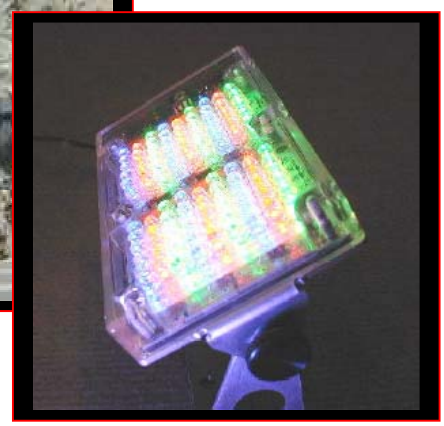
Customer Advanced Technologies Program

Light Emitting Diode (LED) Lighting Systems



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Customer Advanced Technologies Program
Sacramento Municipal Utility District
June 12, 2003

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About the Customer Advanced Technologies Program

SMUD's Customer Advanced Technologies (C.A.T.) program works with customers to encourage the use of and evaluate new or underutilized technologies. The program provides funding for customers in exchange for monitoring rights. Completed demonstration projects include lighting technologies, light emitting diodes (LEDs), residential building shell construction, geothermal heat pumps, indirect / direct evaporative cooling, non-chemical water treatment systems and a wide variety of other technologies.

For more program information, please visit: http://www.smud.org/community/cat/

Introduction

Light emitting diodes (LEDs) seem to be almost everywhere. They are used as indicator lights for video equipment, battery chargers, telephones, digital cameras, clocks, appliances, electronic toys and many other applications. If you've driven anywhere lately, you've probably noticed a growing number of LED traffic signals, exterior signs and cars with LED brake lights.

This evaluation report focuses on LED lighting applications and attempts to address the following questions: How do LEDs work? Are they cost effective? What are some of the benefits and challenges associated with using this technology?

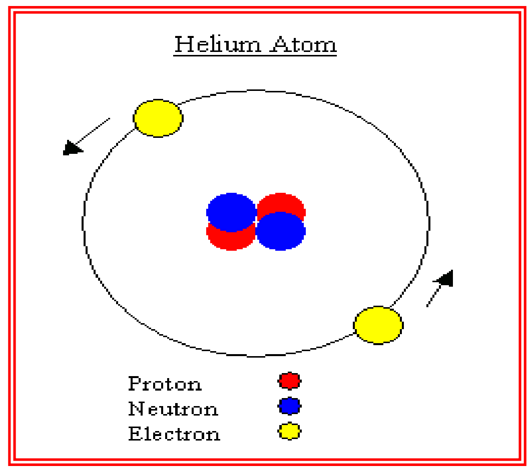
Technology Description: How Do LEDs Work?

In order to understand how LEDs work, we need to first define some of the terms.

Electrical Current

Atoms contain protons, electrons and neutrons. Protons are positively charged particles that reside in the nucleus (center) of the atom. Neutrons also reside in the nucleus but do not have an electrical charge. Electrons are negatively charged particles that orbit the nucleus (**Figure 1**). In any atom, the two charges are exactly balanced, so that to the outside world the atom is electrically neutral. However, when an outside force acts upon the electrons, they can 'jump' from the orbit of one atom to another. This movement of electrons is called **electrical current**. When carefully controlled, electrical current is very useful and can be used for many purposes.

Figure 1



Conductors & Insulators

The ability of a material to allow electrical current to flow is known as conductivity. The more conductive the material, the easier current can flow through it. Materials that easily conduct electricity are classified as **conductors**. Materials that resist the flow of electrical current are called **insulators.**

Semiconductors

Some materials can act as both conductors and insulators. These materials are classified as **semiconductors**. They are usually made of a poor conductor, which has had conductive impurities added to it in a process called doping. This process is used to create materials with an excess of electrons **(N-type material)** or materials with a lack of electrons (**P-type material)**.

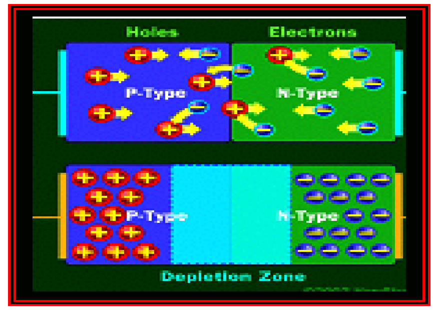
- N-type materials have a negative charge since they have 'extra' electrons. In N-type material, the free electrons move from a negatively charged area to a positively charged area.

- ☐ P-type materials have a positive charge since they are 'missing' electrons. In essence, these materials have 'holes' that free electrons can easily move into. Electrons can jump from hole to hole, moving from a negatively charged area to a positively charged area.

Diodes

Diodes are simple semiconductor devices that consist of a section of N-type material bonded to a section of P-type material, with electrodes on each end. This arrangement allows electricity to flow in only one direction. When no voltage is applied to the diode, electrons from the N-type material fill the holes in the P-type material along the junction where the two materials meet. This area is called the **depletion zone** (**Figure 2**). When all of the free electrons from the N material have filled the holes in the P material, the semiconductor material acts as an insulator and will no longer allow current to flow.

Figure 2

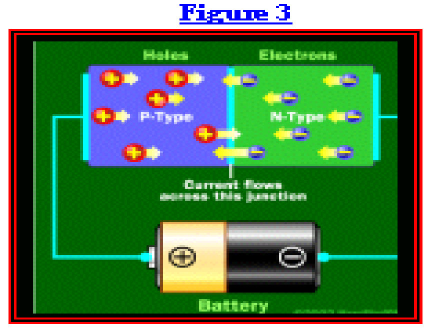


Source: How Stuff Works (1)

When electrons move from one orbit to another within an atom or from one atom to another, light energy is released in the form of photons. Certain types of atoms have electrons in higher orbits and are therefore capable of producing more light energy.

To conduct electrical current through a diode, the depletion zone must be eliminated. This is accomplished by applying sufficient voltage to the electrodes as shown in Figure 3.

Figure 3



Source: How Stuff Works (1)

Figure 4

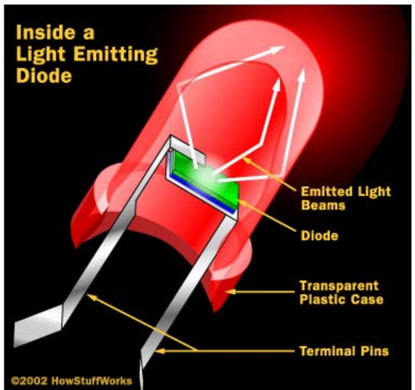
Source: How Stuff Works (1)

When this happens, the free electrons in the N-type material are repelled by the negative electrode and drawn to the positive electrode. Conversely, the holes in the P-type material 'move' the other way. When the voltage difference between the electrodes is high enough, the electrons in the depletion zone begin moving freely again. The depletion zone disappears, and current moves across the diode (Figure 4). The diode now acts as a conductor

Although all diodes produce light, standard silicon diodes produce very little light that is subsequently absorbed within the diode housing. Other types of diodes produce infrared light that is invisible to the human eye. These diodes are commonly used for remote control devices for television, VCRs, stereos and many other devices.

Light Emitting Diodes (LEDs)

As the name implies, light emitting diodes are specifically designed to produce light. The conductive material used to make red LEDs is usually aluminum-gallium-arsenide (AlGaAs). LEDs are encased within plastic housings that are carefully designed to direct the maximum amount of the produced light in a particular direction.



Source: How Stuff Works (1)

High Intensity & Color LEDs

About ten years ago, engineers developed a semiconductor crystal made of aluminum gallium indium phosphide that dramatically improved the light output of red LEDs. These new LEDs were dubbed "high intensity LEDs." Meanwhile, the Nichia Corporation introduced the first practical blue LED.
These two developments had a tremendous impact upon the advancement of LED technology and opened the door to a broad spectrum of new applications including LED traffic signals.[2] By using different semiconductor materials, manufacturers are now able to make LEDs that produce red, green, amber and blue photons.

White LEDs

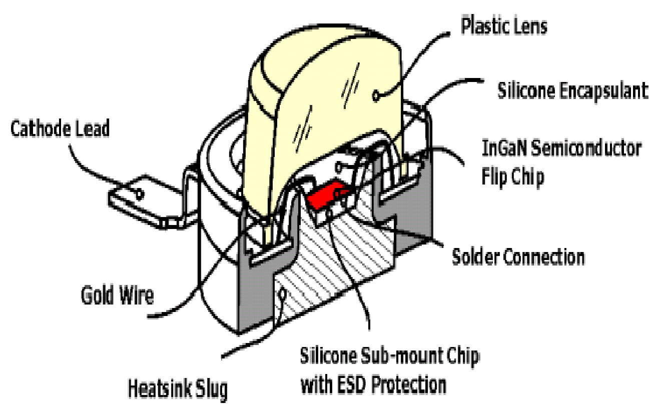
Today the industry is focused upon developing efficient high-intensity LEDs that produce white light. This is crucial in order for LEDs to be able to compete with incandescent and fluorescent lighting systems. However, since white light is actually composed of many colors, and LEDs produce monochromatic colors, this poses a considerable challenge for LED technology. Presently, engineers have developed three options for producing white light with LEDs:

1) Mixing red, green and blue (RGB) LEDs
2) Ultraviolet LEDs with RGB phosphor coatings
3) Blue LEDs with yellow phosphor

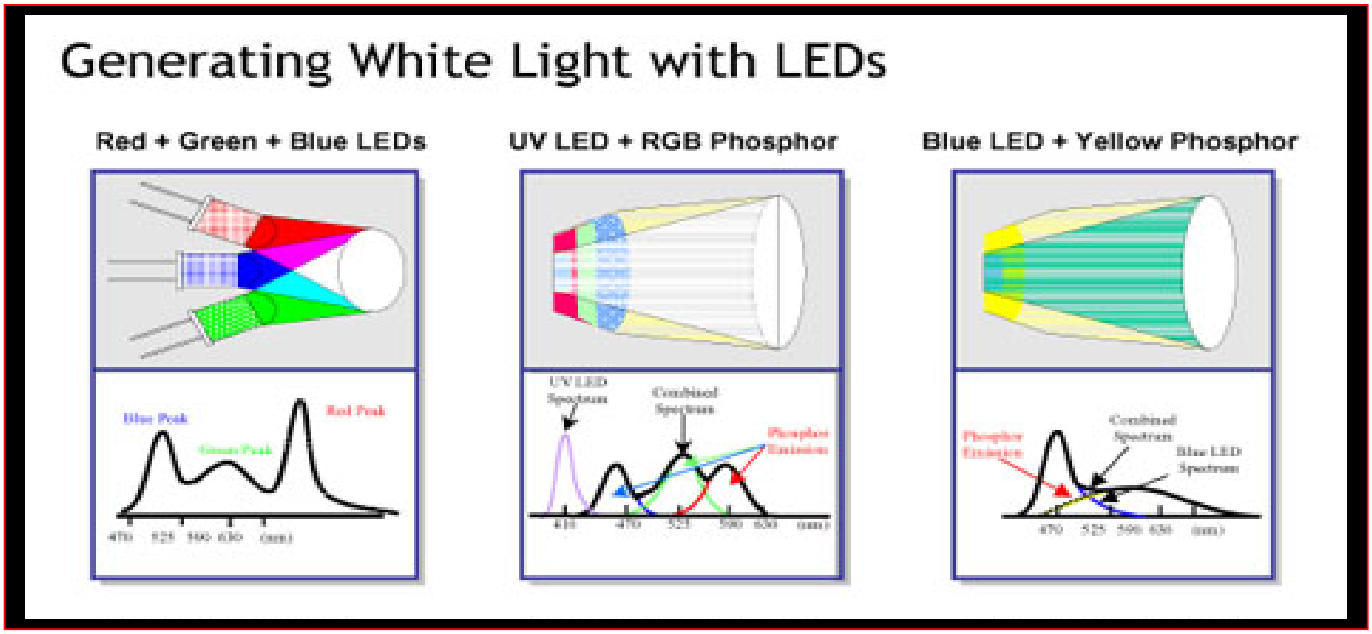
Each of these strategies has their own advantages and drawbacks **(please refer to page 4 for more information)**.

Using LEDs to produce white light is in the relatively early stages of development. Researchers are continuing to make significant progress by experimenting with different materials and manufacturing processes.

Anatomy of a High Intensity LED



Source: Lumileds™ (3)



Source: Lumileds™ (3)

Method	Advantages	Disadvantages
Red + Green + Blue	➢ Excellent control ➢ Excellent color rendering ➢ Large color gamut	➢ Requires complex controls ➢ Deficit in green & yellow
UV + RGB Phosphor	➢ Excellent color rendering ➢ Phosphors determine the color temperature of the source ➢ Theoretically simple to manufacture	➢ Phosphors are temperature dependent ➢ Less efficient due to use of phosphors ➢ Potential for damaging UV light leakage
Blue + Yellow Phosphor	➢ Fair color rendering ➢ Relatively simple to manufacture	➢ Phosphors are temperature dependent ➢ Less efficient due to use of phosphors

Customer Advanced Technologies Showcase Project

Project: **American River Canyon North Waterfall**
100 American River Canyon Drive
Folsom, CA 95630

American River Canyon North

Base Case: The entrance to the American River Canyon North community features a majestic waterfall. Unfortunately, the City of Folsom, which is responsible for maintaining the waterfall, was experiencing serious problems with the lighting system. The original system, which consisted of 250-watt halogen fixtures submerged in the basin, was prone to premature failures and vandalism. To make matters worse, the fixtures often leaked and caused the electrical breakers to trip. This created a potentially dangerous situation since local children often play near the waterfall after dark. City electricians were frequently dispatched to replace lamps, repair the fixtures and restore power to the waterfall. An innovative solution was badly needed to address the problem.

New System: The solution started to form late one night as Kevin Furry, a local resident and founder of LED Effects, was driving past the darkened waterfall. Why not use LEDs? Soon after, a prototype fixture was created and the concept began to take shape. The City of Folsom was intrigued by the idea of using LEDs and began working with the American River Canyon North Homeowners Association, Elliott Homes, LED Effects and SMUD to develop and install the new state-of-the-art LED lighting system. The new system consists of 40 rugged submersible fixtures. Each fixture includes 90 Nichia White 4000K LEDs to produce white light yet only consumes an amazingly low 4.5 watts of power.

Results: Although the new system is not quite as bright as the old system, most residents seem to be satisfied with the results of the project. Since the rated life of the new LED system is 50,000 hours, the City's maintenance costs should be dramatically reduced. The new fixtures are also very energy efficient and are expected to save over 23,392 kWh annually.

Source: LED Effects(4)

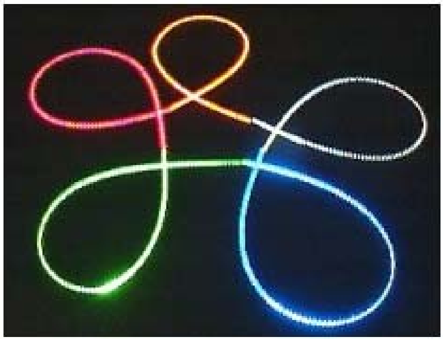
- Project cost = $26,906
- Customer Advanced Technologies Program grant = $13,453
- Net project cost = $13,453
- Estimated annual cost savings (energy & maintenance) = $7,282
- Simple payback = 1.8 years

Comments: ***"Working with SMUD allowed the City to incorporate a new technology (LED) into one of our most financially challenged landscaping and lighting districts. The new system should dramatically reduce the City's maintenance and energy costs."***

- Lorraine Poggione, Landscaping and Lighting District Manager

Customer Advanced Technologies Showcase Project

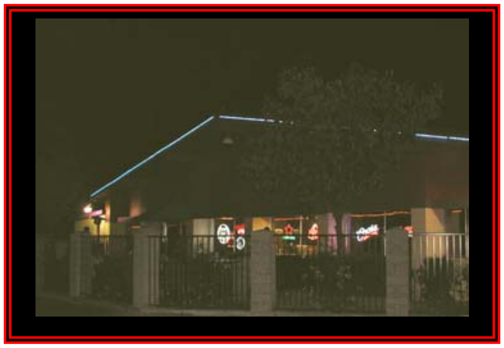
Project: **Folsom Lake Bowl**
511 E. Bidwell Street
Folsom CA 95630



Source: LED Effects(4)

Base Case: Owner Dan Dreher was looking for ways to spruce up the exterior of his family-owned business. He originally thought about using neon to highlight the facade, but knew that local ordinances prohibited the use of open-faced neon because it was vulnerable to vandalism.

New System: Mr. Dreher decided to install a system offered through a local LED lighting manufacturer known as RGB FlexStrips™ The new lighting system is programmable via a desktop computer and can be set to produce red, green or blue light. When combined with an optional controller, the system is able to produce multiple color effects including color mix, fade, wash, flash, and scintillate.



Source: LED Effects(4)

Benefits:

- LEDs are energy efficient and can last up to twice as long as neon lamps (100,000 hours versus 50,000 hours)
- Unlike neon, LED FlexStrips™ are impact resistant
- Lighting system effects attract the attention of potential customers
- Project cost = $9,460
- Customer Advanced Technologies Grant = $4,730

Comments:

"We are very happy with the LED lights, they look great, grab attention, last forever, and they are very cost-effective. Our customers comment on them all the time because it's something that they have never seen before. I would definitely recommend using them."

- Dan Dreher, Owner, Folsom Lake Bowl

Customer Advanced Technologies Showcase Project

Project: **Retail Shopping Center**
Sacramento, CA

Base Case: A major shopping center in the Sacramento area features spectacular architectural details including domed skylights, archways, live trees and water fountains.

Unfortunately, the MR16 lighting system used to illuminate the domed skylights at night was a maintenance nightmare. The lamps were failing at an alarming rate – primarily due to excessive heat. To make matters worse, replacing the lamps required the use of a scissor lift (see photo).

New System: Gil Razo, a SMUD Energy Specialist, saw an excellent opportunity to for using LEDs. After exploring various options, Mr. Razo recommended replacing the MR16 fixtures with an innovative product known as the RGB Smart Dot.™

Results: The new lighting system has dramatically reduced maintenance and energy costs. Each head consumes less than 3 watts and is expected to last at least 50,000 hours! The Smart Dot™ system also offers the ability to create numerous special effects such as fade, wash, flash, and scintillate.

RGB Controller, LED Effects (4)

Source: LED Effects(4)

- Project cost = $8,100
- Customer Advanced Technologies Program grant = $4,000
- Net project cost = $4,100
- Estimated annual energy savings = 14,352 kWh
- Estimated cost savings (energy & maintenance) = $1,803
- Simple payback = 2.3 years

Comments: "The future bet is LED lighting over conventional lighting. Creating LED lighting accents with electronic control is now possible. LEDs provide all temperatures of white and vivid colors, longer lifetime, no fire hazard, and allow for much more compact fixture designs over conventional lighting technologies. The days of changing light bulbs are numbered."

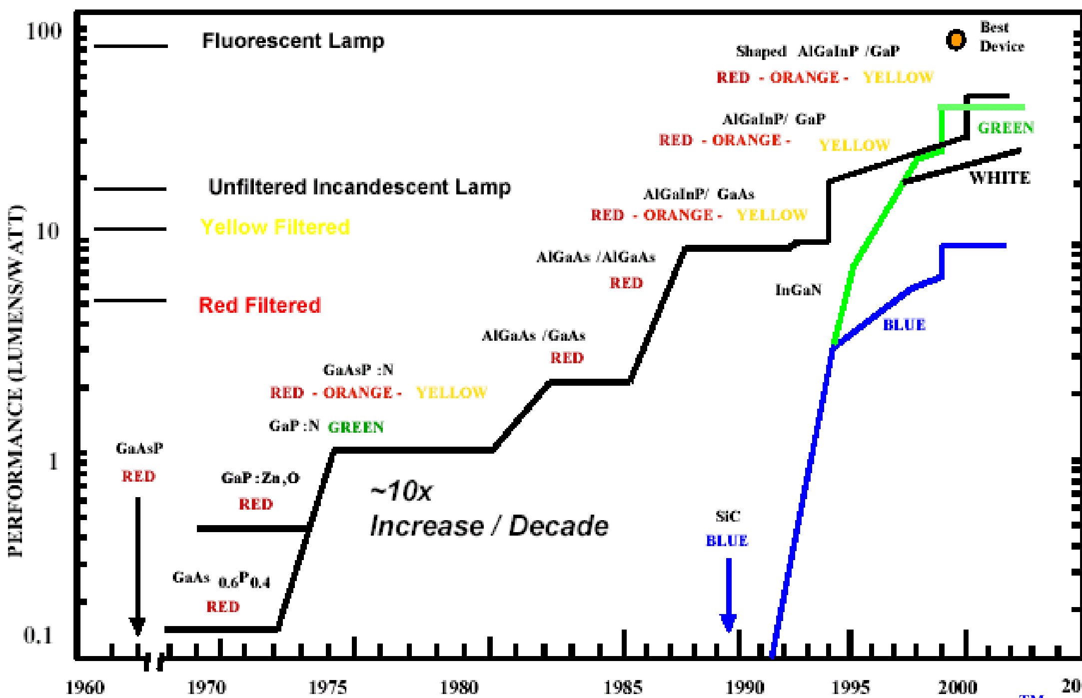
- Kevin Furry, Owner LED Effects

Properties of LEDs

Efficacy

Efficacy is commonly used to compare lighting sources and is measured in lumens per Watt (LPW). The chart below, from Lumileds,[3] depicts the evolution of LEDs. As shown below, the efficacy of LEDs has improved dramatically over the past few decades and is rapidly approaching the efficacy of fluorescent systems. In fact, industry experts predict that LEDs may achieve efficacies of 100 LPW by the year 2005.

Evolution of LED Technology



Source: Lumileds™ (3)

The efficacy of LEDs depends on the color, design and materials used to make it. However, since LEDs are highly directional in nature, efficacy alone doesn't tell the whole story. Consider the following example:

LEDs have been used to replace traffic signal lamps throughout California. The standard 12" incandescent red signal lamp consumes 150 watts and has an efficacy of about 10 LPW. These lamps can be replaced with a 10-Watt LED lamp that has an efficacy of about 40 LPW. Although the efficacy of the LED lamps is better than the incandescents, *it is not that much better!* How then is it possible to replace a 150-Watt incandescent lamp with a 10-watt LED lamp? According to SMUD Energy Specialist Stephen Stinson, who has extensive experience working with LED traffic signals, the key is the directional characteristics of LEDs:

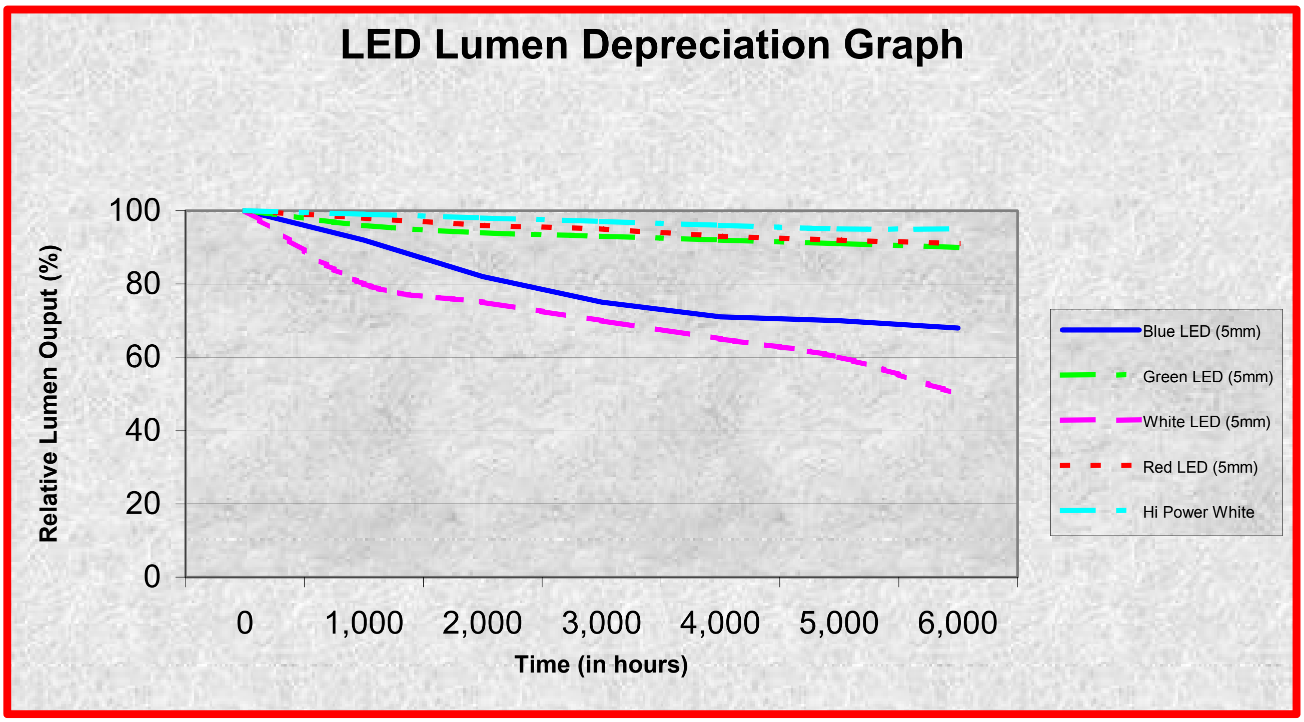
"The highly directional nature of LEDs makes them ideal for traffic signal applications. Motorists can easily see the signal even though the LED lamps consume only a fraction of the energy of the original lamps."

- Stephen Stinson, SMUD Energy Specialist

Life Expectancy & Lumen Maintenance

In the lighting industry, lamps undergo standardized testing to rate life expectancy. In the case of fluorescent lamps, a group of lamps (e.g. 100 lamps) are switched off and then back on again every three hours until 50% of the lamps fail. The point in time in which the 50% failure rate occurs is the value (in hours) used by the lamp manufacturer to rate the life or the lamp being tested. However, there is considerable debate about using this procedure to rate LEDs.

Depending on the type, manufacturers estimate that LEDs will last from 50,000 to 100,000 hours. Indeed, preliminary test results seem to support this assumption. However, the lumen depreciation for certain types of LEDs (see chart below) is significant and must be considered. Although the LEDs may still be functional at 100,000 hours, the lumen output may no longer be adequate to meet the needs of the application. Fortunately, new high intensity LEDs (e.g. high-power white Luxeon™) offer remarkable improvement.



One final note about life expectancy: the weak link with LED systems is often the power supply. Most LED lighting systems use a power supply to convert standard alternating current (AC) voltage supplied by the utility company to low voltage direct current (DC). Power supplies **must** be adequately ventilated and protected from exposure to water. Failure to adequately protect power supplies can lead to frequent system failures, expensive services calls and frustration.

Are LED Lighting Systems Cost Effective?

When considering the cost of LED systems, it is important to consider all of the following factors:

- First cost
- Maintenance costs
- Energy costs
- Life expectancy

According to E-SOURCE, the first cost of LEDs is about three to four times more than incandescent systems and about 30% more than neon or fluorescent systems. However, potential energy and maintenance savings can still make LEDs a good choice for many applications. The table below depicts a life cycle cost comparison for the types of lighting systems commonly used for outdoor sign applications.

Table 1: Cost-effectiveness calculations for incandescent, neon, fluorescent, and LED lighting

This table compare the cost-effectiveness of neon, fluorescent, and LED light sources as alternatives to incandescents in an outdoor sign application. The calculations for all four sources assume that they provi roughly equivalent levels of light. For this example, using representative cost and performance data, the L system costs more to purchase and install than the others but offers the lowest operating costs thanks to savings in both energy and maintenance.

Fixture type: channel letter sign	Base case: incandescent	LED	Neon	Fluoresc
Total equipment cost	$5,928	$23,712	$18,240	$11,85
Estimated labor costs over the lifetime of the fixture	$1,800	$0	$120	$63
Estimated component repair costs over the life of the luminaire	$695	$0	$1,280	$73
Total system lifetime costs over 15 years	$8,423	$23,712	$19,640	$13,22
Total lighting power (watts)	47,280	1,800	11,820	7,88
Annual lighting energy use (kWh), assuming 3,650 operating hours/year	172,572	6,570	43,143	28,76
Annual lighting energy cost, assuming $0.08/kWh	$13,806	$526	$3,451	$2,30
Lamp life (hours)	8,000	100,000	20,000	20,00
Annual operating cost ($/year)	$14,621	$526	$4,739	$3,08
Annual operating cost savings	NA	$13,280	$10,354	$11,50
Simple payback (years)	NA	1.34	1.19	0.5
Return on investment	NA	68.0%	77.4%	187.4
Savings-to-investment ratio	NA	6.72	7.57	17.

Source: E-SOURCE (5)

Conclusions

Potential Benefits

Source: LED Effects(4)

LED lighting systems provide consumers with unprecedented color and control options and have been successfully used for a wide range of applications including signage, landscape lighting and architectural accent lighting. Their compact size and flexible packaging options will accommodate virtually any accent or decorative lighting application needs. LED lighting systems may also offer significant energy and maintenance savings.

Challenges

Presently, major challenges for this technology appear to be:

- **High first cost**: LED lighting systems typically cost three to four times more than halogen (incandescent) and 30% more than the neon and fluorescent systems that are commonly used for landscaping and architectural lighting applications.

- **Producing white light:** although considerable progress has already been made, major improvements are still needed in this area. Strategies such as mixing red, green and blue LEDs to produce white light often require complex controls, while standard 5mm white LEDs suffer from relatively low life expectancies, low efficacies and steep lumen depreciation curves.

- **Directional nature of LEDs:** the light produced by LEDs is highly directional. Although this characteristic may be an advantage for applications such as traffic signals, it is definitely a limiting factor for general illumination. Presently, LED lighting systems appear to be most suitable for accent, decorative and flood lighting applications.

Technology Transfer and Recommendations

LEDs continue to show great promise. Several major lamp manufacturers and electronics firms have recognized this potential and are continuing to make significant investments in the development of LED technologies. As the efficacies continue to improve and LED systems become less expensive, they will become an increasingly attractive option for consumers. In the meantime, utilities should continue to support demonstration projects to encourage their customers to adopt this technology for appropriate applications.

References

We gratefully acknowledge the contributions made from the following sources:

1) "How Light Emitting Diodes Work." HowStuffWorks, (http:/www.howstuffworks.com/led1.htm), by Tom Harris, HowStuffWorks, Inc., 2003

2) "Future Tech: Good-bye, Mister Edison" Discover, Vol. 23 No. 11 (November 2002). Neil Savage, available at http://lumileds.com/newsandevents/news_index.html

3) "Lumileds Technology Tutorials," available at http://lumileds.com/technology/technology_index.html,

4) LED Effects Inc., 2714 Mercantile Drive, Rancho Cordova, CA 95742. tel (916) 852-1719, fax: (916) 852-1740, web http://www.ledeffects.com/

5) "LEDs in Exterior Applications: An Emerging Market," E Source report, November 2001. Platts Research & Consulting, 3333 Walnut Street, Boulder, CO 80301. 303-444-7788. www.prc.platts.com.