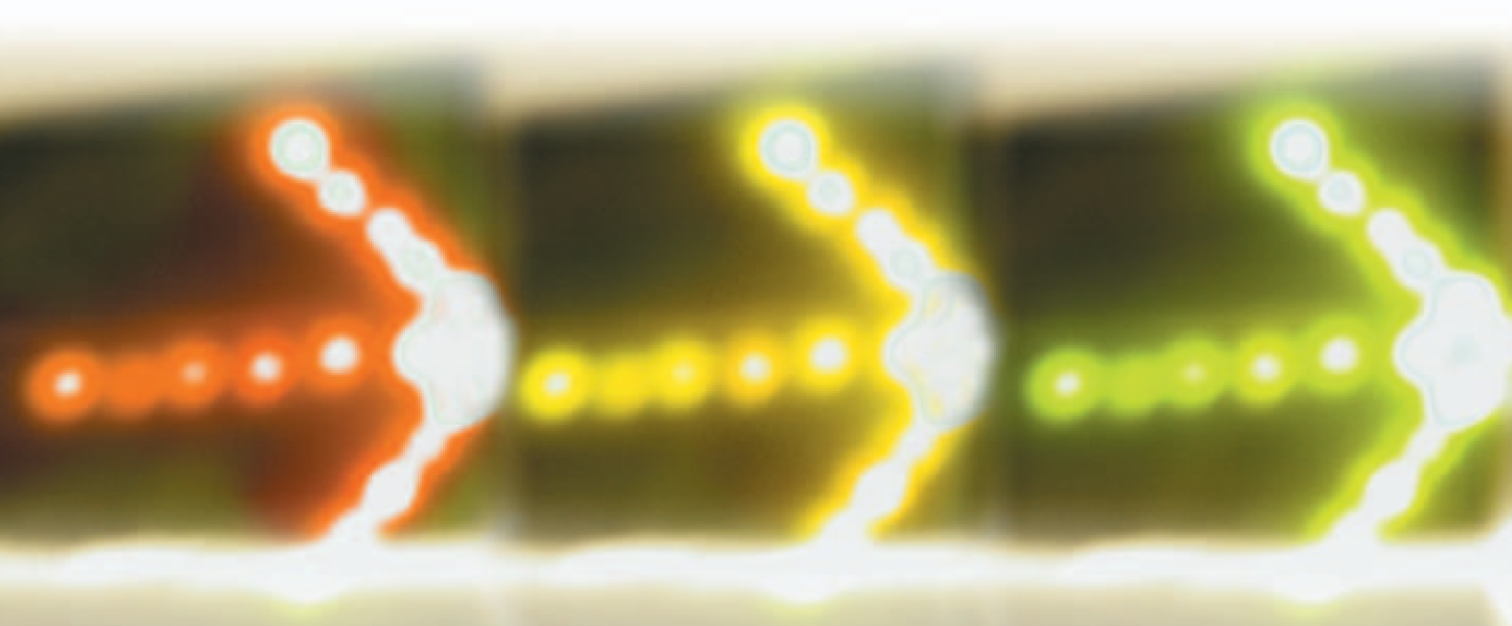
 By Dan Strassberg, Contributing Technical Editor



LEDs GLOW IN ANTICIPATION

LEDs DOMINATE INDICATOR APPLICATIONS IN ELECTRONICS AND NOW OUTSHINE INCANDESCENTS EVEN IN TRAFFIC LIGHTS AND AUTOMOBILE-BRAKE LIGHTS. THAT SCENARIO IS JUST THE START.

Illuminating the dark recesses of the lighting industry is no trivial task. For sure, though, equating lighting with incandescent-lamp technology is *so* 20th century. Even newer forms of lighting, such as compact-fluorescent- and high-intensity-discharge lamps, which continue to evolve at a relatively rapid pace, are no longer at the leading edge. Most of the innovation in lighting now focuses on solid-state light sources—meaning mainly LEDs (light-emitting diodes). Nevertheless, LEDs, despite becoming the dominant form of indicator, have so far enjoyed their biggest lighting successes in specialized applications. A few more years—and maybe more—will almost surely have to pass before solid-state sources mature to the point at which they can wrest the majority of lamp sockets from older forms of illumination.

Some lighting-industry observers place at least part of the blame for this situation on the mature industry's vertically integrated structure. Manufacturers of incandescent and fluorescent lamps aren't set up to buy a major component of their products from third parties. Yet, as things stand, that situation is exactly what most LED-lamp manufacturers face; no major lamp manufacturer makes the semiconductor dice that form the core of LED lamps. (Several Web-based glossaries, including **references 1**, **2**, and **3**, explain lighting terms, such as "lamp.")

Despite this incompatibility with their industry's structure and accustomed ways of doing business, lighting engineers maintain intense interest in LEDs, because, of all forms of electric illumination, only solid-state light emitters are new enough to continue to benefit from rapid technological improvements that bring about dramatic cost reductions. The cost of older lighting technologies is holding constant; only solid-state sources are poised to significantly lower the COL (cost of light).

By some estimates, LED lamps' COL last year became lower than that of halogen units. By approximately 2007, the cost of LED lamps—now slightly less than $27 per MlmH (million lumen-hours)—should decline by approximately 75%. This price drop will bring the lamps' COL to parity with fluorescents' $7/MlmH. Much of this improvement will result from increases in light output, but even if you ignore the increased output, prices of LED lamps used in illumination are declining.

WHAT "COST OF LIGHT" MEANS

The meaning of lighting cost requires explanation. COL involves not only a lamp's initial cost, but also the cost of the energy the device consumes, the cost of the labor required to replace the lamp when it ceases to function satisfactorily, and the average frequency of the required replacements. Incandescent lamps offer low initial cost, but they are relatively inefficient in converting electric energy to light, and they burn out rather quickly. LED lamps hardly ever burn out in the sense that incandescent lamps do. Instead, LED lamps' light output declines over time at a barely perceptible rate. COL calculations typically assume that the end of an LED lamp's useful life occurs when the device's light output has decreased by half.

If patients in some rooms in Children's Hospital Boston tire of watching TV, they can stare at the ceiling. Unlike those in most ceilings, the tiles in these rooms light up in a variety of colors from subtle to vivid (courtesy Color Kinetics).

Lighting engineers usually assume a lifetime of 75,000 hours for a typical LED lamp, compared with 1000 hours for a typical incandescent lamp. Other assumptions to obtain the preceding COL figures are an energy cost of 10 cents/kWH (kilowatt hour) and a $15 labor cost for lamp replacement—a reasonable figure in industrial applications. The calculations ignore the TVM (time-value of money), which accounts for the decline in the dollar's purchasing power over time. Including TVM would somewhat accelerate LEDs' attainment of cost parity with fluorescent lamps. (For additional information, visit the Illumination Engineering Society of North America's Web site at www.iesna.org.)

AT A GLANCE

- ▷ LEDs will eventually become a key technology in illumination, gradually displacing such products as incandescent lamps.
- ▷ The most important motivator for the use of LEDs is their lower long-term cost. Even initial cost, which may never drop to that of incandescents, is rapidly falling, whereas the cost of other lighting technologies holds constant.
- ▷ LEDs have made important inroads in a host of niche applications, such as theatrical lighting.

Still, cost isn't everything in lighting. Aesthetic issues are also important, and, from an aesthetic standpoint, today's white LEDs aren't all that everyone wants. In fact, most commercially available white LEDs really are blue LEDs that excite a white phosphor to broaden their output spectra. Other white-light-emitting LEDs use UV (ultraviolet) emitters that excite a combination of phosphors whose light output appears more or less white. The result is a "cool" light that most people find less pleasing than that of incandescent or even modern fluorescent lamps. Moreover, such LEDs' spectra vary more from sample to sample and change more with operating conditions than do those of incandescent lamps.

LED-lamp designers have devised a solution to this problem that works well in specialized applications, such as theatrical lighting. The approach is currently too expensive for general illumination, however. If you replace the single blue- or UV-emitting device with the combined light output of a red, a green, and a blue LED, and you excite the devices with variable-duty-cycle pulse waveforms, you get a lamp whose output color you can vary over the entire visible spectrum. Such lamps make possible dramatic visual effects and may someday become inexpensive enough to provide a general solution to the white-LED "warmth" problem. More "likely, though, someone will first perfect another lower cost approach—perhaps by adding a low-intensity yellow LED to a single-emitter system.

A MICROPROCESSOR IN *EVERY* LAMP?

Despite the lighting market's cost sensitivity, many LED-based lights now incorporate an incredible degree of technical sophistication. Lamps that contain three LEDs and an 8-bit microprocessor are now common, though lighting engineers try to reserve such intelligence for niche applications that allow prices higher than those of general-illumination products. Lamps that incorporate microprocessors often find use in applications such as theatrical lighting, which involve programmability. Programmability requires communication between a lighting controller and multiple lamps and usually requires the intelligence of a microprocessor or an ASIC inside each lamp. For such applications, the lighting industry has developed the DMX512 communications protocol. DMX512 can run on an Ethernet physical layer. Because of Ethernet's widespread presence in offices and factories, several lighting manufacturers see a marriage between DMX512 and Ethernet as a natural development, in which lighting- and other building-control functions share the Ethernet physical layer.

As is often the case in mature markets, lighting is highly fragmented. Segments have different requirements that require specially designed products. An outsider might easily—and incorrectly—conclude that one product can serve the requirements of multiple segments. However, such a conclusion would likely overlook subtle differences among the needs of the different applications.

Color Kinetics furnishes the following list of lighting-market segments:

- architectural lighting for schools, churches, hospitals, and corporations;

- hospitality lighting for hotels, resorts, restaurants, cruise ships, and spas;
- municipal lighting for buildings, bridges, stadiums, arenas, and airports;
- event lighting for trade shows, ceremonies, concerts, and fashion shows;
- retail lighting for visual merchandising, store design, displays, and cosmetics;
- stage lighting for Broadway, TV studios, film sets, dance, and photography;
- landscape lighting for grounds, water features, fountains, pools, and spas;
- residential lighting for living spaces and home theaters;
- museum and educational lighting for exhibits, planetariums, zoos, aquariums, and monuments;
- transportation lighting for planes, trains, cars, and marine environments;
- fine-art lighting for sculpture, mixed media, images, and performance; and
- science lighting for imaging and color therapy.

Of these segments, one of the currently most visible for LED lamps is transportation. LEDs are making quick inroads into the automotive-brake-light market. When a vehicle makes a quick stop, LED brake lights provide an added margin of safety, because they reach full brightness approximately 100 msec faster than do incandescent lamps. The benefits don't end there, however; LED brake lights are smaller than incandescent units with their associated lenses. Therefore, LED brake lights allow modest increases in trunk space. LED lamps are also more rugged than other types of lamps, making them better able to withstand automotive applications' shock and vibration. LED lamps can also often enable more creative styling at lower cost than can incandescent units. Moreover, brake lights are far from the only places in cars where LEDs are beginning to appear. Two other applications are instrument-cluster-lighting and interior illumination.

LED-based traffic lights have been rapidly displacing incandescent lights because of the solid-state units' lower energy costs, intrinsically longer life, and lower replacement costs (when you include labor costs). Replacement costs are dramatically lower than those of incandescent lamps, even if you fail to account for the boost in reliability that results from using large numbers of LEDs in each lamp. In fact, the lamps in new traffic lights may not require multiple LEDs for much longer. Since the lights' introduction about five years ago, technological improvements have increased each emitter's output by a factor of approximately 20. A further improvement only about one-third as great could enable the design of traffic-light lamps that contain just one emitter—plus a diffuser to make the light appear to emanate from a source larger than a pinpoint.

LIGHTING UP THE THIRD WORLD

Lighting-industry analysts see a bright future for LED-based illumination in underdeveloped countries that lack the electrical-distribution-grid infrastructure of industrialized nations. The analysts believe that the impact of this phenomenon will be similar to that of wireless-communication technology in areas that lack a wired-communications infrastructure. In many underdeveloped areas, productive work is limited to daylight hours. Working or reading at night may be theoretically possible thanks to the use of devices such as kerosene lamps, but the infrastructure for distributing fuel for the lamps sometimes functions inadequately. LED-based lamps that receive power from solar cells and contain batteries to store energy received during daylight require no fuel-distribution infrastructure and are likely to increase by approximately one-third the number of hours each year during which productive work takes place.

For those interested in less grandiose transformations, several companies offer a type of LED-based illumination whose goals almost couldn't be more modest—providing keyboard lighting for on-the-go notebook-PC users who aren't touch typists. If you need to read the legends on your keyboard's key caps and you are working in a darkened room with no ac outlet nearby, you quickly discover that the light that radiates from the PC screen provides inadequate illumination. For people in this predicament, LED lights that plug into the PC's USB port provide an ideal solution. The lights derive only power—no data—from the port. Levenger's $19.95 unit provides five white LEDs at the end of an 18-in. gooseneck arm whose opposite end is a connector that plugs into either a USB 1.1 or a USB 2.0 port.

LEDs' latest conquest in the automotive market: backlighting for instrument clusters (courtesy Fairchild Semiconductor).

LEDs can replace conventional discharge lamps to provide the flash for mobile-phone cameras. Unlike discharge lamps, LEDs require no charge-up time (courtesy Osram).

Designing fixtures—or "luminaires," in lighting-industry parlance—for LED lamps requires attention to issues with which designers of equivalent hardware for incandescent and fluorescent lamps rarely need concern themselves. The two most obvious issues are power supplies and thermal management. Most incandescent lamps operate directly from the ac line and therefore need no power supplies. With fluorescents, ballast modules perform the function most nearly analogous to that of a power supply. With incandescent lamps, thermal management mainly concerns hazards to users: the likelihood of burns from touching a hot fixture or the likelihood of the hot fixture's causing a fire. These issues are usually not a problem with fluorescent lamps, which dissipate less power.

Like fluorescents, LEDs are also highly efficient; depending on the color of the emitted light, LED lamps can be somewhat more or somewhat less efficient than fluorescents. Nevertheless, as LED lamps' light output—and, hence, input power—increases, thermal issues in luminaire design take on greater importance. The reason is that, unlike the filaments of incandescent lamps, which must glow with white heat and thus must withstand extremely high temperatures merely to perform their intended function, LEDs are semiconductor devices, and excessive temperatures can, therefore, shorten or end their lives. Because forced-air cooling is usually undesirable in luminaires, as power levels increase, heat sinks and other methods of enhancing natural-convection cooling play increasingly prominent roles in LED-lamp and luminaire design.

As for power supplies, LEDs' growing importance in illumination comes at a fortuitous time in the evolution of power-supply technology. As the supply voltages for silicon ICs plummet, the voltages at which LEDs operate lie more and more at the sweet spot of power-supply-output voltages. Most of the technology developed for powering low-voltage ICs applies equally well to powering LEDs—especially higher power LEDs. Moreover, LED power supplies should be able to take advantage of the economies of scale that result from the escalating volumes of low-voltage-IC supplies.□

REFERENCES

1. Lighting Research Center, www.lrc.rpi.edu/programs/nlpip/glossary.asp.
2. US Department of Energy, www.eere.energy.gov/buildings/homes/lightingterms.cfm.
3. Philips, www.lighting.philips.com/glossary/index.php.

AUTHOR'S BIOGRAPHY

Contributing Technical Editor Dan Strassberg makes only modest demands on the lighting of his surroundings. Strassberg, who has been working for and with EDN *for more than 16 years, holds a BSEE from Rensselaer Polytechnic Institute (Troy, NY) and an MSEE from the Massachusetts Institute of Technology (Cambridge, MA). Contact him at strassbergedn@att.net.*

FOR MORE INFORMATION...

For more information on LED-related products for illumination and other applications, please contact any of the following manufacturers directly, and please let them know you read about their products in *EDN*.

Agilent Technologies
Manufactures LEDs
1-800-452-4844
www.semiconductor.agilent.com/cgi-bin/morpheus/home/home.jsp

Bridgestone Industrial Products
LED-based industrial lighting products
www.luxaura.com

Catalyst Semiconductor
LED-driver ICs
1-408-542-1080
www.catalyst-semiconductor.com

Christmas Treasures
Retails holiday lighting
1-541-822-3516
www.christmas-treasures.com

CMC Electronics Inc
LED keyboards for night vision in military-aerospace applications
1-630-466-4343
www.cmcelectronics.ca

Color Kinetics
Designs, manufactures, and markets products that apply LEDs in professional-lighting, consumer, and OEM applications; licenses proprietary technology
1-888-385-5742, 1-617-423-9999
www.colorkinetics.com

Cotco Luminant Devices
Manufactures LEDs
011-852-2424-8228
www.cotco.com

Cree Inc
Supplies materials and technology to manufacturers of LEDs
1-919-313-5300
www.cree.com/Products/led_index.asp

Data Display Products
Manufactures illumination products, including LED lamps
1-800-421-6815
www.ddp-leds.com

DuPont OLEDs
Provides OLED (organic-LED) technology and products
1-805-562-9293
www.olight.com

ETG Inc
Manufactures LEDs, custom LED-based products
1-323-937-5463
www.etgtech.com

Fairchild Semiconductor
Manufactures LEDs, including ultrabright surface-mount devices
1-408-822-2146
www.fairchildsemi.com

Forever Bright
Provides LED holiday lighting; among retailers is Christmas Treasures
www.foreverbright.com

Harvatek Corp
Manufactures LEDs
+011-886-3539-9889
www.harvatek.com.tw

Kingbright USA Corp
Provides LED lamps and displays
1-909-468-0500
www.us.kingbright.com

Kodak
Provides OLED technology and products
www.kodak.com/US/en/corp/display

Ledtronics Inc
Manufactures LED illumination products, including direct replacements for incandescent lamps
1-800-579-4875, 1-310-534-1505
www.ledtronics.com, www.led.net

Levenger
Retails consumer LED-based illumination products
1-800-667-8034
www.levenger.com

Lite-On Inc, Optoelectronics Division
Manufactures LED lamps, displays
1-408-946 4873
www.liteon.com.tw

Lumileds Lighting LLC
Provides LED-based illumination products, LED-camera flash using the company's Luxeon technology
1-877-298-9455, 1-408-435-6111
www.lumileds.com

Nichia America Corp
Provides materials used in LED-based products
1-717-285-2323
www.nichia.com

ORled
Offers specialized LED-based illumination products, such as for microscopes
1-503-968-1375
www.orled.com

Osram Opto Semiconductors
Manufactures optical semiconductors, including LEDs, for automotive, communications, consumer, office, and industrial applications
1-248-596-0367
www.osram-os.com

Philips Lighting
Developing PolyLED, a polymer LED technology
www.research.philips.com/Assets/Downloadablefile/passw1_16-2114.pdf

Sharp Microelectronics
Manufactures LEDs
1-360-834-2500
www.sharp-world.com

Spectra Lux
Provides LED lighting for aerospace cockpit control panels
1-425-823-6857
www.spectralux.com

Stanley
Manufactures LEDs
+011-81-3-3710-2222
www.stanley.co.jp

Super Vision International
Provides LED-based signage products
1-407-857-9900 ext 241, ext 270
www.signweb.com

Vishay-Telefunken
Manufactures LEDs
1-408-988-8000
www.vishay.com

Industry organizations

Illumination Engineering Society of North America (IESNA)
www.iesna.org

Optoelectronics Industry Development Association (OIDA)
www.oida.org