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# design brief

## HIGH-INTENSITY FLUORESCENTS

New high-intensity fluorescents outshine their high-intensity-discharge competitors. They are often more efficient and feature lower lumen depreciation rates, better dimming options, instant start-up, and better color rendition.

## Summary

High-intensity-discharge (HID) light sources, such as metal halide and high-pressure sodium lamps, have long dominated the market for lighting indoor spaces with high ceilings. These "high-bay" spaces are typically found in warehouses, factories, large retail stores, and athletic facilities. In recent years, however, improvements in fluorescent lighting technology have resulted in the emergence of new high-intensity fluorescent fixtures, which are superior to HID fixtures in numerous ways.

Combining thin fluorescent tubes (5/8 inch) with electronic ballasts and highly efficient reflective fixtures, high-intensity fluorescent systems are often more efficient than comparable HID systems. Furthermore, they feature lower lumen depreciation rates, better dimming options, virtually instant start-up and restrike, and better color rendition. These additional benefits are so compelling that designers may specify high-intensity fluorescent systems even if they save no energy at all.

HID manufacturers are improving their products as well. For example, new lamp and ballast designs make HIDs more efficient and faster starting. New reflector designs are making HID fixtures much more efficient as well. However, until HID manufacturers make dramatic improvements in start-up times and lumen depreciation rates, fluorescents will continue to be advantageous in a variety of applications.

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## Introduction

High-intensity-discharge (HID) light sources have been the top choice for lighting medium- and high-bay spaces for more than a decade. For high-ceiling spaces found in retail stores, manufacturing and warehousing facilities, parking garages, and athletic facilities, HID lamps offered the right combination of high intensity and high efficacy.

Today, new fluorescent technology has changed the picture. These new systems feature thinner (5/8-inch-diameter), more efficient fluorescent lamps; electronic ballasts; and a new generation of efficient fixtures. Compared with HID solutions, these high-intensity fluorescent systems are more efficient and more convenient to operate, and they produce higher-quality light (**Figure 1**). They are initially more expensive than HID systems but are often more cost-effective on a lifetime basis.

HID technology still has an edge over fluorescent lamps in some applications, including those using lamps of 1,000 watts or more (such as areas with very high ceilings), flood lamps for

**Figure 1: High-intensity fluorescent fixtures in high-bay applications**

In 1998, SMC Metal Fabricators, a sheet metal fabricating company in Oshkosh, Wisconsin, installed 282 T5 fluorescent lights with electronic ballasts in its new high-bay manufacturing facility (left). The fluorescent fixtures saved an estimated 76 percent of the energy that would have been used had 400-watt metal halide lamps been installed. At right, an ice-skating rink in Roseville, California, uses high-intensity fluorescent fixtures in an application that traditionally employs HID lighting.

Source: SMC Metal Fabricators, courtesy of Smartlite Inc.

Copyright 1997, John Swain, courtesy of MetalOptics outdoor applications (such as sports stadiums), and any use where the lamps will be subjected to very cold temperatures (such as streetlighting in regions that experience below-zero temperatures). Small metal halide lamps are also still the best choice for some accent and display lighting applications. Nevertheless, the emergence of fluorescent fixtures that can provide efficient solutions in medium- and high-bay applications is an important development in the lighting industry. The popularity of these new fluorescent fixtures should increase dramatically in the years to come as end users become aware of their numerous benefits.

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## Advantages of the New Fluorescents

The new fluorescent fixtures designed for high-bay applications have six advantages over similar HID fixtures:

- Lower energy consumption
- Lower lumen depreciation rates
- Better dimming options
- Faster start-up and restrike
- Better color rendition
- More pupil lumens

Not only do these advantages make fluorescent fixtures more cost-effective in many applications, but they also enable them to provide better-quality lighting to the spaces they illuminate.

### Lower Energy Consumption

Long twin-tube and linear T5 fluorescent lamps are simply more efficacious than most HID lamps, meaning that they produce as much or more light with less electricity (**Figure 2,** page 5). Although a few HID lamp types are initially more efficacious than T5 fluorescents, they have serious limitations that make them unsuitable for many indoor applications. For example, the most efficient high-pressure sodium lamps produce light with a color rendering index of less than 30, and 1,000-watt metal halide lamps are too bright for most indoor installations.

Although lamp efficacy is important, another factor also strongly influences the overall efficacy of a lighting system: the efficiency of the fixture itself. Fixture efficiency is a measure of how effectively the light generated by the lamp is captured and redirected to where it is needed. Here too, new fluorescent high-bay fixtures have an advantage over most of their HID cousins. HID fixtures typically found in existing high-bay applications are limited to about 70 percent efficiency; new fluorescent fixtures employing highly reflective surfaces with computer-selected curves feature efficiencies ranging from the high 70s to the high 90s. One fluorescent fixture achieves 98 percent efficiency. Because of the linear nature of the source, fluorescent fixtures can also be more readily designed to direct light to narrow areas such as warehouse aisles. A few new HID fixtures that have

## A Primer on HID and Fluorescent Lighting Systems

High-intensity-discharge lamps and fluorescent lamps are commonly applied in commercial and industrial facilities. Although both are based on a similar scientific principle—the striking of an arc through vaporized metal—they are applied in very different ways.

HID lamps produce intense light in such a small volume that they are considered "point sources." As a result, they are often installed in fixtures that direct their light using parabolic reflectors. The high intensity of HID lamps has made them effective in applications that feature large expanses lit by distant fixtures, such as indoor and outdoor sports facilities, factories and warehouses with high ceilings, and streetlighting.

Although there are several different kinds of HID lamps, the most effective types for indoor applications are metal halide and high-pressure sodium lamps. A key difference between these two is the metals that compose the vapor through which the electric arc is struck. Of these two types, metal halides—with their high-quality light, high efficacy, and wide range of sizes—are more versatile.

Fluorescent lamps are essentially the opposite of "point-source" HID lamps. They emit relatively diffuse light from long glass tubes. This characteristic of diffusivity has enabled fluorescent fixtures to dominate the market for lighting commercial, institutional, and industrial spaces with ceilings less than 15 feet high. In recent years, however, the emergence of more intense and efficient fluorescent lamps and of specially designed reflecting fixtures has made fluorescent lamps an appropriate choice for a wider range of applications.

recently appeared on the market feature efficiencies as high as 85 to 90 percent. But these options cost significantly more than fluorescents and still fall short of matching many of fluorescents' other benefits, such as better dimming options, better color rendition, and faster start-up and restrike.

In any event, because most fluorescent fixtures feature higher lamp and ballast system efficacy and greater fixture efficiency, they consume less electricity than most HID systems to produce the same quantity of light on the work plane.

To identify costs and benefits of metal halide and fluorescent lights in new installations, it is useful to compare a typical 400-watt bell-shaped spun-aluminum metal halide fixture with a

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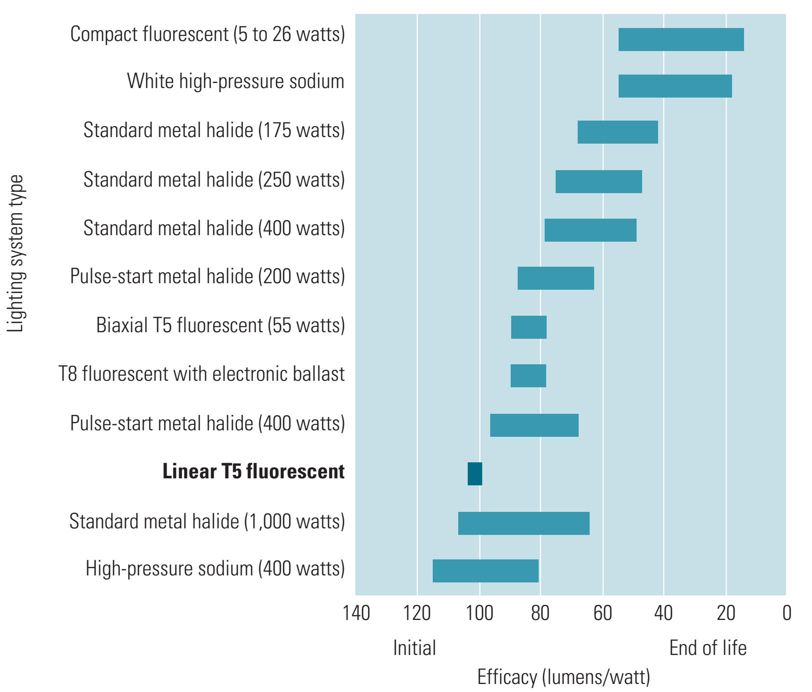
**Figure 2: Typical efficacies of typical indoor lighting systems**

Instead of efficiency, most lighting systems are compared on the basis of "efficacy," which is expressed in units of lumens (light output) per watt (of electrical input). The efficacies of fluorescent and high-intensity-discharge lamp and ballast systems used in indoor lighting applications vary widely. The most efficacious are high-pressure sodium lamps, but they provide light of only mediocre quality, with a CRI of only about 30. As shown here, T5 lamps also maintain their luminous efficacy better than the alternatives throughout their lifetimes.




Source: Financial Times Energy

high-efficiency pulse-start metal halide and these three high-intensity fluorescent fixtures:

- Six 40-watt long twin-tube T5 lamps in a 2- by 2-foot fixture,
- Four 55-watt long twin-tube T5 lamps in a high-efficiency 2- by 2-foot fixture, and
- Four 54-watt linear T5 high-output lamps in a 2- by 4-foot fixture.

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In the analysis (**Table 1**), all three fluorescent fixture installations boasted 30 to 40 percent lower lifecycle costs than standard metal halides and 4 to 19 percent lower lifecycle costs than pulse-start metal halide lamps. As the new high-intensity fluorescent fixtures become more widely available, the costs will drop, reducing lifecycle costs even further. The analysis did not include any savings from the increased dimming potential available with fluorescents, or from reduced air conditioning loads that result from the use of more efficient lighting systems. Those factors would make the fluorescent options even more cost-effective. However, each installation should be evaluated individually before a final choice between metal halide and fluorescent fixtures is made.

## Lower Lumen Depreciation Rates

HID and fluorescent lights lose some of their light output as they age. Figure 2 on the previous page illustrates that light loss, known as lumen depreciation, for typical indoor lighting systems. The greater the lumen depreciation of a light source, the wider its associated bar, going from left to right. Of the light sources shown, with only one exception (compact fluorescent lamps), all the HID sources feature wider bars than the fluorescent sources. Expressed quantitatively, it is common for the output of HID sources to degrade by nearly 40 percent over their lifetime, whereas the latest linear T5 lamps maintain lumen output as high as 95 percent of the original value.

**Table 1: Evaluating fluorescent and metal halide lighting fixtures for new installations**

The table compares the installed and operating and maintenance costs for standard metal halide lamps, pulse-start metal halides, and three types of fluorescent options. All four alternatives to the standard metal halide lamps have lower lifecycle costs, and the three fluorescent choices offer lower lifecycle costs than pulse-start metal halides as well.

| | Metal halide | | T5 fluorescent | | |
|---|---|---|---|---|---|
| | Economy standard, 400-W clear | High-efficiency pulse-start, 320-W clear | Six 40-W twin-tube, electronic ballast, 1.04 BF | Four 55-W twin-tube, electronic ballast, 1.00 BF | Four 54-W high-output, electronic ballast, 1.00 BF |
| Initial lamp output (lumens) | 36,000 | 34,000 | 19,656 | 19,200 | 20,000 |
| Design (40 percent of life) lamp output (lumens) | 24,000 | 27,200 | 18,673 | 18,240 | 19,000 |
| Lamp life (hours) | 20,000 | 20,000 | 20,000 | 15,000 | 20,000 |
| Fixture input power (watts) | 460 | 345 | 228 | 234 | 234 |
| Design lamp efficacy (lumens/watt) | 52 | 79 | 82 | 78 | 81 |
| Fixture efficiency (percent) | 70 | 85 | 80 | 95 | 93 |
| Design lumens from fixture (lumens) | 16,800 | 23,120 | 14,939 | 17,328 | 17,670 |
| Conversion factor, standard lumens to pupil lumens | 1.49 | 1.49 | 1.83 | 1.83 | 1.83 |
| Net design pupil lumens from fixture (lumens) | 25,032 | 34,449 | 27,338 | 31,710 | 32,336 |
| Color rendering index (CRI) | 65 | 65 | 85 | 85 | 85 |
| Number of fixtures[a] | 300 | 217 | 274 | 237 | 232 |
| Annual energy consumption @ 5,000 hours per year (kilowatt-hours per year) | 690,000 | 374,000 | 312,00 | 277,000 | 271,000 |
| Annual energy cost @ 0.08/kWh ($) | 55,200 | 29,900 | 25,000 | 22,200 | 21,700 |
| Annual energy savings versus standard 400-W metal halide ($)[b] | NA | 25,300 | 30,200 | 33,000 | 33,500 |
| Installed cost ($) | 60,000 | 75,950 | 68,500 | 65,175 | 63,800 |
| Extra cost compared with standard metal halide ($) | NA | 15,950 | 8,500 | 5,175 | 3,800 |
| Lamp cost ($) | 13 | 50 | 12 | 15 | 15 |
| Relamping maintenance costs ($/year)[c] | 1,350 | 2,984 | 6,987 | 6,320 | 4,640 |
| Lifecycle cost ($)[d] | 478,000 | 354,000 | 339,000 | 306,000 | 287,000 |

Notes: NA = not applicable
BF = ballast factor
a. Number of fixtures selected to provide equivalent lumen output for each alternative.
b. Does not include any savings from reduced fluorescent burn hours (because of "instant-on") or from reduced AC load.
c. Relamping maintenance costs assume that lamps are changed at end of estimated lamp life at a labor cost of $5/lamp.
d. Lifecycle costs include the installed cost plus the present value of the operating and maintenance costs over a 20-year period. The calculation is based on an inflation rate of 2 percent and a discount rate of 12 percent.

Source: James Rogers Consulting and Financial Times Energy

An important consequence of this disparity in lumen depreciation rates is that, in many cases, it eliminates the small advantage HID lamps hold over fluorescent lamps in rated lamp life. For example, the rated life of a typical metal halide lamp is about 20,000 hours, whereas the rated life of T5 fluorescent lamps ranges from 15,000 to 20,000 hours. However, many users are likely to replace the metal halide lamp well before the end of its rated life because the area it is illuminating has become too dark and therefore unsafe or unproductive, or both. The T5 lamp, with its low lumen depreciation rate, is likely to remain in place for a time period much closer to its full rated life. That's why the slightly longer rated lifetime of HID lamps often doesn't result in lower lamp replacement costs when compared with fluorescent lamps.

High-intensity fluorescent fixtures have more options for varying light levels than HID systems have.

## Better Dimming Options

High-intensity fluorescent fixtures have more options for varying light levels than HID systems have. Because most of these fluorescent fixtures have multiple lamps, they can be wired with multiple circuits that can be switched to provide varying light levels. Alternatively, the fixtures can use dimming ballasts to provide varied light levels.

The light output of HID fixtures can also be varied using dimming ballasts. This will permit varying light levels, which can compensate for lumen depreciation. However, the light output from dimmed HID lamps does not vary linearly with the energy consumed; in some cases, very little energy is saved when the light level is reduced. As a result, most HID dimming is done not to achieve varying light levels, but to compensate for the inability of a cold HID lamp to instant-start. The color appearance of HID lamps also changes as the lights are dimmed. The effect typically becomes pronounced as the light dims below 60 percent of its initial output.

To see the benefits of the dimming capabilities of the fluorescent solution, consider the example of a school gymnasium. In some such locations where HID lights are installed, if the lights cannot be dimmed, portable lighting has to be brought in to provide lower levels of illumination for certain nonsport events such as school assemblies. Even at sporting events, the illumination can be uneven, and some sections of the bleachers can become unbearably hot under the glare of the metal halide lamps.

Instead, a system of fluorescent fixtures, each with multiple lamps, can be installed. If the system is wired so that each lamp/ballast combination can be turned on separately, then four lighting levels can be obtained: 25 percent, 50 percent, 75 percent, and 100 percent of full output. Thus, the gym can be illuminated at the level appropriate for a given activity. For example, when maintenance staff clean the gym and set it up for an event, they can work with the light at 25 percent of full output. Then, if the event is a basketball game, the lights can be turned to full power.

Whereas HID lights require a warm-up period of about 4 to 6 minutes, fluorescent lighting systems come on almost instantly.

### Faster Start-Up and Restrike

Fluorescent lighting systems provide "instant-on" operation, or very close to it. HID lighting sources, however, must undergo a warm-up period of about four to six minutes before they produce adequate light. This delay makes it inconvenient to frequently switch HID lights on and off (so, for example, they are unsuitable for being switched by occupancy sensors). To make matters worse, when extinguished by a power interruption, HID lights must cool down before they can be switched back on—and they still must go through the warm-up cycle. After a power disruption, 15 minutes may elapse before HID lights come up to full brightness again. Pulse-start lamps, the newest HID technology, have shorter warm-up times, but they still do not come to full brightness for several minutes—much longer than the typical user will tolerate.

The benefits of instant-on starting can be seen in a warehouse example. In many warehouses, aisles are vacant for long periods. One approach to lighting this type of site would be to use metal halides that dimmed whenever sensors determined that an aisle was unoccupied. However, metal halide lamps dimmed to 10 percent of their full output still use 50 percent of their full output energy. Instead, a system using instant-on fluorescent fixtures allows the lighting to be turned on and off in response to activity in the aisles. The savings possible with such a solution need to be evaluated based on the amount of activity expected at a specific site.

## Better Color Rendition

The color rendering index (CRI) for a particular source is a measure of the degree of color shift that objects undergo when illuminated by the light source as compared with those same objects when illuminated by a reference source. Most HID lamps offer a poor to mediocre CRI (**Table 2**), meaning that objects under their illumination look different from how they might appear in sunlight. The CRI of a metal halide lamp is typically about 65; for a high-pressure sodium lamp it is about 27. Higher-CRI versions of these lamps are available, but they improve color rendering at the expense of efficacy. T5 lamps, in contrast, are available with CRIs that range from the high 70s to the high 90s.

**Table 2: The color rendering index of fluorescent and HID lamps**

The color rendering index (CRI) describes, on a scale of 0 to 100, the capability of a light source to accurately render a sample of eight standard colors relative to a standard source. Light sources that exhibit higher CRIs render color better than sources with low CRIs.

| Lamp type | CRI |
|---|---|
| T8 fluorescent | 75–98 |
| T5 fluorescent | 75–98 |
| High-color-rendering metal halide | 80–93 |
| White high-pressure sodium | 60–85 |
| Standard metal halide | 65–70 |
| Pulse-start metal halide | 65–70 |
| High-pressure sodium | 27 |
| Low-pressure sodium | 5 |

Source: Financial Times Energy

The high CRI of fluorescent lamps is particularly important in retail applications as well as in manufacturing and warehousing. Good color rendering can attract shoppers to merchandise on display and can make it easier for workers in warehouses and manufacturing plants to perform their tasks.

## More Pupil Lumens

For light levels in building interiors, the human eye is most sensitive to light in the blue/green area of the spectrum. Based on that phenomenon, a new unit called the “pupil lumen” has been defined that accounts for the eyes’ varying sensitivity to different areas of the color spectrum.[1] Correction factors have been developed to convert conventional lumens per watt to pupil lumens per watt (**Table 3**). When rated by pupil lumens, T5 fluorescent lighting increases its lumens/watt rating more than metal halide and high-pressure sodium lighting. In other words, the human eye can make better use of the light from a T5 lamp than it can from HID sources.

## High-Intensity Fluorescent Fixture Designs

Fluorescent lighting technology has improved in efficiency because of the cumulative result of improvements in three areas: fluorescent lamps, electronic ballasts, and reflective fixtures. For example, improved phosphors made possible the development of the contemporary T5 lamp, which features higher light output, improved color, and longer life than its more rotund predecessors.

Electronic ballasts, which improve the efficiency of lamp operation and reduce flicker, are now available for nearly all fluorescent lamp sizes and voltages. The newest electronic ballasts also

**Table 3: Conversion factors for lumens to pupil lumens**

Correction factors applied to conventional values of lumens per watt yield a value of pupil lumens per watt, which is a measure of how effectively the eye sees the light that is emitted. The pupil is more receptive to light at the blue end of the spectrum.

| Light source | Conventional lumens per watt | Correction factor | Pupil lumens per watt |
|---|---|---|---|
| Low-pressure sodium | 165 | 0.38 | 63 |
| 5,000-K T5 fluorescent | 104 | 1.83 | 190 |
| 4,100-K T8 fluorescent | 90 | 1.62 | 145 |
| Clear metal halide | 85 | 1.49 | 126 |
| 5,000-K pure triphosphor fluorescent | 70 | 1.58 | 111 |
| 3,500-K triphosphor fluorescent | 69 | 1.24 | 85 |
| 50-watt high-pressure sodium | 65 | 0.76 | 49 |
| 2,900-K warm white fluorescent | 65 | 0.98 | 64 |
| Daylight fluorescent | 55 | 1.72 | 95 |
| 35-watt high-pressure sodium | 55 | 0.57 | 31 |
| 5,000-K 90 CRI fluorescent | 46 | 1.70 | 78 |
| Vitalite fluorescent | 46 | 1.71 | 79 |
| Deluxe mercury vapor | 40 | 0.86 | 34 |
| Standard incandescent | 15 | 1.26 | 19 |
| Tungsten halogen | 22 | 1.32 | 29 |

Note: K = Kelvin; CRI = color rendering index

Source: Financial Times Energy

allow low-temperature starts and frequent switching without reducing lamp life. And computer-aided design has improved fluorescent luminaires from efficiencies of 70 to 80 percent to more than 95 percent. (Before the advent of computers that could optimize the complicated equations involved in optic design, manufacturers weren't able to produce designs that provided even light distribution and extremely high efficiency. Instead, they optimized distribution at the expense of efficiency.) Improvements in manufacturing techniques have lowered the price and improved the availability for all three of these components.

The new fluorescent fixtures for high-bay applications are offered by several manufacturers in several basic design variations. Most are square or rectangular and are derived from either recessed troffers or surface-mounted fixtures. To facilitate one-for-one replacement of existing HID fixtures, the new fluorescent fixtures are usually hung from chains or pendant-mounted from a single point.

One manufacturer sells fixtures with conical reflectors that closely imitate the look of a typical metal halide fixture (**Figure 3**, next page). However, the compact size of these fixtures limits them to the use of shorter compact fluorescent lamps, which are less efficient and have a shorter life than long twin-tube and linear T5 lamps. This manufacturer also sells lay-in and canopy fixtures that use T5 lamps. Some manufacturers also make fixtures that imitate HID fixtures with prismatic reflectors.

Other design variations have been introduced to address aesthetics and some specific customer needs. Several manufacturers package their fixtures into an attractive pyramid shape and offer them in several colors (**Figure 4**). One manufacturer also offers a double-reflector "wing" design very suitable for high-bay warehouse applications (**Figure 5**). Another offers an entire family of fixtures based on a star design, in which smaller arms radiate out from a central core that encloses the ballasts (**Figure**

**6,** page 14). The firm offers fixtures with various numbers of arms (which house the lamps) so end users can achieve the desired light level and distribution. Also, the arms can be individually switched to provide a wider range of light level and control options.

The earlier 2- by 2-foot and 2- by 3-foot fixture designs, which easily accommodate 24-inch-long twin-tube lamps, are not long enough for the standard 4-foot-nominal linear T5 lamps. Because of the superior characteristics of these lamps, several manufacturers are introducing larger fixtures to accommodate them. These 2- by 4-foot T5 fixtures have very high light output, making them appropriate choices for high-bay applications.

## Epilogue: Boosting HID Performance

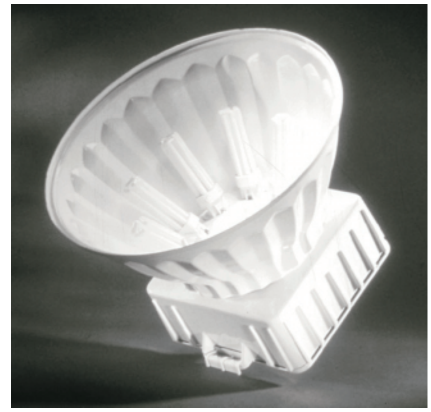
Although the new high-intensity T5 fluorescent lighting fixtures have distinct advantages for many medium- and high-bay applications, the HID industry has introduced some improved products as well. These developments promise to improve the energy efficiency of HID lighting and also mitigate some of its other disadvantages. As with fluorescent lighting, the improvements are being made in three component areas: lamps, ballasts, and luminaires.

With lamps, the greatest improvement has been the introduction of the pulse-start metal halide lamp. Pulse-start lamps are superior in nearly all respects to the standard metal halide lamps. They have higher initial lumens, less lumen degradation, improved color uniformity, and faster warm-up and restrike times.

Pulse-start lamps cannot be used with standard magnetic ballasts, so a new pulse-start ballast must be included in any retrofit. One company has introduced an electronic ballast for use with pulse-start lamps that a company spokesperson claims increases system efficiency by 15 percent and reduces lumen depreciation to only 20 percent—still greater than the 5 to 10 percent loss for T5 fluorescents. It appears that much more can

**Figure 3: Conical reflector**

This fixture uses eight 42-watt compact fluorescent lamps and is designed to resemble a typical HID fixture.



Source: Sportlite

**Figure 4: Pyramid fixture**

The purpose of the pyramid design is to provide a single point from which to hang the fixture.

Source: Intrepid Lighting Manufacturing

**Figure 5: Wing design fixture**

By tilting the lamps, this design provides a broader spread of illumination.

Source: Intrepid Lighting Manufacturing

**Figure 6: Star design fixture**

By putting on two, four, or six arms, the manufacturer can vary the amount of light each fixture puts out.

Source: MetalOptics

Although new high-intensity T5 fluorescent lighting fixtures have distinct advantages for many medium- and high-bay applications, the HID industry has introduced some new technologies as well. As with fluorescent lighting, the improvements are being made in three component areas: lamps, ballasts, and luminaires.

be done to improve the ballasts for HID lamps, and it would not be surprising to see some significant developments in the next few years—particularly in electronic HID ballast technology.

The third area for HID improvement is luminaire design and efficiency. Although the typical "hooded" HID fixture has an efficiency of about 70 percent, efficiencies as high as 90 percent are possible and, in fact, are available from a few manufacturers. However, these high-efficiency luminaires are considerably more expensive than the typical fixture, so they don't yet have a significant share of the HID fixture market.

Some HID manufacturers offer a line of metal halide fixtures that incorporate many of the advanced features described previously. It is doubtful, however, that the more efficient HID fixtures will surpass the efficiency and quality of high-output fluorescents in the near future. Although improvements in lamps, ballasts, and luminaires may eventually make HID lighting systems as energy efficient as the new fluorescent systems, it is unlikely that lighting manufacturers will ever be able to eliminate the warm-up and restrike delay associated with HID lights. This inability to instant-start severely limits the use of occupancy sensors and other switching methods that can save energy.

## Notes

1 Lindsay Audin, David Houghton, Michael Shepard, and Wendy Hawthorne, E SOURCE *Technology Atlas: Lighting,* Chapter 2 (1997), p. 37.

Energy Design Resources provides information and design tools to architects, engineers, lighting designers, and building owners and developers. Energy Design Resources is funded by California utility customers and administered by Pacific Gas and Electric Company, San Diego Gas and Electric, and Southern California Edison under the auspices of the California Public Utilities Commission. To learn more about Energy Design Resources, please visit our Web site at www.energydesignresources.com.