Promises and Limitations of Light-Emitting Diodes

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Full citation: Zehner, Ozzie. "Light-Emitting Diodes." In *Green Technology*, edited by Paul Robbins, Dustin Mulvaney and J. Geoffrey Golson, 288-91. London: Sage, 2011.

Abstract: Light-emitting diodes (LEDs) are highly efficient, durable, and long lasting lighting devices. Since a fifth of electrical generation goes toward lighting, LEDs hold the potential to greatly reduce energy use. However, energy efficiency rebound effects could partly or entirely offset these savings.

Light-emitting diodes, also called solid-state lighting or simply LEDs, are highly efficient, durable, and long lasting lighting devices. The technology has improved enormously since the 1960s when the first LEDs came to market. LEDs are now the industry standard in a variety of specialty lighting markets and the popular bulbs are rapidly entering the general illumination market. LED bulbs are more energy efficient and last longer than incandescent, halogen, and fluorescent bulbs but their up front costs are higher. Since a fifth of electrical generation goes toward lighting, LEDs hold the potential to greatly reduce energy use. However, energy efficiency rebound effects could partly or entirely offset these savings.

A Short History of LEDs

Designers and product engineers have long appreciated LEDs for their extended life spans, which makes them ideal for indication lighting in electronic devices. Early bulbs were dim and expensive. Over subsequent decades the industry successfully improved both light output and energy efficiency. During the 1970s, the cost per lumen of light output from a standard LED bulb was about $10. This quickly dropped to about $1 per lumen in the 1980s and to just ten cents per lumen in the 1990s.

LEDs from the 1960s and 70s could only emit yellow-green, orange, red, or infrared light. White LEDs, based on blue LED technology, arrived on the market in the 1990s. Early LED designs for general illumination emitted a bluish white light. Developers worked to improve white LED light quality for general illumination and specialty lighting applications. Subsequently, a more complete spectrum of LED illumination became available to lighting engineers who then tinkered with the subtleties of “warm” or “cool” white LED output. In the 2000s, LEDs became standard for aircraft, ship, and automotive lighting as well as emergency lighting, signage, flat screen display backlighting, operating room lighting, supermarket freezer lighting, and a variety of other specialty lighting applications. In 2010, numerous LED manufactures released bulbs designed for general illumination priced at around $60. Prices have since dropped but up-front cost for the bulbs still poses a barrier to broader LED adoption.

Technical Operation and Efficiency

LEDs contain a tiny flake of semiconducting material with surface area that is often less than 1 square millimeter. These semiconducting materials, such as aluminum-gallium-arsenide (AlGaAs) and gallium nitride (GaN), are not conductive in their pure form. However, they become conductive when doped with impurities to create N-type material (containing extra negatively charged particles) or P-type material (containing extra positively charged particles). When N- and P-type materials are joined, the charged particles migrate and stabilize to create a non-conductive zone. Like a typical diode, the non-conductive zone blocks electrical current in one direction. However, applying current in the other direction pushes the charged particles out of the non-conductive zone. The gate then regains conductivity and current can freely flow. In a light-emitting diode, this current induces electroluminescence. Semiconductor properties determine light output color, which corresponds to the energy of the released photons. Integrated optical and reflective components shape the light output.

Lighting engineers determine the efficiency of lighting devices by measuring the lumens of light output per watt of electrical input. The most efficient incandescent lights (i.e. filament light bulbs) can convert one watt of electricity into 17 lumens of light output. Compact fluorescent bulbs yield about 60 lumens per watt and linear fluorescent bulbs produce about 80 lumens of light output per watt. In 2006, commercially-available white LEDs surpassed the efficiency of linear fluorescent technology. Since then, researchers have developed prototype LEDs with a luminous efficacy of over 200 lumens per watt.

Benefits and Drawbacks

Beyond energy efficiency, LEDs offer users several other distinct benefits as well as a few drawbacks and limitations. Since they don't contain filaments or glass, they are generally more durable than incandescent and fluorescent bulbs. LED bulbs generally have long life spans, ranging from 25,000 to 100,000 hours, compared to 15,000 hours for fluorescents and 2,000 hours for incandescent filament bubs. The long life span of LEDs makes them especially ideal for applications where bulb failures are difficult to replace or create dangers.

For instance, LEDs are now standard for municipal traffic signals. LED signal lights cost much less to power than incandescent signal lights. Furthermore, since the bulbs fail less frequently, traffic intersections updated with LED signals are safer for motorists and pedestrians. Though, LED signal lights do have a couple of drawbacks. Blowing snow can completely cover the signal lamps since the bulbs don't emit enough heat to resist icy buildup. When first introduced, green LED signal lamps frequently failed under real-world conditions. Fortunately, most LED lamps contain multiple LEDs so when failure does occur, it typically emerges incrementally over time rather than all at once.

LEDs provide adjustable and high-quality lighting options, making them ideal for backlighting various types of flat screens, from mobile phones to televisions. LEDs are not prone to the flickering or humming associated with fluorescent technologies. Likewise, their ability to quickly and reliably switch on and off makes them well suited for fiber optic communication devices. LEDs produce a highly directional light that is ideal for task lighting, street lights, and flashlights but is more challenging to integrate into bulbs for general illumination. Visible spectrum LED bulbs produce comparatively little ultraviolet radiation or heat compared with other types of bulbs. However, even small amounts of heat trapped inside the LED's electronics can cause the devices to fail if not adequately dissipated. LED products offer lighting designers flexibility since the bulbs are small, dimmable without color shifts, and shock resistant. Furthermore, environmentalists value LEDs because they consume less energy than other lighting options and they don't employ regulated toxic substances such as the mercury found in fluorescent lighting.

The total economic benefits of switching to LEDs are only realized over their long life span. Even though LEDs are less expensive to operate over time, the up-front costs are higher than other available alternatives. Despite this restriction, LED bulbs are displacing conventional bulbs in numerous lighting markets. Over the past decade, the market for high-brightness LEDs has doubled every 2-3 years. LED demand for traffic signals, vehicle lighting, signage, and backlighting drove this exponential growth. Demand for LEDs is set to remain strong over coming years.

Potential for LEDs to Reduce Energy Consumption

According to the United States Energy and Information Administration, lighting applications in commercial buildings consume more energy than air conditioners, refrigerators, computers, and office equipment combined. Presumably, broad LED adoption could cut electrical demand for lighting by half or more, but only in certain contexts. Even though LEDs use less energy, they don't necessarily hold the potential to reduce energy consumption on a large scale unless countries or regions first institute stops to prevent the energy efficiency rebound effect, or Jevons' Paradox, from negating efficiency gains. For instance, if LEDs make illumination less expensive, then homeowners, organizations, and municipalities may increase their use of lighting services as a result, thereby offsetting the gains achieved through higher device efficiency. Or, as energy users save money on lighting, they may choose to spend those savings on energy-intensive purchases that would otherwise have not been made. Therefore, LEDs are only valuable as energy reduction mechanisms in regions where backstops, such as increased energy taxes or regulations, are in place to prevent the rebound effect from taking hold. Otherwise, deploying LEDs may simply shift energy consumption from the lighting sector to other sectors.

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Bibliography

Hadhazy, Adam. “17 Projects Shaping the Future of LED Lights.” Popular Mechanics (January, 2010).

Horace Herring and Steve Sorrell, eds. *Energy Efficiency and Sustainable Consumption: The Rebound Effect*. New York: Palgrave Macmillan, 2009.

Pimputkar, Siddha, et al. “Prospects for LED Lighting.” *Nature Photonics* (v.3,2009).

U.S. Department of Energy, “Solid-State Lighting.” Available online at: www.ssl.energy.gov (accessed September 2010).

Zehner, Ozzie. *Green Illusions: The Dirty Secrets of Clean Energy and the Future of Environmentalism*. Lincoln, NE and London: University of Nebraska Press, 2012.

Zehner, Ozzie. "Population/Overpopulation." In *Green Culture*, edited by Paul Robbins, Kevin Wehr and J. Geoffrey Golson, 366-69. London: Sage, 2011.

Zehner, Ozzie. *Producing Power: The Semiotization of Alternative Energy in Media and Politics*, Department of Science and Technology Studies Amsterdam: University of Amsterdam, 2007.

Zehner, Ozzie. "Unintended Consequences." In *Green Technology*, edited by Paul Robbins, Dustin Mulvaney and J. Geoffrey Golson, 427-32. London: Sage, 2011.