pulse-start MH lamps. For each ballast type, we plotted system efficiency versus lamp Watts and developed a best-fit line for all of the electronic ballasts. We then reduced the elevation (maintaining a constant slope) on this line until we had an equation that differentiated between most of the electronic and magnetic ballasts (see Figure 3).

Figure 3. Pulse-Start MH Ballasts on the Market and Possible Standards

We recommend that this equation be used to establish standards for interior luminaires for pulse-start lamps between 150 and 500W effective January 1, 2008. The specific equation is: Minimum system efficiency = (0.0002 * Lamp Watts) + 0.864.

Specifically, we recommend that the following provision be added to Section 1605.3 of the current CEC Appliance Efficiency Regulations:

*(n)**Luminaires for Metal Halide Lamps.***

Energy Efficiency Standard for Luminaires for Metal Halide Lamps. *Luminaires sold in the state on or after the applicable dates shown in Table N shall meet the requirements shown in Table N.*

Table N

Lamp Position	*Included Lamp Wattages*	*Effective Date*	*Requirements*
Vertical	*150-500*	*Jan. 1, 2006*	*Luminaires shall not contain a probe-start metal halide ballast*
All	*150-500*	*Jan. 1, 2008*	*Luminaires (except "exempted outdoor luminaires and luminaires operating at 480V) shall contain a metal halide ballast with minimum lamp/ballast system efficiency = (0.0002 * Lamp Watts) + 0.864*
All	*150-500 that are not subject to the row above*	*Jan. 1, 2008*	*Luminaires shall not contain a probe-start metal halide ballast*

Notes: Fixtures are covered if they are capable of operating lamps that fall within the range of included lamp wattages. Vertical includes both base-up and base-down products. Vertical includes products rated for use within 15° of vertical.

For this recommended standard, the following terms need to be defined in Section 1602 (n):

Ballast – A device used with an electric discharge lamp to obtain necessary circuit conditions (voltage, current and waveform) for starting and operating. [from 2000 IES Lighting Handbook Glossary]

Exempted outdoor luminaire – a luminaire certified by the manufacturer as meeting both of the following criteria: (1) rated for use in wet locations as required by the National Electrical Code, Section 410.4(A);[5] *and (2) containing a ballast that is rated to operate at ambient air temperatures above 50 degrees C.*

[5] This is reference in the 2002 NEC. The 2005 NEC will be published in September 2004 and the citation (and possibly the definition) will be updated at this time.

High-intensity discharge (HID) lamp – An electric-discharge lamp in which the light-producing arc is stabilized by bulb wall temperature, and the arc tube has a bulb wall loading in excess of 3 W/cm^2. HID lamps include groups of lamps known as mercury, metal halide, and high-pressure sodium. [from IES Handbook Glossary]

Lamp-ballast system efficiency: The efficiency of a lamp and ballast combination expressed as a percentage and calculated by dividing the output circuit lamp power by the input circuit power as measured in accordance with ANSI C82.6-1985 (American National Standard for Reference Ballasts for Metal Halide Lamps - Methods of Measurement). [based on discussions with manufacturers and review of ANSI standard; please note that the ANSI standard was last changed in 1985 but was reaffirmed by ANSI in 1996]

Metal halide lamp – A high-intensity discharge lamp in which the major portion of the light is produced by radiation of metal halides and their products of dissociation, possibly in combination with metallic vapors such as mercury. Includes clear and phosphor-coated lamps. [from 2000 IES Handbook Glossary]

Probe-start metal halide ballast – a ballast used to operate metal halide lamps which does not contain an ignitor and which instead starts lamps by using open circuit voltage and a third starting electrode ("probe") in the arc tube. [definition suggested by lighting experts]

Wet location fixture – fixtures specified for indoor or outdoor locations that experience dry, damp or wet locations. If the environment exposes the lighting system to moisture condensation, then the location is a damp location. If the lighting system is exposed to direct impact by water, which will make the fixture wet, then the location is a wet location. Wet locations include fixtures installed in concrete that is in direct contact with the earth. [from Lightsearch.com, based on NEC; definition will be revised when the 2005 NEC is published in September 2004.]

In addition, we recommend that the CEC and the state's utilities undertake an education program for purchasers, distributors and installers of metal halide fixtures advising them of the higher light output from pulse-start lamps and therefore that lower wattage pulse start lamps are needed to achieve the same light output.

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