Advance response to CEC proposed rulemaking for ballast efficiency and alternate proposal. February 6, 2006

Summary
Advance re-iterates its position that the reliance on ballast efficiency as a means of saving energy with metal halide luminaries is misguided and will result in disruption of the marketplace that will adversely affect the citizens and luminaire manufacturers of California. Advance takes the position that the true measure of energy efficiency that should be specified is "System Efficacy" and that ballast efficiency is an indirect measure of this at best. Advance points out that "lamp efficacy" represent more economical means of increasing "system efficacy". In addition, Advance maintains that specifying ballast efficiency alone will compromise developments in other means to achieve high system efficacy. Advance further takes the position that by basing their assumed energy savings on system efficacy while specifying ballast efficiency, proponents of the ballast efficiency are overstating the energy savings that can be expected. Finally, Advance proposes a standard based on "System Efficacy" that is better able to realize the energy savings sought by the California Energy Commission while allowing proven technologies and development of alternative energy savings means.

<u>Background</u>
In their background paper justifying rulemaking for metal halide luminaire energy efficiency regulations PG&E experts identify three potential areas for energy improvement

- Luminaire efficiency
- Lamp efficacy
- Ballast efficiency.

<u>LUMINAIRES</u>
Luminaire efficiency is stated as currently existing in a range of 75% - 90%, representing a potential energy savings of 20% if luminaries with 75% efficiency are replaced with luminaries with 90% efficiency. A review with the Luminaire section concerning possibly including luminaire efficiency brings Advance to the same conclusion as PG&E, namely that luminaire efficiency is complicated too much by the multiple types of luminares to consider for legislation.

<u>LAMPS</u>
A survey of the websites of the four major lamp manufacturers indicates that pulse start metal halide lamps can have the following efficacy ranges for lamps rated for "open luminaries" (only lamps rated for open luminares were surveyed as they can be used in the most efficient luminares).

Power	Mean Lumen range	% improvement possible
150W	8250 – 11,000	33%
250W	16,000 – 19,200	20%
320W	19,000 – 25,000	31.5%
350W	21,700 – 29,500	36%
400W	23,400 – 33,000	41%

The ranges of lamp efficacy for a given power level are so wide, it can be seen that **energy efficiency improvement levels of as much as 20% – 40% are possible through change of lamp type alone**.

Comparisons of lamp prices, is a little difficult to document given the myriad of types available, but some conclusions can be drawn At the 400W level availability was found for 31,000 to 33,000 lumen types at prices in the $25 - $40 range, while the lowest price observed for any 400W pulse start lamp was found to be $10 (distributors "bulbs.com" and "buisinesslights.com"). This indicates that a premium of $30 could be expected to improve from the lowest efficacy to the highest at the 400W level (costs of 400W metal halide lamps were seen as high as $90+ however for premium lamps).

Given that **in the case of lamps a $30 increase in product cost could potentially result in a 40% increase in energy efficiency**, lamp performance represents a very cost effective means to save energy.

Much has been said about the difficulty in verifying "mean lumens" for lamps and Advance does not argue otherwise. It is **"rated mean lumens"** however that **determines application of lamps and is**, arguably, **the basis for the majority of PG&E's energy savings claims** for their ballast efficiency proposal and Advance proposes that "rated mean lumens" be considered as a criteria for efficiency requirements..

<u>BALLASTS</u>

The PG&E report claims an 11% energy savings to be expected by changing from an electromagnetic ballast to an electronic ballast in a system with a 400W baseline. This 11% energy savings includes a decrease in lamp power of 30 watts (of the 44watts saved). One can see that what the PG&E study ASSUMES is that "SYSTEM EFFICACY" will improve without actually specifying it. If one removes the 30W lamp power savings, the electronic ballast energy savings drops to **3.5%!!!** This is in line with NEMA and Advance estimates. **The argument that high efficiency ballasts always results in increased mean lumens is simply NOT TRUE.** Some high efficiency ballasts can actually DECREASE mean lumens according to tests done at Philips.

The following represents potential energy savings from ballasts using both "NEMA" data (which Advance considers the more reliable of the two) and PG&E data (which Advance considers "optimistic").

Power	NEMA data	% improvement possible
150W	.773 - .888	15%
250W	.833 - .899	8%
320W	.865 - .925	7%
350W	.864 - .931	8%
400W	.864 - .926	7%

Power	PG&A data	% improvement possible
150W	.77 - .92	20%
250W	.83 - .98	18%
320W	.87 - .94	8%
350W	.87 - .97	11.5%
400W	.86 - .98	14%

From this data it can be seen that potential energy savings from ballast efficiency is much lower than what can be achieved from lamp efficacy. **The potential for energy savings from lamp efficacy is arguably twice that of the potential for energy savings from ballast efficiency**. This is consistent with the PG&E study that shows a 7.5% energy savings from lamp efficacy versus only 3,5% energy savings from the use of an electronic ballast in their justification for legislation.

The PG&E study claims only a $30 premium for an electronic ballast based on their contention that a $70 electronic ballast will be available in the 4th quarter of 2004. Advance **strongly disputes** this claim. Advance contends that the cost premium is approximately $100 at the 400W level where a majority of potential energy savings is to be found. Advance supports this contention in two ways. First, the only **"published"** comparison of electronic ballasted luminaire cost compared to conventionally ballasted luminaire cost that was found in the course of investigation for this paper was a LCA (Lighting Controls Association) study from November 2004 (High/Low-Bay Applications: Fluorescent of Metal Halide?, by Craig DiLouie) that cites Acuity Lighting information indicating a **$174 premium for an electronically ballasted luminaire.** Second, statements made by Acuity Lighting in the course of debate concerning the Cec proposed legislation indicates that there are **currently no viable sources for 400W electronic ballasts** let alone a low cost $70 product.

Based on this Advance respectfully requests that the CEC uses what Advance feels represents a conservative, even optimistic, estimate of a $100 premium for electronic ballasts when evaluating the cost/benefit relationships for ballast efficiency standards.

<u>Photopic versus Scotopic – further energy savings potential?</u>

One objection that Advance has with only legislating ballast efficiency is that it limits "overall" technical advancement of high efficiency HID systems. A case in point is **Ceramic Metal Halide (CMH)**. CMH is one of the latest advancements in high efficiency HID promising (and delivering) the same type of energy improvements (and more) over "pulse start" that "pulse start" did over "probe start". In the "Advance" survey of available lamp efficacy it was found that **CMH** had a **5.6% higher efficacy**, on average, than quartz metal halide at the 400W level. In addition CMH lamps have **superior CRI**, generally 88-94, compared to 65-70 for "standard" quartz lamps, making them an attractive **high performance** solution for many retail applications. In addition, CMH lamps "score" very well in the "scotopic/photopic" relativity index that some studies (by Sam Berman affiliated with Lawrence Berkely Laboratories and others) suggest can allow even lower levels of "photopic" (the standard "lumens" measurement) illumination. Stan Walerczyk (author of the PG&E study) in his paper "Hibays It's All About The Details" Mr. Walerczyk credits a **7.5% improvement in "task modified lumens"** for CMH's s/p ratio compared with standard pulse start metal halide. Combined with the higher average photopic efficacy (on average at 400W) this can result in as much as a **13.5% higher "task lumens per watt"** for CMH compared with standard pulse start. On average, per the Advance lamp survey and assuming Advance ballasts at 400W, **CMH lamps operating on CWA ballasts have higher system efficacy than standard quartz metal halide operating on electronic ballasts**. This is as much as 10% higher when "task modified lumens is used as the criteria.

Contrary to a statement made in Mr. Walerczyk's paper however, **CMH cannot operate on (all) the same electronic ballasts as pulse start.** While that statement might be true for the lower power range electronic ballasts that utilize low frequency square wave design, the **high frequency designs** used at higher power levels **generally are not compatible with CMH lamps.** This has been established to be true for Philips CMH and while Advance cannot speak for other lamp manufacturers, Advance "Dynavision" series of high frequency ballasts is **not approved by any lamp manufacturer for CMH lamps**.

Advance continues its objection to any legislation that is based on the use of high frequency electronic ballasts.

<u>Verification</u>

Verification of compliance to the proposed legislation has been used as a reason for not including lamp efficacy in standards proposals in the past. There are however standards used by lamp manufacturers for verification of lumen output and these standards are followed in generating rated lumen outputs by the lamp manufacturers. While difficult to independently verify, market pressures keep these ratings reasonably accurate and it is **these ratings** that **are used when designing lighting systems**.

Electronic ballasts however do not have a standardized test procedure. In the PG&E study it is proposed to use **ANSI C82.6-1985 (1996 revision**) to verify ballast efficiency compliance. This standard **only applies to 60Hz ballasts**. The revision specified by the paper even allows for the use of analog meters! The standard was again revised recently (no analog meters) but is still only applicable for 60 Hz ballasts.

Advance has made the point before and will make it again. **Electronic ballast performance verification is difficult and accuracy will not be as high as it is for other ballast types.** ANSI has only now begun to address the standardization of low frequency electronic ballast "methods of measurement" and has no current plans to begin a high frequency electronic ballast "method of measurement" (the standard for high frequency electronic ballasts is just now beginning its development). This means that to specify performance of high frequency ballasts **the California Energy Commission will need to specify the method of measurement**.

If one considers a **"system efficacy"** approach to the legislation however, using input Watts and rated mean lumens, **verification becomes easy.** Input power is very easy to verify and any one of a number of standards can be specified to verify compliance (probably even ANSI C82.6).

Cost / Benefit analysis

The PG&E paper of August 2004 claims an energy savings of 219 kWh/year at an incremental cost of $30 for ballast efficiency legislation. Their calculations give this proposition a "Net Present Value Savings" of $168. As indicated previously in this paper Advance considers these numbers misleading.

While the method of determining this net present value is not fully disclosed, if one first adds the assumed incremental cost of $30 back into the "NPVS" to get an assumed "NPVS" for energy of $198 and multiply that by 3.5/11 to get the savings actually attributable to the ballast one gets a "NPVS" for energy of $63. If one then subtracts out what Advance feels is a more appropriate incremental cost of $100 you are left with a **negative Net Present Value Savings of ($37) per fixture.** Obviously **ballast efficiency alone does not offer energy savings value for the end user**. This does not even take into account the lost energy savings through the elimination of more energy efficient alternative HID systems.

If one considers lamp efficacy as an energy savings means however the equation becomes more positive. For lamp efficacy, the $30 incremental cost becomes much more realistic and energy savings (especially if s/p ratios are taken into account for example) can be comparable to those proposed by PG&E. For this example a Net Present Value Savings of $168 becomes believable. Even if one assumes an incremental cost of $30 per lamp the Net Present Value savings is over $100. The fact that changing to a lamp such as a Philips CMH can offer this type of energy and Net Present Value savings attests to not limiting technology to electronic ballasts alone.

Conclusions and Recommendations

Advance questions the viability of further HID luminaire energy efficiency legislation at this time. HID system technology is advancing at a quick pace and legislation at this time can have a negative effect on this development. In addition to this paper, Advance has presented a report documenting **new product development trends that promise to**

offer system efficiency levels eclipsing those attainable today while offering further performance **advantages in "dimming" and "hot restrike"** that will further enhance acceptance of these energy efficient systems. These systems however **can not be realized on ballasts meeting the currently proposed CEC ballast efficiency requirements.**

Advance is of the opinion that energy savings claims for legislation involving ballast efficiency alone are grossly overstated and that **when ballast efficiency alone is the criteria energy savings never recoups the cost of investment** in energy efficient ballast types.

Advance supports the NEMA Luminaire Section position of suspending development of further HID luminaire energy legislation until such time as a meaningful study can be undertaken. It also however feels even more strongly that **the CEC certainly should not proceed with legislation based on high frequency ballast efficiency alone.**

For that reason Advance proposes that **if the CEC does proceed** with its current legislation that it also allow an alternate requirement that would result in the energy savings projected by PG&E while offering industry to choose system components best suited to attaining that goal.

Advance proposes as an alternate to the PG&E ballast efficiency equation of

0.00016*Plamp + 0.8621

the CEC allow, as an alternative, the lamp/ballast efficacy requirement

Rated mean lumens/input ballast Watts =/> 48 + .048*Plamp

where "rated mean lumens" is the rating of the lamp supplied with the luminaire and "input ballast watts" is the input power to the ballast.

This equation is **based on the above PG&E ballast efficiency equation and the average quartz pulse start metal halide lamp mean lumens.**

By making the mean expected savings from the PG&E the minimum requirement for this alternative, Advance feels that this alternative will offer **as much or more energy savings** than the original proposal.

It has the added advantage that it is much **easier to verify compliance**.

This alternative, while still restrictive, offers the lighting industry multiple options to meet California energy objectives.

ENERGY SAVINGS THROUGH CONTROLLABLE, HIGH EFFICIENCY CERAMIC HID SYSTEMS – BOTH LAMP AND ELECTRONIC BALLAST CONSIDERATIONS

WILL NOT MEET PROPOSED TITLE 20 BALLAST EFFICIENCY REQUIREMENTS.

ROBERT ERHARDT 1-11-06

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Abstract

HID lamps and systems have existed for more than 50 years, leading to the most energy efficient light sources available. Lamp development efforts have led to white light sources with following properties:

- Efficacies of ~100 lm/W
- Long lamp life of >15000hrs
- Good lumen maintenance
- Excellent color control of +/- 200K in color temperature

Ballast developments have focused more and more on electronic ballasts with advantages of:

- Very good lamp power control
- High efficiency +10% compared to conventional magnetic ballasts
- Low in weight and volume
- Simple wiring

An overview of the history of HID developments, the latest state of the art technology and the potential for the future is given. It is Philips' strong belief that major steps in further improvement of energy efficiency must be achieved through system developments: i.e. lamps and ballasts should be developed as a system to achieve the highest energy benefit, potentially leading to:

- Compact well designed white light systems
- Energy savings of up to 30% compared to conventional lamp and ballast combinations
- Dimmable systems, with maintained color performance
- Lamps with integrated ballasts

The final effect will be greater availability of high efficiency HID systems with the associated energy savings and application flexibility.

Background

Lamp Technology

HID lamps and systems have existed for many years. A brief overview of HID lamps is shown in the table below.

Table 1: HID lamp overview

Type	Introduction	Positive	Negative
Mercury Vapor	'50's	Long Life Reliable	Color Rendition Efficacy
High Pressure Sodium	'60's	Long Life Efficacy	Color Rendition
Quartz Metal Halide	'70's	Color Rendering Efficacy	Lumen Maintenance
Ceramic Metal Halide	'90's	Efficacy Color Rendering Maintenance	Dimmable

HID lamps gained their popularity in the market place as one of the most efficient point sources of light, which allow distribution of light easily where it is needed as well as having long life well suited for their application. Generally, HID lamps are applied in professional applications where total cost of ownership is the main consideration:

Lowest energy cost through good efficacy and lumen maintenance
Lowest installation and maintenance cost through life

Typical drawbacks of HID systems are:

Lumen maintenance of Metal Halide (MH)
Systems are big and bulky with complicated wiring

Currently, the market is dominated by High Pressure Sodium (HPS) and Quartz Metal Halide (QMH) lamps. Key characteristics of HPS lamps are given below.

Table 2: Characteristics of HPS lamps

Wattages	Efficacy	CRI	CCT
35W – 1000W	65 – 140 lm/W	10 - 25	1900 – 2100K

Due to high efficacy, long life and reliability and excellent lumen maintenance, HPS lamps are most prevalent in street and outdoor applications. Poor color rendition and low CCT have stopped broader penetration of HPS lamps to other applications. The main characteristics of QMH lamps are given in Table 3.

Table 3: Characteristics of QMH lamps

Wattages	Efficacy	CRI	CCT
35W – 2000W	70 – 110 lm/W	60 - 85	3000 – 5000K

Good initial efficacy and color rendering as well as "white light" can be considered as strong points of QMH lamps. The lumen maintenance of QMH lamp is fair. The weakest characteristics of QMH lamps are the spread in its color and lumen maintenance, which varies from lamp to lamp and can be influenced by lamp power, lamp life and burning position. Attempts by many companies on several fronts have not successfully addressed this variation, much of which is intrinsic to the interaction of the quartz material and the metal halide salts used. QMH lamps are found in major applications in industrial and retail lighting.

The visible spectra of HPS and QMH lamps are shown in Fig. 1 and Fig. 2, respectively.

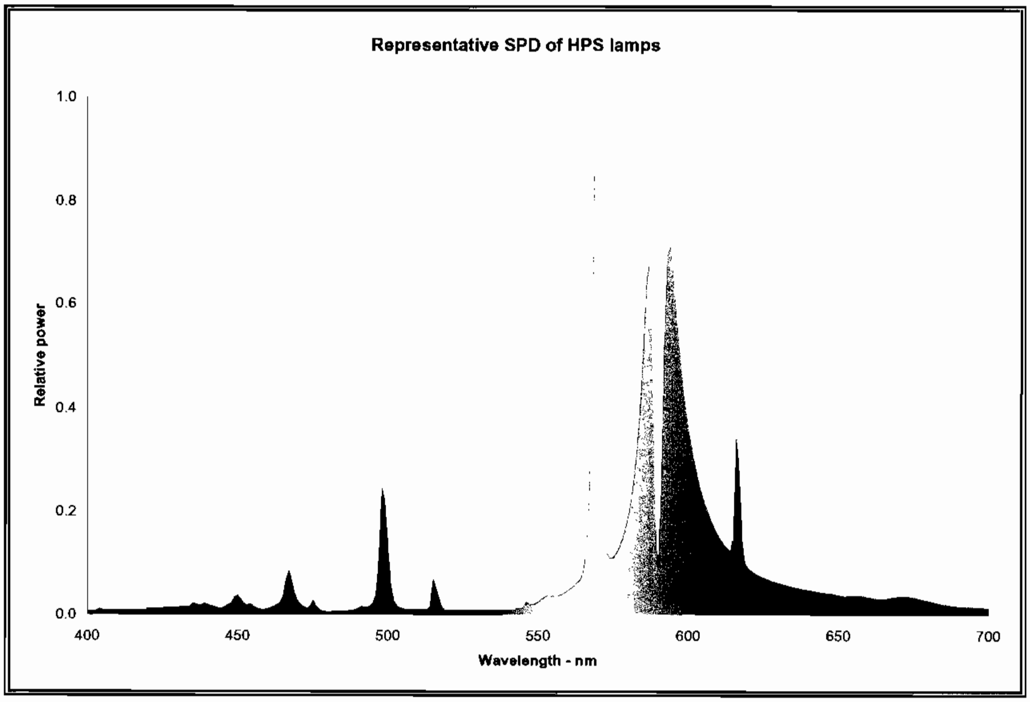

Fig. 1. HPS lamp spectrum

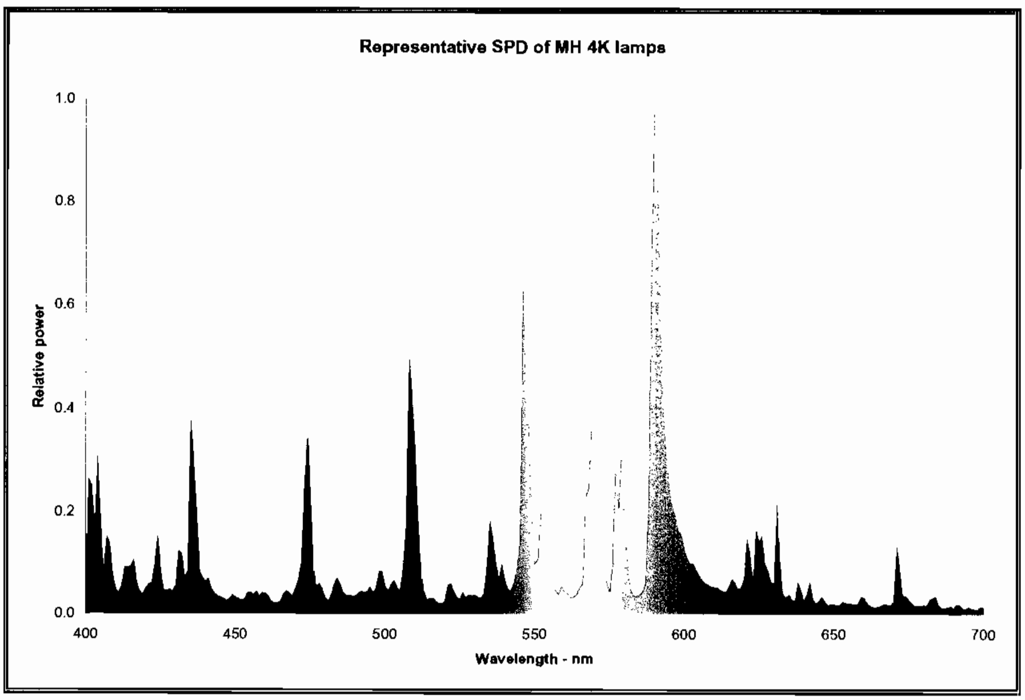

Fig. 2. QMH lamp spectrum

Ballast Technology

Although introduction of the first HID system reaches back to the 1930's, the majority of HID systems are still currently powered in a conventional fashion, by magnetic ballasts. There are a number of negative aspects related to the operation of HID lamps on conventional magnetic ballasts. The first limitation is related to their 50/60Hz lamp operating frequency. The decay time of typical HID plasma is in the range of 20 – 200 μs, which is much shorter than the time corresponding to the current zero crossing of the mains. This consequently leads to the occurrence of reignition peaks that may limit lamp performance, especially under dimming conditions. Many problems associated with conventional operation of HID lamps, especially metal halide lamps, are directly related to this reignition behavior.

While lamp radiation is modulated with double line frequency (100Hz or 120Hz), small asymmetries can produce a light flicker component at the line frequency. Those asymmetries may originate from dissimilar lamp electrodes, but also from vertical operation of the HID lamp. Light modulation is more critical at 50 Hz than 60 Hz, since the human eye sensitivity significantly decreases with increasing frequency in this region. For 50 Hz operation, the flicker level of 1.5% causes serious complaints, whereas for 60 Hz operation corresponding threshold level lies approximately at 5%.

Conventional magnetic ballasts feature relatively poor power control characteristics, relative to electronic ballasts. Consequently variation of the input line voltage as well as differences in the lamp design or changes of lamp characteristics during life, will strongly influence luminous flux, color characteristics and in many cases lifetime of the lamp itself. Attached figures (Fig. 3. and Fig. 4.) depict graphical interpretation of above mentioned characteristics.

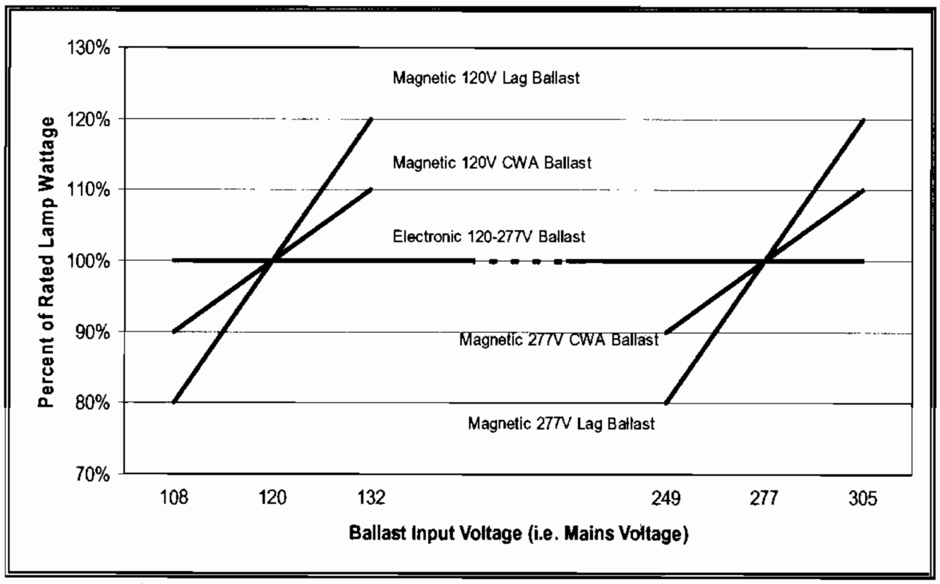

Fig. 3. Lamp wattage regulation; magnetic vs. electronic, as a function of line voltages

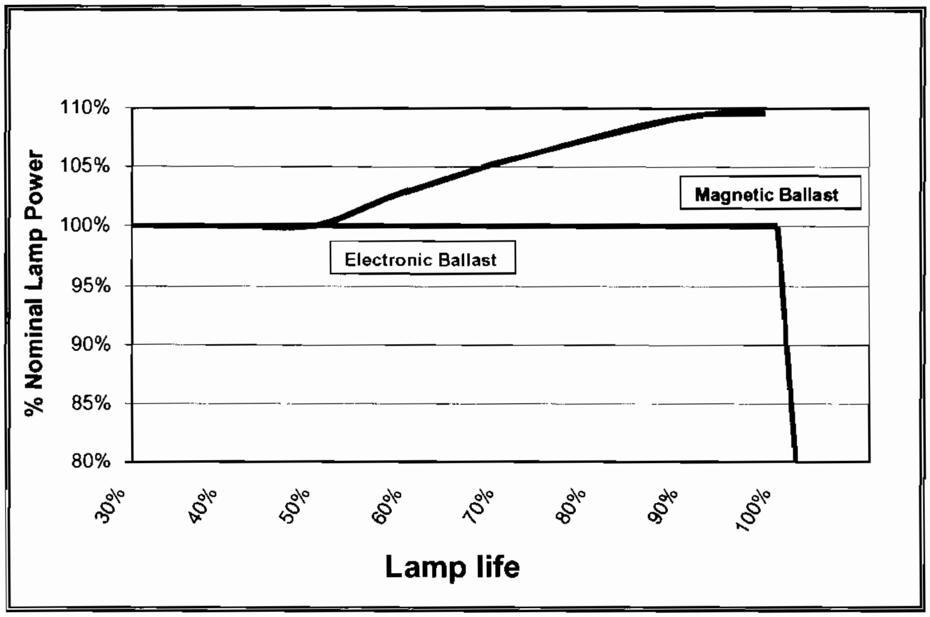

Fig. 4. Lamp wattage regulation; magnetic vs. electronic, as a function of lamp life (Metal Halide lamp example).

Run-up on conventional gear is relatively slow, which is due to the low lamp voltage and to the power that the conventional circuit can deliver during this phase of operation. As a result, run-up phase may last from one to several minutes, before luminous flux will reach 80 – 90% of its steady state value. Conventional ballast systems consist often of several components: the magnetic ballast, a capacitor and sometimes a separate starter (HID lamps may need a starting pulse up to 5 kV).
Until the mid 1990's, the progress of HID systems development with electronic ballasts was rather slow. From the electronic ballast point of view, unavailability of advanced technologies and high cost did not allow them to penetrate faster in HID lighting applications.
As far as development of HID lamps is concerned, the fact that MH lamps were mostly developed as retrofit for existing conventional ballasts, did not allow more aggressive introduction of novel technologies.

Existing Technology

Since our focus in this paper is on HID lighting systems powered by electronic ballasts, this chapter will discuss the current status of Electronic ballast options and Ceramic Discharge Metal Halide (CDM) lamps, which are considered the most advanced existing HID "white light" technologies.

Differences in performance between electronic and conventional operation

Given an existing lamp, upgrading from conventional magnetic to electronic ballasts may change overall the lamp-ballast system efficiency; however, there will be no fundamental increase in lamp efficacy. In contrast to conventional operation, on electronic ballasts the lamp power factor is almost unity and the time-dependent fluctuation of the plasma temperature will be absent. This can lead to small variations in the relative intensities of spectral lines. As a result of this, changes in efficacy will be rather insignificant (less than ~3%). The changes in CCT will be also rather small (at the most 200K – 300K). In some cases the CCT is lower, caused by the lower peak plasma temperature, which results in less blue radiation. A big advantage of electronic operation is the elimination of line frequency flicker, which is related to the current zero crossing on conventional gear. Since the plasma cooling effect at the current zero crossing will be amplified by lower lamp power, prospects of dimming on electronic gear are significantly improved. In fact dimming with conventional gear is generally limited to a two level switching between 100% and 50% power operation. These switching systems are typically complex in wiring. The opportunity for dimming will be much greater with electronic operation due to high di/dt, very accurate lamp power control in steady state operation, and flexibility of run-up current control, improved lamp maintenance under dimming conditions may be expected. Currently, there are available HID systems with electronic ballasts that allow dimming range of 100% – 60% and 100% – 30% for MH and HPS lamps respectively.

Electronic ballasts have the following main advantages:

- Excellent power control independent of line voltage and lamp setting
- Better ballast efficiency leading to lower losses in the ballast
- Greater compatibility with the demands of dimming
- Fewer components next to the lamp, which simplifies wiring (only 1, for magnetic is typically 3)
- Further increase of system efficiency due to power factor of almost unity
- Lower in weight and volume than conventional gear

Generally speaking, the efficiency of conventional magnetic ballasts is in the range of 84% – 86%, whereas most recently introduced electronic ballasts may reach efficiency of 90% – 92%. For some dedicated applications electronic ballast efficiencies may even reach 96%. The table below shows the relation of lamp and system power, to achieve comparable illumination level for incandescent and CDM HID lamps, powered by conventional magnetic and electronic ballasts.

Table 4: System power @120V, incandescent vs. CDM (lamp watts)

Type	P1	P2	P3
Halogen Incandescent	75W (75W)	100W (100W)	150W (150W)
CDM on conventional	NA	56W (39W)	72W (50W)
CDM on electronic	26W (20W)	45W (39W)	56W (50W)

Furthermore, electronic ballasts allow the installation of substantially more fixtures on one circuit, thereby lowering installation costs for new constructions.

Table 5: Lamp watts/number of fixture per 20A circuit @120V

Type	P1	P2	P3
Halogen Incandescent	75W/25	100W/19	150W/12
CDM on conventional	NA	39W/22	50W/20
CDM on electronic	20W/69	39W/40	50W/32

Ceramic discharge MH lamps – current status

Philips introduced the first Ceramic Discharge Metal Halide lamp in 1995. The following picture in Fig. 5 shows a typical ceramic and quartz metal halide arc tube. The ceramic and quartz refers to the wall material of the arc tube, the light emitting part inside the glass bulb of an HID lamp.
CDM lamps have been produced for 10 yrs with excellent color properties. The ceramic arc tube material is much more resistant to the lamp chemicals at much higher temperatures leading to lamps giving white light with excellent color rendition and efficacies. The ability to operate ceramic arc tubes at higher temperatures than quartz ones is a fundamental advantage of the ceramic system, and one that

cannot be compensated for, by quartz designs. Together with the good control of the dimensions of the ceramic arc tube material compared to quartz, this leads to much less color variation initially and over the life of the lamps so that these lamps can be applied in many new, more color critical, applications. Dimensional control of the ceramic also leads to lamp powers that are not possible with quartz: 35W, 20W and even smaller wattages are possible, further extending the application possibilities of these efficient light sources since the arc tubes can be more compact.

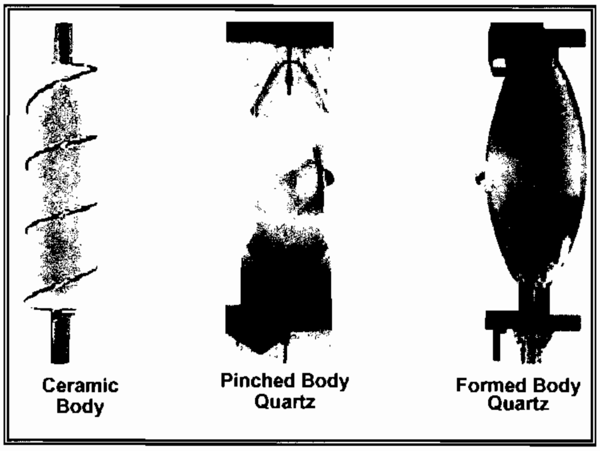

Fig. 5. Shapes of discharge tubes; CDM vs. QMH

Due to excellent color and light technical properties, CDM lamps have gained very wide acceptance in the marketplace. Key characteristics of CDM lamps can be summarized in the table below.

Table 6: Characteristics of CDM lamps

Wattages	Efficacy	CRI	CCT
20W – 400W	90 – 95 lm/W	80 - 95	2700 – 4200K

Figure 6 shows comparison of CDM and quartz MH lamps spectra.

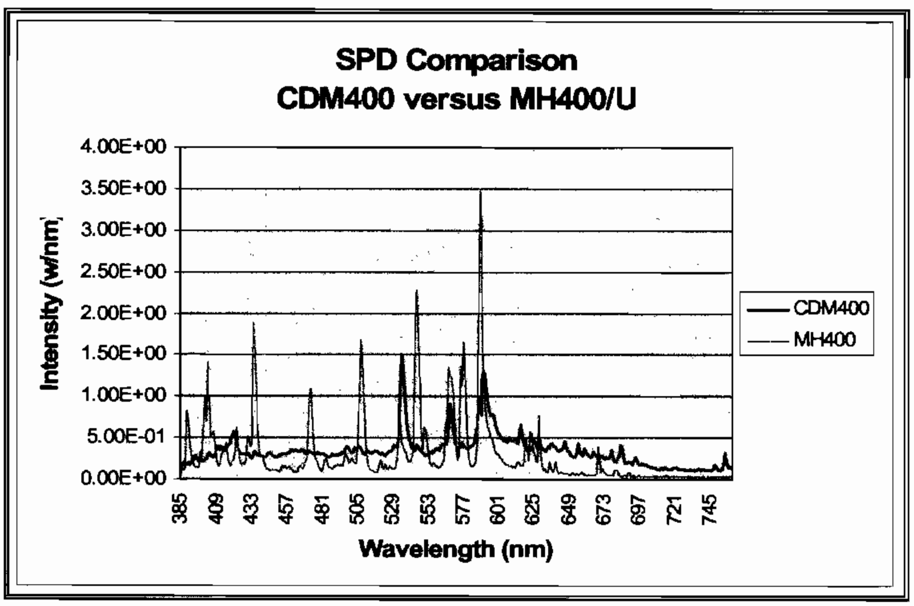

Fig. 6. CDM vs. QMH lamp spectra

The benefits of Ceramic MH technology versus Quartz MH are listed in Table 7.

Table 7: Benefits of CDM vs. QMH (typical values, 20-400W)

Feature	QMH	Typical Ceramic Improvement	CDM
Color rendering R8	3000K, CRI of 65-75 4200K, CRI of 80 – 85	10 points	2700K, CRI of 81 – 85 4200K, CRI of 92 – 95
Lamp efficacy	80 – 90 lm/W	7 lm/W (~10%)	90 – 95 lm/W
Color stability	+/- 300 – 400K	+ 50% – 100%	+/- 200 – 250K

Graphical representation of color consistency of CDM lamps is shown in Fig. 7.

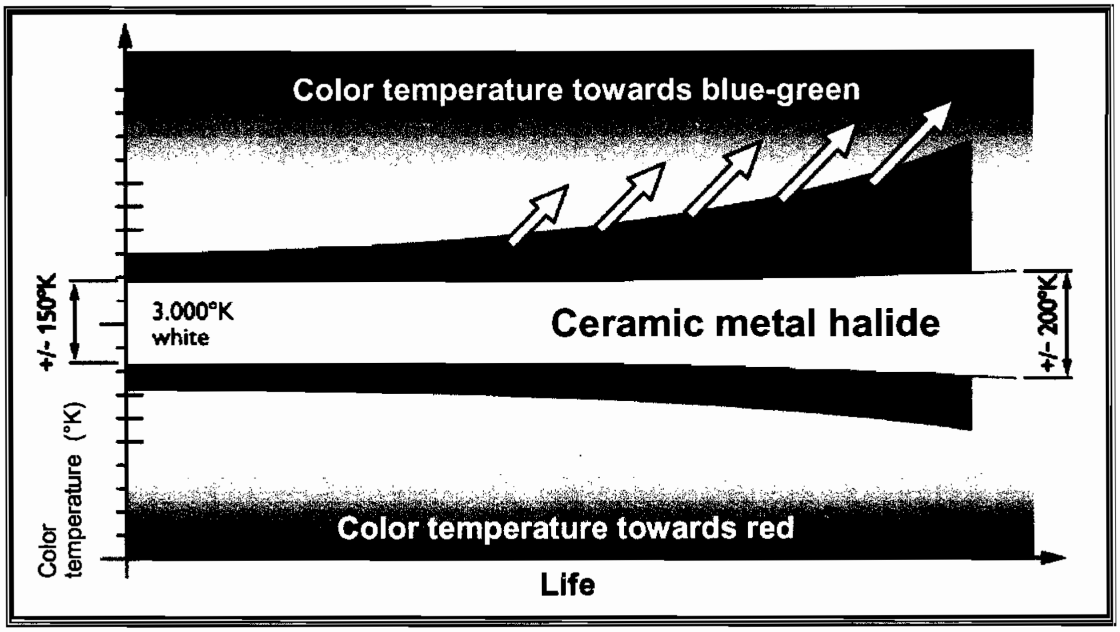

Fig. 7. Color consistency of CDM vs. QMH lamps over life

Considering the data discussed above, regarding efficiency improvement of electronic ballasts as well as Ceramic MH lamps, it is becoming very clear that by combining both technologies, significant energy savings can be achieved and new, efficient systems may become possible that were not in the past.

Current Research and Potential Technical Enhancements

Within Philips Lighting it is our sincere conviction that lamps and ballasts should be developed concurrently as systems to achieve the highest energy benefits:

- Our experience shows that ballast efficiency improvements on their own can have negative effects on the lamp efficiency by the change of the spectrum. Efficacy improvements should focus on the total system because the total system energy use counts. See notes at end of paper.
- Dimmability is only good if the color of the lamps is kept under control
- System development can lead to systems with integrated ballasts for further ease of use and spread of the application potential of HID systems

New electronic ballast developments

Current research for electronic ballasts is dedicated to further size reduction, increased efficiency and extended ballast functionality. Most recent years have brought significant size reduction of electronic ballasts. Continuous development in the area of semiconductors and passive components as well as new ballast topologies enable significant size reduction of electronic HID gear.

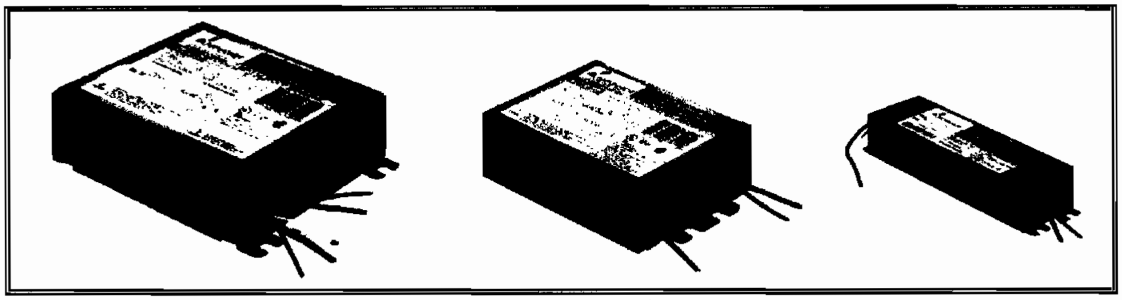

Fig. 8. Progression of E-HID ballast miniaturization for MH lamps.

Typical progression of E-HID ballast volume in most recent years is depicted in the table below.

Table 8: Volume progression of E-HID ballasts (cm^3) for MH lamps

Wattage	1998 2002	2003 2004	2005 2006
39W	420 cm^3	170 cm^3	105 cm^3
70W	420 cm^3	330 cm^3	205 cm^3
100W	420 cm^3	420 cm^3	310 cm^3
150W	1100 cm^3	650 cm^3	420 cm^3

This significant size reduction contributed to novel, more efficient topologies and more robust components that may withstand higher ambient operating temperatures. Together with compact lamps and lower wattages, more compact ballasts allowed the design of more efficient, smaller and more aesthetically pleasing luminaries as shown in Fig. 9.

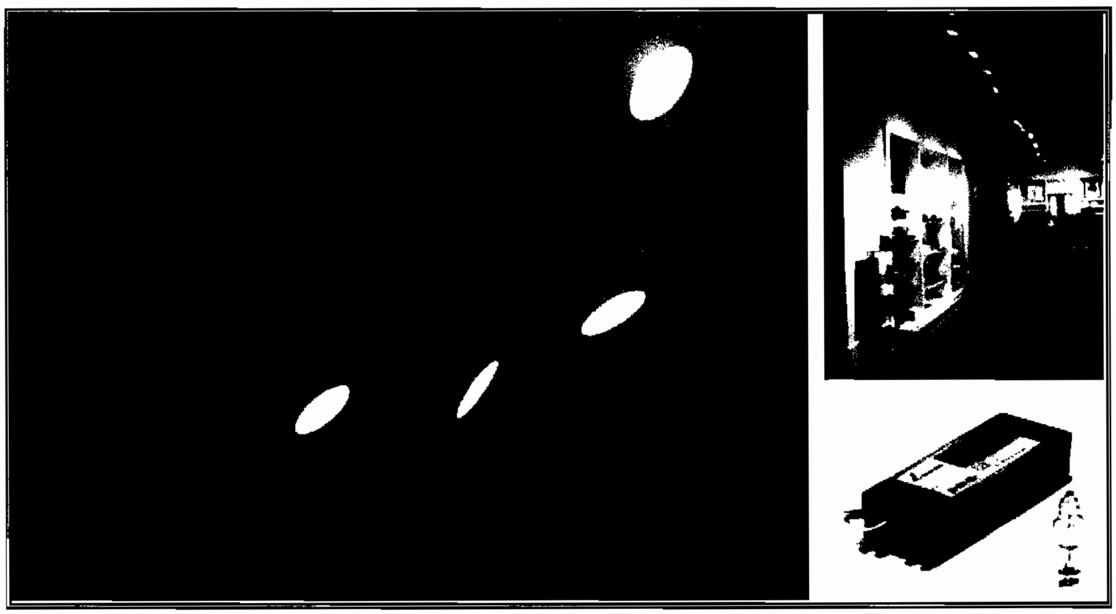

Fig. 9. E-HID 20W NI system introduced by Philips in 2004.

New E-HID ballast development is targeted to other areas as well. A lot of emphasis is put on lower ballast cost and also lower ballast cost per socket. We plan to introduce an E-HID ballast to operate 2 HID lamps independently on one driver.

Also, implementation of microprocessor technology as well as new sophisticated control and communication protocols allow easier and more flexible dimmability of HID lighting systems. Currently, 0 – 10V control protocols are readily available in 250W – 400W systems. Dimmable ballasts for lower wattages are in an advanced development stage and will be introduced in the next couple of years. It is worthwhile to note, that introduction of new generation of CDM lamps, one that is suitable for dimming application, is an important factor in making possible the extension of dimming HID systems to lower wattages. This innovative HID lamp will be discussed in more detail in the following section of this paper.

The new area of E-HID ballast development is related to advanced control algorithms, which are based on wire-less communication. This novel technology should further expand capability and penetration as well as ultimate flexibility of dimming HID lighting systems.

Future CDM lamp development

Further improvements of CDM lamps will be achieved by implementation of new ceramic arc tube shapes (see Fig. 10 for examples), new fillings and integration with electronics. Leading to:

- Higher efficacies going up to 120 lm/W
- Lumen maintenance improvements to >90%
- Dimming with constant color
- Much shorter restart time after lamp turn off
- Compact lamps, well aligned in the luminaire for less glare

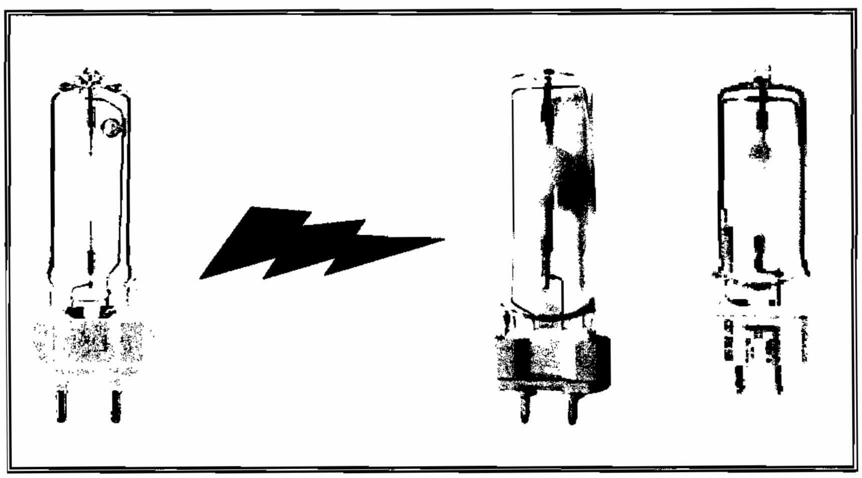

Fig. 10. Evolution of cylindrical to other tube shapes in CDM lamps.

Improved lamp lumen maintenance over life will proportionally increase mean lamp efficacy. This improvement will directly translate to further enhancement of energy savings potential. A product now under development will introduce a new generation of CDM lamps. This lamp features;

- reliable dimmability down to 50%
- increased lumen output and hence mean efficacy
- improved lumen maintenance
- improved color rendering

Graphical representation of key lamp characteristics is shown in Fig. 11

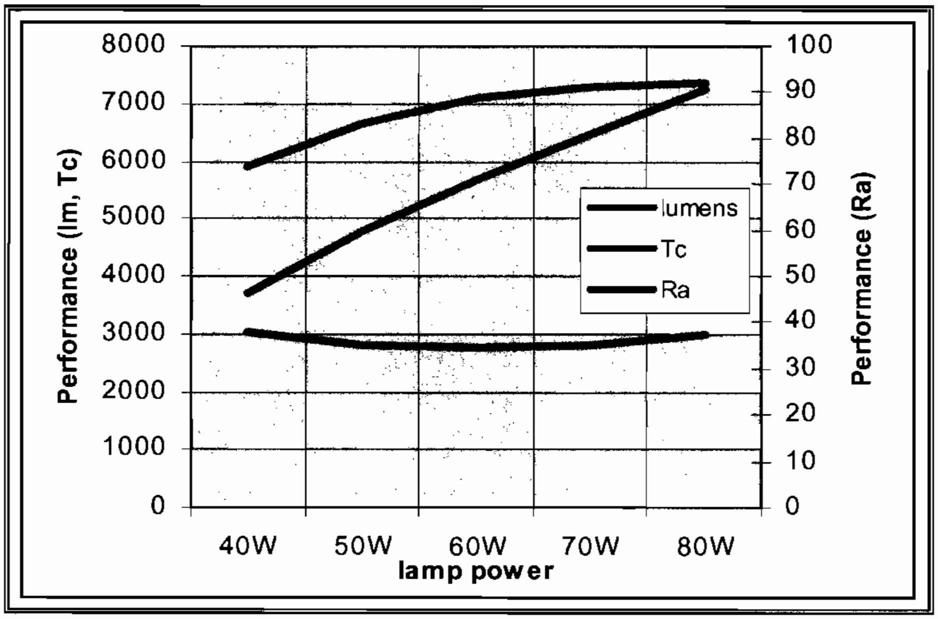

Fig. 11. Key characteristics of new generation dimmable CDM lamp.

A remarkable characteristic of this lamp, that during dimming down to 50%, it maintains CCT within 200K and color rendering stays above 75. This product is not ready for market introduction, but is much more than a general concept. We believe it represents the future of white lighting by ceramic, electronically driven and controlled metal halide systems.

Future/New Lamp – Ballast system development

During recent years some major developments in electronic ballast as well as CDM lamps have occurred. However, we strongly believe that the best chances to achieve ultimate performance of E-HID systems will be established by the combination of new HID lamp concepts with the appropriate electronic gear. Two examples to highlight this are the following.

The first example is related to a new lighting system for outdoor applications that is in the final stages of development. The lamp system is comprised of two types. One type is based on metal halide salts and generates white light. The second type is based on HPS technology and generates yellow light. Both types of lamps share the same dimensions and the same optical center in the reflector, which is very unique feature of this system. Lamp power is in the range of 60W – 140W. The key features of this system are following;

- compact lamp, base and ballast system: 50% smaller than conventional systems (see Fig. 12)
- high efficiency lamp – ballast system with energy savings of 10-30%
- operation on electronic ballast only
- excellent life and lumen maintenance

The main benefits of this system are;

- maximum fixture design freedom
- precise optical positioning
- lowest cost of ownership
- greater application flexibility
- higher reliability

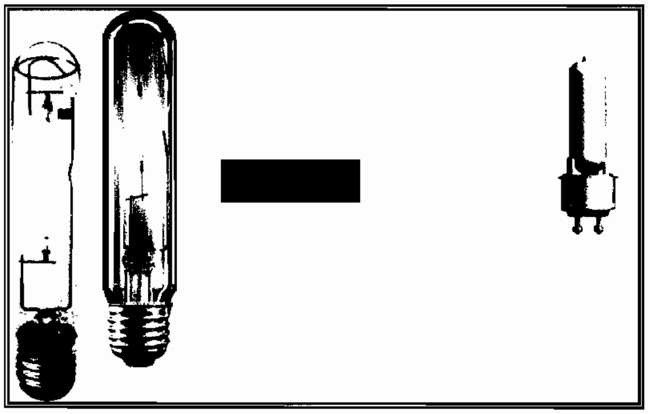

Fig. 12. Size evolution of HPS and CDM lamps into one size.

This novel system will feature excellent maintenance and reliability over lifetime. One of the strongest advantages of this system is optimal matching of both types of lamps (MH and HPS) with the same fixture. The development focus was to achieve the highest system efficiency and this leads to two different ballasts: one for the "white light" and one for the "more efficacious, yellow light". Matching dimensions for the "white" and "yellow" light means that both lamps will fit the same fixture. Having a new base/holder for good alignment in the fixture this leads to less glare and roughly an extra 5% efficiency gain (examples shown in Fig. 13)

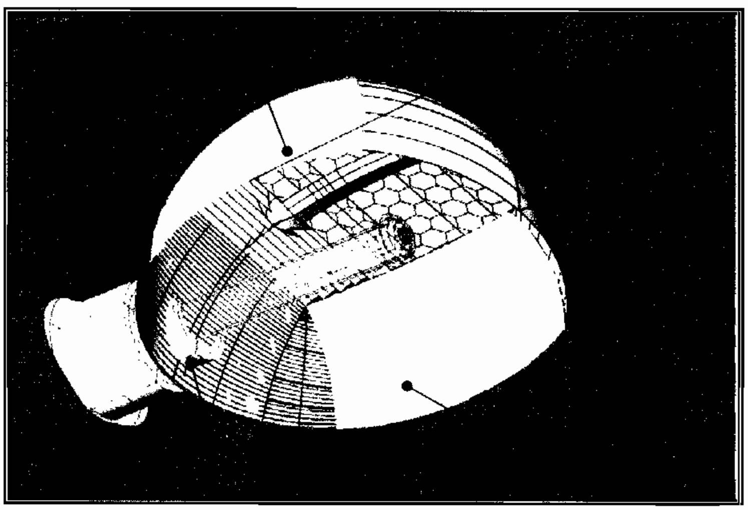

Fig. 13. Lamp integration with the luminaire.

The second example is an integrated system introduced in the marketplace in the past few months. The combination of advancements in lamp and ballast miniaturization, has allowed development of 25W integrated Ceramic Metal Halide lamp in a PAR 38 reflector. It was already shown in Table 4, that this new integrated system, in terms of lumen package, would replace 75W incandescent halogen lamp, but offer 60% energy savings and 3 times longer life. As in the previous example, the key component of this system is integrated optics. A mechanical sketch of this system is attached below.

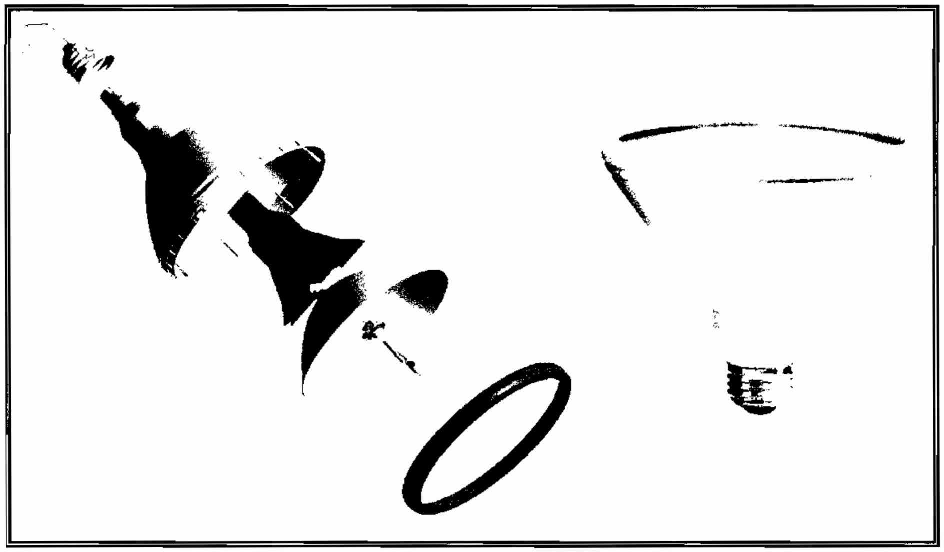

Fig. 14. 25W E-HID integrated system.

R&D and Technical challenges

As shown, HID and specifically Ceramic HID systems are very energy efficient white light systems but with still limited usage. In order to expand its application area, the following technical challenges for HID systems needs to be resolved.

- Achieving the highest efficacies (120 lm/W or higher) ***with*** an excellent maintenance (>90%) ***and with*** long life (20000hrs) ***also for*** higher powers (250 - 1000W).
- Dimmability of these systems with maintained color.
- Instant light during lamp start-up as well as warm restart. In this case Philips has successfully demonstrated practical solutions (automotive HID lamp and UHP projectors), however complexity and system price did not allow introduction of this system in general lighting applications. Not only cost is the main roadblock to expand this technology to general lighting. Sockets for existing indoor installations are only rated for not more than 5 kV, limiting available voltage for warm restrike of HID lamps.
- Achieving reliable life of electronic systems in outdoor applications, facing extreme temperatures conditions and for instance lightning strikes.
- HID systems and concepts discussed in this manuscript are a closed system. By closed system we mean that ballast and lamp are designed as a pair. A main challenge is to develop standards that would enable such closed systems to find applications with other lamps or ballasts, that were not part of the original optimized design. This is a big and very difficult challenge.
- Excellent color properties have been achieved for 3000K lamps, which established the benchmark. The challenge is to extend these excellent color properties to other color temperatures.

Thoroughly analyzing above challenges, the following top three priorities can be established:

1. ***Instant light and warm restrike of HID lamps***
2. ***Conversion of closed systems to commonly available open systems***
3. ***Initial cost of the system.***

Conclusions and recommendations

With the support of several examples, this paper shows that the most significant energy savings in HID lighting systems can be achieved combining Ceramic MH lamps with Electronic ballasts. Even further improvements, in terms of system efficiency and lamp maintenance are possible, but this ultimate goal may be only achieved by combination of CDM lamps with dedicated electronic ballast and very precisely designed compact optical reflector, in other words: **focus on system developments.** Philips Lighting has been actively working on the topics discussed in this article. We are strongly convinced that this work on E-HID lighting systems points the way to the future of white light, HID systems with the energy saving, color and dimming features that the market will demand. It is also believed that the success in the project, dealing with high efficiency Ceramic HID Systems - both lamp and electronic ballast, will accelerate **the energy savings potential** of this new high – payoff technology.

The energy saving potential can be reinforced by:

- Further system efficiency improvements.
- Further maintenance improvements: lower lamp powers needed at the start.
- White light in more outdoor applications may lead to an improved feeling of safety and perhaps to the requirement of lower lighting levels.
- Lower wattages and integrated lamps will increase the application scope of these efficient light sources.
- Dimmability down to 50% of power leads to huge energy savings in low use hours.
- Control leads to better maintenance scheduling.

It is therefore recommended to support the development of these systems.

Erhardt comments:
Current Philips ceramic metal halide lamps are not operable on HF ballasts. Currently, there are no lamp companies authorizing the use of Advance HF electronic HID ballasts with ceramic metal halide lamps. Developments described as further innovations in this paper are only being realized on LF ballasts and multiple features require additional circuitry that lower ballast efficiency below that of existing LF electronic ballasts. Features described here have only been achieved with ballasting systems with efficiencies in the 86-90% range. This information comes from consultation with Jerzy Janczak, a co-author of this paper

Power	Manf.	Type "O"	CRI	CT	Initial Lumens	Mean Lumens	M Lumems per Watt	Ave Ml/W	Ballast Efficiency	Lamp - Ballast l/W	Ave quartz	Ave ceramic	48 + .048*Plamp
150	GE	Quartz	70	3.5k	12,500	8,600	57.3		88.61%	50.8			55.2
150	GE	Quartz	70	3.5k	12,000	8,300	55.3		88.61%	49.0			55.2
150	Venture	Quartz	65		13,300	10000	66.7		88.61%	59.1			55.2
150	Venture	Quartz	70		12,600	9500	63.3		88.61%	56.1			55.2
150	Osram	Quartz	88	4.2k	12,500	11,000	73.3		88.61%	65.0			55.2
150	Osram	Quartz	75	2.9k	11,600	9,000	60.0	62.7	88.61%	53.2	55.5		55.2
150	GE	Ceramic	80	3k	12,900	9,500	63.3		88.61%	56.1			55.2
150	GE	Ceramic	90	4.2k	11	8,300	55.3		88.61%	49.0			55.2
150	Osram	Ceramic	89	3k	13,000	11,000	73.3		88.61%	65.0			55.2
150	Osram	Ceramic	89	3k	12,000	10,000	66.7		88.61%	59.1			55.2
150	Philips	Ceramic	85	3k	12,900	9545	63.6		88.61%	56.4			55.2
150	Philips	Ceramic	92	4k	11,000	8250	55.0	62.9	88.61%	48.7		55.7	55.2
250	Venture	Quartz	65	4k	23,800	19,000	76.0		90.21%	68.6			60.0
250	Venture	Quartz	70	3.7k	22,600	17,600	70.4		90.21%	63.5			60.0
250	Osram	Quartz	65		22,500	17,000	68.0		90.21%	61.3			60.0
250	Osram	Quartz	70		21,000	16,000	64.0	69.6	90.21%	57.7	62.8		60.0
250	GE	Ceramic	90	4.1k	23,000	18,400	73.6		90.21%	66.4			60.0
250	GE	Ceramic	90	4.1k	22,000	17,600	70.4		90.21%	63.5			60.0
250	Osram	Ceramic	94	4.2k	24,000	19,200	76.8		90.21%	69.3			60.0
250	Osram	Ceramic	94	4k	22,500	18,000	72.0		90.21%	65.0			60.0
250	Philips	Ceramic	85	4k	22,500	19,125	76.5	73.9	90.21%	69.0		66.6	60.0
320	GE	Quartz	70	3.7k	30,600	24,500	76.6		91.33%	69.9			63.4
320	GE	Quartz	70	3.7k	30,500	21,500	67.2		91.33%	61.4			63.4
320	Venture	Quartz	65		31,000	25,000	78.1		91.33%	71.4			63.4
320	Venture	Quartz	70		29,000	23,000	71.9		91.33%	65.6			63.4
320	Osram	Quartz	65		33,500	24,000	75.0		91.33%	68.5			63.4
320	Osram	Quartz	70		27,700	19,000	59.4		91.33%	54.2			63.4
320	Philips	Quartz	65	3.8k	29,500	20,650	64.5		91.33%	58.9			63.4
320	Philips	Quartz	65	3.7k	27,200	19,040	59.5	69.0	91.33%	54.3	63.0		63.4
320	Philips	Ceramic	90	4.2k	28,800	23,000	71.9		91.33%	65.6			63.4
320	Philips	Ceramic	90	4.2k	28,000	22,400	70.0	70.9	91.33%	63.9		64.8	63.4
350	GE	Quartz	65		35,200	28,200	80.6		91.81%	74.0			64.8
350	GE	Quartz	70		33,400	26,700	76.3		91.81%	70.0			64.8
350	Venture	Quartz	65		35,000	28,000	80.0		91.81%	73.4			64.8
350	Venture	Quartz	70		33,000	26,000	74.3		91.81%	68.2			64.8
350	Osram	Quartz	65	3.5k	40,000	29,500	84.3		91.81%	77.4			64.8
350	Osram	Quartz	70	3.5k	32,000	23,000	65.7		91.81%	60.3			64.8
350	Philips	Quartz	64	4k	34,000	23,800	68.0		91.81%	62.4			64.8
350	Philips	Quartz	67	3.7k	31,000	21,700	62.0	73.9	91.81%	56.9	67.8		64.8
350	GE	Ceramic	90	3.6k	34,000	27,200	77.7		91.81%	71.3			64.8
350	GE	Ceramic	90	3.6k	33,000	26,400	75.4		91.81%	69.3			64.8
350	Philips	Ceramic	90	4.2k	31,500	25,200	72.0		91.81%	66.1			64.8
350	Philips	Ceramic	90	4.2k	30,600	24,500	70.0	73.8	91.81%	64.3		67.7	64.8
400	GE	Quartz	65		42,000	29,500	73.8		92.61%	68.3			67.2
400	GE	Quartz	70		40,000	28,000	70.0		92.61%	64.8			67.2
400	Venture	Quartz	65		41,000	33,000	82.5		92.61%	76.4			67.2
400	Venture	Quartz	70		39,000	31,000	77.5		92.61%	71.8			67.2
400	Philips	Quartz	65	3.8k	40,000	28,000	70.0		92.61%	64.8			67.2
400	Philips	Quartz	68	3.6k	36,000	23,400	58.5	72.0	92.61%	54.2	66.7		67.2
400	GE	Ceramic	92	3.7k	40,000	32,000	80.0		92.61%	74.1			67.2
400	GE	Ceramic	92	3.7k	39,000	31,200	78.0		92.61%	72.2			67.2
400	Philips	Ceramic	88	4.2k	35,000	29,750	74.4		92.61%	68.9			67.2
400	Philips	Ceramic	90	4.2k	36,000	28,800	72.0	76.1	92.61%	66.7		70.5	67.2