LED Lighting Technologies and Potential for Near-Term Applications

Market Research Report

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LED Lighting Technologies and Potential for Near-Term Applications

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EXECUTIVE SUMMARY

Introduction
Light emitting diode (LED) based exit signs and traffic signals have fulfilled their promise of an energy-efficient, long-lasting, compact, and low-maintenance light source in real-world commercial and industrial applications by saving millions of kilowatt-hours of electricity and thousands of maintenance hours. While a number of technological and economic challenges have combined to limit the availability of LED consumer products beyond these existing niches, this trend is changing: a number of sources have projected that LED-based lighting will gradually replace 25% to 30% of incandescent lighting applications by 2025. The intent of this report is to provide an overview of the market for LED-based lighting systems in the U.S. in order to inform the Northwest Energy Efficiency Alliance (the Alliance) future funding and program decisions regarding this technology.

This report coverage is limited only to LED-based lighting products – that is, devices that create light in the part of the spectrum that is visible to the human eye. To date, this includes LEDs that emit visible and to a small extent, ultraviolet energy. This study emphasizes so-called high brightness LEDs (HB LEDs), although there is no standard industry definition of the $1.8 billion market for HB LEDs currently. The report surveys the newest, brightest products, which are more assertively termed ultra-high brightness LEDs (UHB LEDs). In any case, this study does not address the older technology, lower brightness LEDs that are used as indicators on equipment, nor does it comprehensively address solid-state lighting, which includes organic light emitting diodes, or OLEDs.

LED and LED Lighting Technology Overview
LEDs represent a lighting technology fundamentally different in design from the incandescent light bulb or fluorescent light. In fact, LED technology has more in common with the microchip than any of the current light sources. LEDs are composed of thin layers of semiconducting materials that emit light when a voltage is applied across the LED layers, forming a light producing “chip.” The LED chip must be encased in epoxy with a heat sink, metallic leads, and a light reflector to form a functional light source – collectively referred to as “the package.” Packages are then incorporated into lighting systems. It is important to have a fully optimized and integrated LED package as well as luminaires specifically designed to fully utilize the light output of LEDs.

Another difference of LED lighting is that LEDs produce colored light. The use of different semiconducting materials result in different light colors being produced. This makes the LED technologies especially attractive for applications that require colored light. To get white light, variety of color mixing techniques are used to create “white light” LEDs, including packaging colored LED with a phosphor, or with other complementary colored LEDs that overlap to produce white.
**LEDs and Efficiency**

LEDs bring many advantages to the lighting marketplace, one of the most notable being energy efficiency, especially in applications requiring colored light. In these situations, colored filters applied to white light sources reject 80 to 90% of the spectrum, wasting the energy expended to create those wavelengths. By contrast, LEDs make only the wavelengths desired, which is the major reason that monochromatic LEDs to date have been more successful and efficient than white ones. In exit signs and in traffic signals, for example, red LED systems demand only 10% to 15% of the input power that an incandescent light source system would require.

Another admirable quality of the LED technology is that it has a long rated life – up to 100,000 hours. This represents a significant leap when compared to 1000 hours or less for an incandescent, 6,000 to 20,000 hours for fluorescent sources, and about 24,000 hours for a high-pressure sodium lamp. The longer life of a LED system makes LEDs more attractive because it lowers the replacement frequency of the system and increases the time that a customer benefits from the energy savings. Thus, the rated life of LEDs is important to consider when analyzing the overall cost of a LED system as compared to the overall cost of a conventional system.

Measuring LEDs and reporting LED output for use in place of traditional lighting sources actually represents a significant challenge. The introduction of LEDs into lighting applications has created a demand for photometric descriptions of LEDs. This is due the fact that most lighting designers and energy efficiency program managers are accustomed to comparing the relative efficacy of light sources in terms of lumens per watt (lm/w). This metric assumes that the light source being measured emits light in a fairly broad spatial distribution pattern. However, LED packages emit light in a relatively narrow cone of distribution, so it is more difficult to determine lumens per watt for LED-based systems. Thus, a redefinition of efficacy may be needed in order to effectively compare the performance of these different light sources.

**LED Cost and Performance Trends**

A recent report by Sandia National Laboratories observed that the light output and efficacy of LEDs roughly doubles every 18 to 24 months, and that the future LED performance will likely follow a trend similar to that of the past 30 years.¹

Figure ES1 details the performance and cost data for the LEDs. Not only is the performance of single-colored LEDs improving, but LED cost is also decreasing, making the technology more cost effective in the marketplace. The development of white LEDs, on the other hand, involves hybrid technologies, so that its performance trends are less predictable than that of colored LEDs. Nevertheless, technology roadmaps maintained by the U.S. Departments of Energy and Defense, in cooperation with manufacturers, forecast white LEDs bright enough for general illumination applications by 2010.²

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Efforts to Advance LED Technologies and Applications
To date, LED technical breakthroughs have emerged primarily from proprietary research efforts. In fact, many of the key patents in the history of LED development have spawned intense legal actions. These disputes have restricted some of the major manufacturers to producing only the colors of LEDs for which they held the critical materials and process patents. Within the past two years, this trend has undergone a reversal. Many of the parties have settled and agreed to cross-licensing or other barrier-lowering deals, cooperative efforts, university-based collaboratives, R&D partnerships, and mergers. In the past, some LED manufacturers have received substantial research funding from governments, and recent performance gains have increased the likelihood of additional funding.

Along with R&D funding opportunities, we also examined other efforts to introduce existing LED-based lighting products into the market. To date, these efforts have been led by utilities, government, or consortia and alliances focusing on advancing energy efficiency through market transformation and other incentive programs. While the program targets have been limited to exit signs and traffic lamps, they have helped these products achieve significant market penetration. Overall, these types of programs have compiled an impressive track record of reducing the time to market or sped up the typical market penetration process of products with significant energy savings potential. As more LED products become available, these types of programs will be instrumental getting them more quickly into the market place.

Available LED Products for Near-Term Applications
When mature, the LED-based lighting market will encompass the residential, commercial, and industrial markets. However, we expect products in the near term (one to four years), will first see application in specific niches in the commercial and industrial
arenas before finding their way into more mainstream and residential applications. Even with the quickened pace of product development in recent months, we do not fully expect the residential market to see a large number of LED products within this near-term timeframe. Because developments are taking place rapidly in this field, the information presented here represents a snapshot of these markets at this point in time. The emphasis is more on products that are market-ready, or will enter the market in the near future.

**Displays:** Until very recently, very small-diameter fluorescent lights have been used to provide backlighting for liquid crystal displays (LCDs) in computer monitors, TVs, and a few other niche applications. The use of LEDs in these displays instead of fluorescent lamps has the potential to improve color vibrancy, motion display, and longevity in LCD screens. It also might be possible to save a significant amount of energy by switching to this technology.

**Industrial Opportunities:** LED-based industrial/commercial lighting products can make a significant impact in airport, ports, and roadway lighting. Traffic intersections, aviation, and shipping facilities require colored light sources as guidance signals, which rely solely on incandescent lamps with a very limited lifetime. Typical life expectations for these applications range from only 2,000 to 4,000 hours for traffic signals, up to 8,000 hours for airport applications.

**Commercial Signage:** Signs are high-profile energy users not only because they are used to attract public attention, but also because many are on 12 to 24 hours per day, consuming about 2% of the total electricity in the US. Fluorescent signs currently account for about 48% of this market, with neon signs holding about 41%, and the remainder of the market dominated mostly by incandescent products. LED signs are still relatively new to this market.

**Retail Food and Beverage Displays:** Another retail area where LED lighting has the potential to excel is in the grocery market, specifically in coolers and freezers. Currently, this market segment accounts for about 15% of all refrigeration energy use in the US, and is dominated by fluorescent lighting. However, LEDs have inherent characteristics that are much more suitable for this particular application: LEDs are more efficient at directional illumination, less affected by cooler temperatures, and do not require as much space. While improved fluorescent systems may promise incremental energy savings, none have the same promise of savings and versatility as the LED systems.

**Retail Lighting:** LED-based lighting in retail applications is a nascent, but potentially enormous market, as LEDs can and will displace incandescent products in a way that CFLs have never been able to do. LEDs offer unprecedented flexibility in colors and configurations to lighting designers in creating displays and particular “moods” in retail lighting. The potential for LEDs in retail and display markets may not be fully realized for some time, as designers and engineers explore and discover its possibilities.

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Barriers, Opportunities, and Next Steps
LEDs bring many advantages to the lighting marketplace, and offer significant energy saving potential. Since the technology is so new and fundamentally different than the two dominating conventional technologies – incandescent and fluorescent, it faces significant challenges from several fronts. A number of the challenges faced by LEDs are categorized and summarized below, along with near-term opportunities and next steps.

**Barriers**

- **Technological Barriers**: LEDs still have a number of technological hurdles to overcome. LEDs are currently more difficult to fabricate than their microchip cousins, though more improvements in production methods may be able to increase yield and help to further drive down prices. Additional work also remains to be done in the systems design and integration area before LEDs can fully compete as a viable light source in the general lighting market. There still is no consistent approach to creating an LED system to date. Finally, because it is a new technology, the upfront cost for LED-based systems is often more than conventional systems.

- **Comparing LEDs to Other Sources**: LEDs also face measurement hurdles as they enter the lighting market. Measuring LEDs’ performance with conventional lighting metrics, which are based on the incandescent standards, could actually hinder the process of using LEDs in applications. In addition, until LEDs are marketed in a more convenient assembly, it remains difficult to compare the output of different light sources to LEDs.

- **Educational Barriers**: LED-based lighting remains a new technology that is not well known in the marketplace. This unfamiliarity applies equally for users at all experience levels: lighting designers, residential and commercial users, installers, building inspectors, and government code officials. Most lighting designers are used to thinking, designing, and working with white light sources instead of colored light sources. They are also not accustomed to taking advantage of the energy-efficiency, long-life and maintenance characteristics of LEDs.

- **Infrastructure**: Because it is a new technology, manufacturers of LED luminaires, systems and controls are few, and some products have reached the market via different routes instead of the traditional distribution channels used by more established lighting products.

**Opportunities**

- **Design**: Because LEDs are an inherently colored light source, they present new design and application opportunities in a variety of areas where conventional lighting has dominated, as designers and specifiers become more aware of their qualities. In the near-term, however, there are quite a number of “niche” opportunities for LED technologies to become more established, displacing incandescent and even CFLs.
Applications: LEDs excel in low temperature operations, rugged environments, and applications that require fast ‘on-time.’ LEDs systems also tend to be more compact, due to their generally small footprint, allowing for easier installations and smaller space and materials requirements.

Safety: LEDs’ lower power consumption provide some obvious safety advantages over incandescent lighting systems, including:
- Easier system adoption and installation (low voltage, reduced component size and complexity)
- Less electric shock risks
- Lower fire risks

Technological, Environmental and Market: Technological advances are taking place quickly, enabling LEDs to match the progress mapped out by experts. As LED technologies improve and displace current technologies, there is substantial opportunity for energy savings in both lighting and display areas. Estimates of the lighting savings potential alone is significant, as more efficient LED lighting technologies can substantially reduce the projected 600 TWh annual consumption by US general lighting needs by 2007. Similarly, LED penetration into the display market can yield huge energy savings.

Next Steps
The Alliance has a variety of options to advance LEDs lighting technologies in the Pacific Northwest. It can choose to support some market-ready products with marketing and other assistance to increase their market penetration, study and invest in potentially promising technologies to help speed up the to-market time, and conduct pilot projects to ensure market-readiness of others. Available program options can run from resource acquisition to innovative market transformation (Table ES1). The Alliance can also choose to work with other organizations in a national forum to bring the need for measurement metrics for LED-based lighting to the forefront. With regards to which products to pair with what approach, some initial suggestions are covered below:

Table ES1. Available Program and Funding Options

<table>
<thead>
<tr>
<th>Product Status</th>
<th>Product</th>
<th>Possible Approach</th>
<th>Additional Approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>Market-Ready</td>
<td>LED Signage</td>
<td>Education/Marketing</td>
<td>Codes, Incentives</td>
</tr>
<tr>
<td>Market-Ready</td>
<td>Aviation/Shipping/Roadway</td>
<td>Pilot</td>
<td>Demonstration, Group Procurement</td>
</tr>
<tr>
<td>Market-Ready</td>
<td>Traffic Signals</td>
<td>Code Development</td>
<td>Case Studies</td>
</tr>
<tr>
<td>Near-term/MR</td>
<td>Niche Products Group</td>
<td>Education/Marketing</td>
<td>Regional Promotion</td>
</tr>
<tr>
<td>Near-term</td>
<td>Programmable/combo</td>
<td>Research/Assistance</td>
<td>Market Assessment</td>
</tr>
<tr>
<td>Near-term</td>
<td>White LEDs</td>
<td>Research/Assistance</td>
<td>-</td>
</tr>
<tr>
<td>Developmental</td>
<td>LED-Based LCDs</td>
<td>Education/Demonstration</td>
<td>Pilot</td>
</tr>
<tr>
<td>Developmental</td>
<td>Retail Lighting (visi-coolers)</td>
<td>Demonstration</td>
<td>Pilot</td>
</tr>
<tr>
<td>Developmental</td>
<td>Retail Lighting</td>
<td>Designers Challenge</td>
<td>Demonstration</td>
</tr>
</tbody>
</table>

4 Ibid
- **Market Ready**: Among the market-ready products, LED-based aviation/shipping, roadway lighting, and signage are poised to become competitive with traditional incandescent and even CFL products, yet they still need some assistance to overcome barriers. With aviation, shipping, and signal products, the LED-based replacement modules’ initial costs remain a deterrent in their penetration of the NW market despite their clearly superior lifetime, maintenance, and energy conserving characteristics. With regards to the signage market, the level of awareness and demand for LED signs, especially outdoor signs, is still non-existent locally. The Alliance may want to consider programs to encourage the 15 to 30 major airports and the hundreds other of airports and ports in the NW to consider LED lighting modules, and business customers to consider LED signs over neon or even fluorescent signs. A successful campaign targeting these areas can yield significant savings. In the case of LED exit signs, Alliance involvement with code development could be the next steps.

- **Near-Term**: Near-term LED products opportunities include a mix of products in both the grid-connected and the off-grid categories. Of interest among them is the group consisting of niche LED product categories whose savings potential by each may not appear to be significant, but collectively, they can yield significant savings. Among these are LED-based nightlights, holiday lights, light strips, pathway lighting (some of which are available now), and possibly emergency/backup lighting. As in the case with LED signs, the promotion of some of these systems, such as decorative lighting or pathway lighting can have the effect of load-building rather than reducing energy consumption. However, a well-designed program focusing on transforming the market for these products can minimize such effects while helping to reduce future needs.

- **Developmental**: Opportunities to further help the development of LED technologies include a mix of program design options, ranging from research assistance (an option less aligned with Alliance mission), to additional market assessment, or participation/initiation of regional or national efforts. For example, the development of the nascent white LED market remains uncertain, and still requires additional investment in R&D. The most cost-effective way to leverage Alliance resources here may be in the form of a design competition, or demonstration projects to highlight the issues of applications for LEDs and LED-lighting systems. Within this group, LED-based displays hold the most energy-saving potential, and options remain for the Alliance to significantly affect energy consumption in this area. For example, in the TV market, plasma displays are beginning to make significant inroads, including usage as monitors in public spaces. LED displays’ two significant advantages over plasma technology – energy consumption and lifetime – are not well known. A small, well-focused program to address these factors can result in significant energy savings. This effort also lends itself well to regional and even national cooperation, such as working with the Consortium for Energy Efficiency. Other small Alliance efforts
in this area can include sponsoring additional studies or evaluation of retail and refrigerated cooler lighting.

**Summary of Savings Potential**

Table ES2 below summarizes the savings potential of a number of LED products in the US, their status, major barriers, and the potential for the NW.

Table ES2. Summary of LED Products, Savings Potential, and Barriers

<table>
<thead>
<tr>
<th>LED Product Category</th>
<th>Current Product Status</th>
<th>Est. US Potential</th>
<th>Est. NW Potential</th>
<th>Major Barriers</th>
<th>Basis for NW Estimates</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Lighting</td>
<td>Long-term</td>
<td>500 TWh/yr</td>
<td>20 TWh/yr</td>
<td>Technological</td>
<td>~4% of US</td>
</tr>
<tr>
<td>Aviation &amp; Shipping</td>
<td>Market Ready</td>
<td>~59+ kW/Airport</td>
<td>13.4 GWh/yr</td>
<td>Price, Awareness</td>
<td>Savings only from 26 major NW airports</td>
</tr>
<tr>
<td>Roadway/Signal</td>
<td>Market Ready</td>
<td>30 TWh/yr</td>
<td>1.2 TWh/yr</td>
<td>Price, Awareness</td>
<td>120,000 in NW @ 10,000 kWh/yr ea</td>
</tr>
<tr>
<td>Exit Signs</td>
<td>Market Ready</td>
<td>3.6 TWh/yr</td>
<td>120 GWh/yr</td>
<td>Awareness</td>
<td>~4 million in NW @ 30,000 kWh/yr ea</td>
</tr>
<tr>
<td>Commercial Signage</td>
<td>Market Ready</td>
<td>16 GWh/yr</td>
<td>600 MWh</td>
<td>Awareness</td>
<td>~2% of commercial electricity</td>
</tr>
<tr>
<td>LCD Monitors</td>
<td>Near-term</td>
<td>38 GWh/yr</td>
<td>1.5 GWh/yr</td>
<td>Technological</td>
<td>~4% + of US</td>
</tr>
<tr>
<td>Niche Products</td>
<td>Ready/near term</td>
<td>Varies</td>
<td>Varies</td>
<td>Availability</td>
<td>_</td>
</tr>
<tr>
<td>LCD TVs</td>
<td>Developmental</td>
<td>800 GWh/yr</td>
<td>32 GWh/yr</td>
<td>Technological</td>
<td>~4% of US</td>
</tr>
<tr>
<td>Food &amp; Beverage</td>
<td>Developmental</td>
<td>NA</td>
<td>NA</td>
<td>Awareness</td>
<td>_</td>
</tr>
<tr>
<td>Retail</td>
<td>Developmental</td>
<td>NA</td>
<td>NA</td>
<td>Technological</td>
<td>_</td>
</tr>
</tbody>
</table>
1. INTRODUCTION

Light emitting diode (LED) based exit signs and traffic signals have fulfilled their promise of an energy-efficient, long-lasting, compact, and low-maintenance light source in real-world commercial and industrial applications. These products have received recognition for their energy efficiency and performance by the US Department of Energy (DOE) and the Environmental Protection Agency (EPA) through the formation of ENERGY STAR® programs for their product categories. In these capacities, LEDs have saved millions of kWh of electricity and thousands of maintenance hours. However, the development of high-quality LED-based lighting products for commercial and residential applications in the last decade has progressed at a much slower pace.

While a number of technological and economic challenges have combined to limit the availability of LED consumer products beyond the existing niches, this trend may be changing. A recent report prepared by Roland Haitz, Fred Kish, Jeff Tsao, and Jeff Nelson projects that, based upon recent developments, LED lighting will gradually replace 25 to 30% of incandescent lighting applications by 2025. Recent market progress seems to confirm this projection. In the past two years, LED-based lighting products have been appearing at a much faster pace. LEDs have also generated more interest, manufacturer alliances have developed, and the US DOE has indicated its intent to fund new LED product research and developments. Emerging applications for LEDs include retail and architectural lighting, replacement for neon and fluorescent signage and pathway markers, among others.

The intent of this paper is to provide an overview of the market for LED-based lighting technologies in the U.S. in order to inform the Northwest Energy Efficiency Alliance (Alliance) future funding opportunities and program decisions regarding this technology. Important background information on the current state of LED technology, U.S. market, and distribution channels will first be detailed. A number of key players and manufacturing alliances are also covered. Finally, as there exist numerous examples of successful utility and government initiatives promoting LED exit signs and traffic lights, descriptions of current programs and policies are also provided here.

We have also conducted preliminary cost-effectiveness analysis of selected LED lighting systems where data are available. The paper concludes with a summary of the market barriers and opportunities for LED lighting adoption, as well as near-term applications with energy-savings potential that may be suitable for further investigation and/or promotion. A note of caution is warranted here – because developments are taking place rapidly in this field, the information presented here represents a snapshot of the market at this point in time. The emphasis is more on products that are market-ready, or will enter the market in the near future, rather than the latest development that may not be ready for another decade. Moreover, we have attempted to focus the discussion on possible applications, and not the use of any specific technology or product.

2. LEDS: A TECHNOLOGICAL OVERVIEW

This report coverage is limited only to LED-based lighting products – that is, devices that create light in the part of the spectrum that is visible to the human eye. To date, this includes LEDs that emit visible and to a small extent, ultraviolet energy. This study emphasizes so-called high brightness LEDs (HB LEDs), although there is no standard industry definition of the $1.8 billion HB LEDs market currently. The report surveys the newest, brightest products, which are more assertively termed ultra-high brightness LEDs (UHB LEDs). In any case, this study does not address the older technology, lower brightness LEDs that are used as indicators on equipment, nor does it comprehensively address solid-state lighting, which includes lasers and organic light emitting diodes, or OLEDs (a short discussion of OLEDs is included at the end of this section for completeness).

**LEDs: Born Out of Materials Science**

Materials in electric and electronic applications are classified into three groups according to their conductivity, a property that describes how easily current flows in the material. In conductor materials such as copper and gold, current flows with virtually no resistance. The opposite of a conductor is an insulator, a material like plastic and rubber. Virtually no current is able to pass through insulators. Lying in the middle of these two extremes and familiar to us through the microchip industry are semiconductors. Semiconductors are solid crystalline materials that are more conductive than an insulator but less conductive than pure conductors.

**LEDs are Layered Semiconductors**

By layering semiconductor materials that have different levels of conductivity, one can produce a diode, or a valve-like device through which electrical current flows in one direction and is blocked from flowing back in the other direction. More specifically, by applying a voltage difference across two distinct layers of the diode, current flows through the material. Light emitting diodes, or LEDs, are special types of diodes that convert electrical energy into light through a phenomenon called electroluminescence.

In LEDs, the flowing current effectively excites electrons in one semi-conducting layer to a high-energy state. These excited electrons then combine with “holes,” or places in the material where there are a lack of electrons. This combination of electron and hole allows the electron to settle into a lower energy state. As it relaxes into the low energy state, the electron emits a photon, or “light packet.” All of the photons that are emitted from this recombination make up what we perceive as light from the diode. The point at which the light is emitted is called the p-n junction (positive-negative). Photons that are produced from this electron-hole recombination process typically have nearly identical energies.

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6 Sometimes UV emitting semiconducting chips are coated with a phosphorescent layer that emits light in the visible spectrum when it is exposed to UV light. Ultimately, the user sees visible light. This technique is sometimes used to produce white light.
Consequently, each LED emits light that falls within a narrow bandwidth. This band can be produced in the visible range of the electromagnetic spectrum, but also in the infrared and ultraviolet. It is the narrow bandwidth in the visible light range that causes the light from LEDs to appear monochromatic.

Manufacturing the LED Wafer
Like other semiconductors, each LED consists of extremely thin, “sandwiched” layers of materials that typically are compounds formed of two to four elements. These thin layers are brittle and must be either created on or transferred to a more durable rare earth metal, such as sapphire, gallium, or indium. These materials function as a substrate; their crystalline structure is selected to be compatible with the compound semiconductor materials. Substrates are grown as large masses of a tapered cylindrical shape known as boules. Boules are sliced into circular wafers. The wafers are trimmed and thinned to an even thickness, then polished and treated to accept the thin layers. The wafers must be extremely pure and free of surface defects, or the thin semi-conducting layers that are laid down upon them and make up the LED will also be defective.

Unlike the semiconductors used in computer processing and memory chips, however, LEDs are far more difficult to fabricate. They cannot be produced on large wafers. While the more general semiconductor industry target for manufacturing is now the 300mm wafer (approximately 12 inches), most LED wafer substrates are four or six inches in diameter. More exotic wafers such as indium are limited to two inches in diameter, due to the challenges of growing defect-free boules, and the brittleness of the materials.

Impurities, or dopants, purposely introduced to the semi-conducting layers of an LED determine the electrical properties of the compound materials. Typical dopants include magnesium and zinc. By doping layers differently, different colors and efficiencies of LEDs can be achieved. Some doping processes are well known and established (such as the process that produces red LEDs), while others are in earlier stages of development. The creation of the thin layers that make up the LED involves many carefully designed and controlled steps and additional materials, including some toxic gases such as arsine and phosphine. The processes for creating LEDs require cleanrooms and sophisticated controlled-system equipment, similar to the processes used for creating other semiconductors. The most common processes for creating the newest generation of LEDs are molecular beam epitaxy (MBE) and metalorganic chemical vapor deposition (MOCVD).

After a wafer is coated with the requisite layers of compound semiconductor materials, the conductivity and other characteristics of luminescence are tested. Typically there are zones on the raw product that display performance characteristics that are superior to other zones. The objective at this stage is to create uniform and high-performing areas. Wafers that pass quality control criteria are further processed to create individual LEDs. Layers of conductive metals and photoreactive films are applied and then etched in geometric patterns to create the basis for microscopic circuits. Optical materials can also be applied and shaped at the wafer level of production. The result—still on the wafer—is
a gridded matrix of individual LEDs with the required shapes and layers. Wafer size and composition are important economic and process factors because they limit the number of individual LEDs that can be produced from one wafer.

Once the microscopic circuits are in place, the next step is to separate the individual LEDs. Originally, wafers were cut with fine, circular blades; that is, they were diced, and thus the term, LED die. Newer machining advances include scribe and break techniques. The newest techniques involve laser scribing and separation. The techniques result in increasingly clean edges on the die, leading to a higher yield of functional die per wafer. Approaches that are less destructive mechanically involve lifting off the delicate thin layers and transferring them to another substrate, sometimes inverting the layers in the process to position the light emitting thin layers closer to the surface of the finished device (Often referred to as flip chips).

The LED Package
The LED wafer itself is not a functional light source. Once the die pieces are separated, there are several more steps to create the functional circuit and efficient emitter known as a package. The LED die can be placed inside reflective cups, or coated on some planes with highly reflective material. Metal leads are attached to one or more surfaces of the LED. These are usually made of gold. Sometimes the die pieces are encased in a highly transmissive material, usually an epoxy. The encasing material can be molded into an optically desirable shape, laser-shaped, or deposited in a fine film. Extraction efficiency is the term used to describe the amount of photons that exit the LED package (Figure 1).

The final steps in manufacturing LED packages are as critical to performance as all of the preceding steps. The brightest LEDs to date are carefully shaped in three dimensions to allow as much light as possible to exit the device. In addition, most of the high-brightness LEDs making the news today incorporate either a thermal heat sink, or a means of direct attachment to a thermal heat sink. Thermal heat sinks help maintain the temperature of the LED, which is critical because higher temperatures at the p-n junction adversely affect the quality and quantity of light emitted from the package. The heat sink can be a metal such as aluminum, copper, or a conductive ceramic material. In general, the higher the thermal temperature of the LED’s p-n junction, the lower its light output will be. High temperatures are capable of permanently affecting the performance characteristics of a LED, shortening its useable life span, lowering its light output, and shifting the color of light that is emitted.

Although less energy is wasted as heat in the most advanced LEDs compared to incandescent lamps, many people incorrectly believe that LEDs are “cool.” Puns aside, LEDs still generate significant thermal output despite the fact that they tend to be very low power devices. Nonetheless, a high brightness LED without an appropriate heat sink would become very hot to touch. The heat build-up at the p-n junction causes mechanical failures as the disparate materials inside the device expand at different rates, causing physical stress. For instance, the gold lead wires can snap, or the epoxy encapsulant can expand, tearing apart the nearby components.
LED: Colors and White

The Human Eye and Color
Because LEDs are an inherently colored light source, it is important to consider the way the human eye perceives color under certain conditions. These biological characteristics can help lighting designers and product developers make informed decisions about LED technology.

The human eye response to light varies by color and by the ambient lighting condition: it is most sensitive to color in general, and particularly in the green part of the spectrum, in high brightness (photopic) conditions, such as daylight. In very low ambient light (scotopic) conditions, such as nighttime, color sensitivity shifts somewhat to the blue portion of the visible spectrum. More technically, the relative sensitivity of human vision to the spectral power distribution of light in photopic conditions is described by the V-lambda curve, as established by the Commission Internationale d’Eclairage (CIE) (Figure 2).
LEDs Produce Colored Light
Unlike conventional light sources, most of which emit some version of white light and must be filtered to produce colored light, LED sources are inherently colored light sources (due to their narrow photon bandwidth). The compound semiconductor materials determine the spectral power distribution (or color) of the light that is emitted from a LED.

Currently, three major material systems are used for high brightness LEDs.
(Conventional LEDs and experimental prototypes may use other material systems.)

- AlGaAs (aluminum gallium arsenide): the red end of the visible spectrum (longer wavelengths, low energy)
- AlGaInP (aluminum gallium indium phosphide): red-orange-amber-yellow portion of the visible spectrum (mid-wavelength, middle energy)
- AlInGaN (aluminum indium gallium nitride): theoretically spans the visible spectrum, with the exception of some gaps in green; however, it is primarily used for the green-blue end of the visible spectrum, and ultraviolet (short wavelengths, high energy)

The term dominant wavelength denotes color in LED specifications, just as the term hue is used to denote color in most art-related vocabularies. LEDs can also vary in color purity, that is, how pure the color of light is, versus how close to white the emission is.

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7 Mark S. Rea, IESNA Lighting Handbook Reference and Application, Illuminating Engineering Society of North America, 9th ed. 2000, Figure 3-10, section 3-6.
might be. (Pure color is denoted as 100%, white as 0%). In other naming systems this would be referred to as saturation. Most red, orange and blue LEDs are near 100% color purity. Many green LEDs have lower color purity, and as noted above, there are some gaps in dominant wavelengths in the green part of the visible spectrum. LED die from a single wafer can vary in dominant wavelength and also in color purity. Manufacturers sort LEDs into bins by both of these characteristics. This expensive process is reflected in the price of the die: bins with the least variation are most costly.

Using LEDs to Make “White Light”
What humans perceive to be white light is actually the perception of the combination of two or more colors of light. When white light passes through a prism, it is split into component colors, making some version of a “rainbow.” Mixing two colors that are opposite each other in a color space, such as blue and yellow, creates binary white light. Also red, green and blue (RGB) can be mixed together to make white light. A common appliance that uses an RGB-like technique is the cathode ray tube monitor, where three beams of colored light are used to create a myriad of colors and white. Regardless of the technique used, the relative amount of energy of each color must be balanced to create the perception of a neutral white; otherwise the result appears “cool,” closer to the blue end of the spectrum or “warm,” closer to the red end of the spectrum (Figure 3).

Figure 3. Color Mixing Chart

A variety of color mixing techniques are used to create “white light” LEDs. The more colors of light that are represented in a white light, the more satisfying the result may be, because human vision has evolved in the very broad spectrum of daylight. The most common ways of creating white light with LEDs are:

- Placing discrete red, green and blue LED die close enough to each other to create the impression of white when viewed directly, called trichromatic white. For example, large video display walls are composed of millions of units, like pixels,
of colored LEDs. Sometimes the two or more color die are combined within a single package, called a **multichip** LED

- Placing discrete red, green and blue LEDs inside a device with a diffuser, so that viewers only see the “blended” light, not the discrete colors

- Encapsulating a blue or ultraviolet LED in a layer of phosphors. The phosphors are excited by the short wavelength radiation, and then emit light in longer wavelengths, such as yellow and red. This combination of colored light produces at a minimum a *binary* or *dichromatic* effect. The blue LED/phosphor solutions are less efficacious than the discrete RGB systems.

Less commonly, more than three colors of LEDs are placed together to create a more satisfying white light. LED manufacturers are struggling to create LED light sources that mimic more conventional sources such as incandescent and fluorescent lamps. A lack of a common goal for “white” light makes their efforts somewhat disorganized, but several groups, including the National Electrical Manufacturers’ Association’s (NEMA) Solid State Lighting Section, are trying to create reasonable targets for the LED industry.

**LEDs and Phosphor Technology**

The production of phosphor based true white light LEDs are limited not only by the progress of the LED technology, but also of the progress of the phosphor technology. Phosphors must be ‘tuned’ two ways. They must be tuned to accept a certain wavelength of excitation light, or the light that ‘pumps’ the electrons in the phosphor to higher energy levels. Secondly, the phosphor must be tuned to release a certain emission light, or light that is produced as a result of the electron falling from the pumped-up state to a lower energy state. The emission light is what the eye sees. The tuning of these two parameters is achieved by changing the chemical structure of the phosphor. For example, a green phosphor that is pumped with a UV LED would not emit green light if pumped with a red LED because the UV and the red have different wavelengths and associated energies. This tuning means that phosphors that have been developed for other applications, such as cathode ray tube TVs and plasma displays may not be easily transferable to the white LED technology.

Other factors important to consider with phosphor technology include: degradation rate of the phosphor compared to the other phosphors and the LED and the emission efficiency. Phosphors degrading at different rates can lead to a change in color temperature and color rendering over the lifetime of the LED. A phosphor with too short a lifetime would limit the lifetime of the LED. The emission efficiency of the phosphor is important so that the ratio of output of the different colors is appropriately balanced to give good color rendering and temperature.

Currently the phosphors associated with making tri-color white LEDs are not a mature technology. Two approaches are currently being tried: a UV LED with UV pumped red,

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8 Although there are currently white LEDs on the market that are a blue LED with a yellow phosphor, these do not have the necessary color rendering characteristics to be used for most lighting applications.
green, and blue phosphors, and a blue LED with blue pumped red and green phosphors. Whether we see white LEDs emerge as a combination of red, green, and blue LEDs, or whether we see the phosphor plus LED technology emerge as the white LED technology depends on the comparative rate of development of the LED and the phosphor technologies.

**Organic Light Emitting Diodes (OLEDs)**

OLEDs use a technology that is similar to the LEDs technology detailed earlier in this report. As indicated by their name, OLEDs differ from their silicon-based counterparts in their makeup. OLEDs are created when an engineered organic (carbon based) material is placed between an anode, which is transparent, and a cathode, which is metallic. When a voltage difference is applied across the two layers sandwiching the organic material, the organic material emits light as electrons and holes recombine in the material.

In actuality, “OLED” is a general term that encompasses two different types of technology: small molecular-based device (SMOLED) and polymer-based device (PLED). Both of these technologies are finding their way into a number of consumer devices that require low-power, high definition color displays. Although many market analysts are predicting a bright future for OLEDs in the display market, the opportunities for general lighting applications are limited currently. Experts expect that OLEDs lighting devices will not reach full potential for another 20 years or so.

To date, the most popular and successful OLEDs applications include multicolored cellular phone and car stereo displays. In fact, OLEDs’ current development trajectory places the technology in line to compete with LCD displays within two to three years. An advantage the OLED display has over the LCD display is that OLED displays permit wider viewing angles and have a shorter response time. In addition, OLED displays require no backlight or color filter. They are also much easier to manufacture than LCDs. The biggest challenge for OLEDs is their short lifespan – currently at only 10,000 hours. This shorter lifespan makes them impractical for displays that operate for long hours (high duty-cycle), such as a laptop computer displays. At present, companies such as RiTdisplay, Sanyo, Pioneer, TDK, and NEC are offering small OLED-based displays.
3. LED LIGHTING: A CHIP IS NOT A LIGHT BULB

**LEDs and LED Lighting Systems Characteristics**

LEDs must be incorporated into a system in order to be used in most lighting applications. At a minimum, the system contains LEDs, a circuit (either on a board, or formed of wires), a thermal heat sink, a driver/power supply that connects the circuit to the source of electricity and modifies it to meet the particular LEDs’ operation requirements, and a control device. The input power demand of individual LEDs varies tremendously. Micro-LEDs need only a few milliwatts to operate, standard packages operate in the tenths of watts, and the newest HB and UHB LEDs operate with five to ten watts apiece. Like any other light source, the entire system must be taken into account when comparing input power demands, because other components in the system, such as the driver, have their own added requirements.

LEDs are direct current devices, so the use of alternating current requires additional components. The driver is analogous to the ballast in conventional fluorescent systems. The newest, highest power LEDs require sophisticated drivers. The control component can be as simple as an on/off switch, or it can be quite elaborate, as in digital color, dimming and programmable systems. Usually a LED system includes some type of housing or support, and often it includes reflectors or lenses to direct or diffuse the light. Beyond these basics, there are myriad LED systems marketed or assembled from components, and very few standards available. Thus most of the LED systems in the market are nearly customized, single-source solutions. There are however, two basic types of systems:

- **Chip on board (COB) and surface-mount type (SMT)** LEDs are mounted on the surface of a circuit board. The board can either be rigid or flexible. The system can be very small, with many die packed densely into a small area to function as a point source. Or, it can cover larger areas or long lengths, with the LEDs spaced to achieve particular light distribution patterns. This type of solution is used extensively in the automotive industry, to backlight instrument display panels, and to create sleek units for brake lights.

- **LED modules, clusters or “lamps”**: These systems have discrete LED packages soldered into place in more conventional circuits, such as LED holiday lights and LED neon sign replacement kits. Some LED-based lighting devices are designed for use in conventional screw-base or pin-base sockets; they have all the system components integrated into a single product.

Relatively few companies have stepped into the market to provide complete LED systems. Most LEDs are sold as components. Purchasers must procure and assemble compatible components to meet their system needs. This lack of integration is typical of the early stages in the introduction of a new technology, but it does present a barrier to the lighting community.
Although it is difficult to make direct comparisons of LED systems to conventional lighting systems, the following characteristics hold true for most LED-based lighting systems:

- The size of a LED system is often smaller in profile than that of other lighting systems, especially for chip-on-board systems. Also, the drivers tend to be smaller than the ballasts for fluorescent and HID lamp systems.

- The performance of LED systems, like fluorescent lamp systems, declines if heat builds up. Red and amber LEDs are more sensitive to heat than are green, blue and white LEDs. If various colors are mixed within a system, and the system lacks circuitry to balance the light output as temperature varies, the overall color appearance of the light output may shift.

- The life of LED systems, like any other system, is determined by the duration of the shortest-lived component. So, it may be more reasonable to consider the “useful life” of a LED in the context of the system in which it operates.

- There is no industry consensus on a standard life expectancy or its measurement method for LEDs, but many manufacturers suggest 30,000 to 50,000 hours would be reasonable for the LEDs themselves.

- The relatively long life of the LED components coupled with other well-designed system components reduces or eliminates the need to change out lamps. This leads to significant maintenance cost savings over nearly any other type of lighting system. If the LED system is not designed with a removable LED module, however, the entire device may need to be discarded and replaced when the light output becomes too low. Thus a return-on-investment analysis should include a long enough time period to cover at least one replacement of the LED module.

- LEDs have a fast ‘on-time’ (60nanoseconds vs. 10milliseconds for incandescent). This has been an attractive factor for automotive brake light designers.
4. LED PRODUCTION AND THE ENVIRONMENT

To date few studies examine LED life cycles – the effects of LED production and disposal on the environment. Information and parallels may be found in the semiconductor and electronics literature. Some LED manufacturing processes may be governed by standards promulgated for the semiconductor industry. This section raises issues that could be explored as the number of LED lighting systems in use increases, and as some of the older LED devices such as exit signs and traffic signals begin to near the end of their useful lives.

Highly toxic and controlled substances are used to manufacture LEDs and other electronics. For example, ammonia, arsine, nitrogen and phosphine gases are used in the fabrication process, and stored in bulk on-site at LED chip fabrication facilities. Dust from the sawing or scribing of chips can contain toxins or potential toxins. However, LEDs are manufactured in clean rooms, so much of the exposure to humans would be limited by processes put in place similar to that of other semiconductor manufacturing. The wafer and chip fabrication processes are highly energy-intensive, as are the mining and refining of the precursor metals (gallium and indium) and rare earth phosphors (for white LEDs). Unlike most gas discharge lamps, no mercury is contained in LEDs.

Assembly of LED lighting systems is similar to that of other electronics devices. Much of it is automated, and involves soldering of components onto etched circuit boards. Lead solders are commonly used, but lead-free solders could be an alternative. Depending on environmental regulations in place at the manufacturing plant’s location, highly volatile solvents may be used to clean finished circuit boards. Much like the computer industry and, increasingly, the lighting industry, LEDs, components, and LED lighting systems are manufactured in Asia, particularly in Malaysia and in Taiwan. LED manufacturing is beginning to spread into other areas of China, as well.

LEDs last longer than the light sources they may replace, but as noted previously, the lifespan of the system itself, including the housing, may be more or less than conventional systems, depending on the types of components used. Due to the smaller size and lighter weight of LED lighting systems, they have a lower volume and weight than conventional systems. If the system has integral components, the entire device would have to be disposed of at end of useful life. The use of thermo-bonded plastics and metals may make it difficult to separate components for reuse or recycling. We have seen no studies at all that address the disposal of LEDs per se. However, older red LEDs are likely to contain small amounts of arsenic – a potent toxin. Many new LEDs contain no arsenic, but they do contain gallium and indium, about which little is known of possible health and environmental effects. Recent efforts to stem the dumping of cellular phones could serve as a model for end-of-useful life issues for LED lighting systems.
5. LEDS AND EFFICIENCY

Light emitting diodes, invented in 1969, are the first fundamentally new lighting technology since the gas-discharge lamps. They bring many advantages to the lighting marketplace, one of the most notable being energy efficiency. In order to understand why they are fundamentally more energy efficient, it is useful to make a comparison to two conventional technologies, incandescent and fluorescent lamps.

With incandescent sources, electricity is used to heat up a filament until it glows in the visible spectrum enough to create white light. The main product of this process is heat. In fact, by some conservative estimates, only 5% of the energy that goes to a light bulb comes off as light energy in the visible spectrum. Much less than 1% of the energy is released in the form of usable light if a filter is applied to the front of the bulb to create colored effects. In general, higher wattage incandescent lamps radiate more of their energy in the visible spectrum than lower wattage incandescents, which explains in part the efficiency advantage LEDs have demonstrated over the small incandescent lamps in flashlights, headlamps, and nightlights.

Fluorescent sources generally consist of a glass tube filled with argon or argon-krypton gas, and a small amount of mercury. The inside of the lamp is coated with phosphors and is equipped with an electrode at both ends. When a voltage is applied between the ends of the lamp, it causes electrons to shoot across the tube and excite the gaseous mercury atoms that are floating around in the inert gas mixture. Sometimes the electrons excite the mercury atoms, which cause the mercury to emit light in the UV spectrum, which then strikes the inside of the tube and causes the phosphor to emit light in the visible spectrum.

A characteristic that both of the above light sources share is that they emit white light. If colored light is desired with either source, a filter must be applied, and efficiency is reduced as energy is lost through the filtering process. In contrast, with the current state of LED development, colored applications are where LEDs have the greatest advantage in efficiency because they are inherently engineered to emit colored light at relatively low power levels. Most of the energy in a LED is directly converted into emitted visible light and not translated into an intermediate form such as heat (in the case of incandescent lighting), or ultraviolet radiation (in the case of fluorescent lighting).
In theory, when a voltage is applied to either sides of the p-n junction, the electrons and holes combine and release a photon of a specific energy, and no energy is wasted. In practice, there is some resistance in the diode itself. In addition, for reasons unknown to researchers, sometimes when electrons and holes combine, they produce phonons (or heat) that induce thermal vibrations in the lattice of the material. The heat that is produced is much less than an incandescent bulb, and gains on this front have been made since the conception of the LED. For example, the red LED, which is the most well established LED today, produces 40% of its theoretical photon (light) value, while the green LED only produces 10% of the photons that are theoretically possible.9 10

The above findings are one reason why researchers are so confident in the technological curve that is used to describe the LED’s progress. Other findings regarding LED efficiency include:

- The efficacy of a LED light source is highest for monochromatic applications. Red is the most efficacious source. Amber, green and blue are less efficacious, in descending order. This is due to the high utilization of all the light produced by the LEDs, as opposed to waste of the conventional system due to the filtering out of unnecessary wavelengths.

- The efficacy of color LED light sources is higher than it is for white LED light sources. Polychromatic white LED sources are more efficacious than are blue+phosphor white sources.

- The efficiency of a LED lighting system is higher for luminance applications (direct view) than it would be for illuminance (reflected light) applications.

- Conventional light sources emit beyond the visible spectrum (and thus there is associated heat build-up, which negatively impacts performance for all but incandescent light sources). For example, in exit signs and in traffic signals, red LED systems require only 10% to 15% of the input power of an incandescent light source system. Amber, green and blue LED systems range from 15% to 50% of the incandescent demand. White LED systems are not yet mature enough to make a reliable comparison.

In order to take advantage of the efficiency benefits of the LEDs sources, it is important to have a fully optimized and integrated LED package, as well as luminaires specifically designed to fully utilize the light output. Without this systematic integration, it is difficult to take advantage of the efficiency benefits of LEDs. Nevertheless, LEDs sources are on a stellar trajectory: their performance has doubled every four years for the past thirty years. The best commercial performers are now in the range of 30-60 lumens per watt, with much higher performance measured in laboratory specimens.


10 Note that these are general statements based on available information – predictions of actual performance versus theoretical limits for different LED types are still being debated by experts.
Measuring LED Light Output

Measuring LEDs and reporting LED output for use in place of traditional lighting sources actually represents a significant challenge. Conventionally, LEDs performances are measured using radiometry, a system that measures light as energy (electromagnetic radiation), or overall optical power. Photometry is the measuring system that more accurately describes the manner in which the human eye perceives light. Until recently, many manufacturers’ LED specification sheets only showed radiometric data.\footnote{Although it is a useful system of measurement for industrial applications, radiometry is not the appropriate means of measuring LEDs for lighting applications.}

Compounding the situation is the fact that currently, the light from colored LEDs cannot even be measured very accurately with inexpensive illuminance meters; they must be measured with spectroradiometers, or with more expensive illuminance meters that can be corrected with calibration factors.

The introduction of LEDs into lighting applications has created a demand for photometric descriptions of LEDs. This is due to the fact that most lighting designers and energy efficiency program managers are accustomed to comparing the relative efficacy of light sources in terms of lumens per watt (lm/w). This metric assumes that the light source being measured emits light in a fairly broad spatial distribution pattern. However, LED packages emit in a relatively narrow cone of distribution, so it is more difficult to determine lumens per watt for LED-based systems.

There are, however, some metrics available to describe light sources with a narrow cone of distribution that may be adapted for LEDs: incandescent or fluorescent down lights and various directional light sources are usually described both in lumens per watt and foot-candles/watt, or some measure of the intensity of the light they provide. Thus, for LED-based lighting products to enter and successfully compete in the incandescent and fluorescent lighting world, adjustments to these metrics may be needed in order to effectively compare the performance of these different light sources. Still, it is important to note that the usefulness and entry of LEDs into various niches in the lighting market will depend on their higher luminous performance as measured by conventional lighting standards.

LEDs and Conventional Lighting Metrics

Similar challenges to LED measurement and reporting exist in the classification and application of LED-based lighting products. There are two basic ways to use LEDs in lighting: Luminance applications, where we look directly at them as a light source, such as in a traffic signal, and illuminance applications where LED light sources are used for illumination, such as in an overhead lamp. In the second case, the viewer sees only the light that is reflected from the object—while the object also absorbs some of the light. These are two fundamentally different situations, and each has a corresponding set of...
measurement methods, tools, and vocabulary that exist before LED-based lighting was a reality.

Lighting designers and other evaluators and specifiers of white light are familiar with two descriptors of light quality: correlated color temperature, and color rendering. Very simplistically put, these are measures that are conventional but not entirely useful for LEDs. Correlated color temperature (CCT) describes the relative warmth or coolness of a light source when it is compared to an incandescing object, such as the sun, or a heated filament. Since LED “white” light is a combination of several LED light sources, it is difficult to accurately ascribe CCT. Another descriptor of light sources, the familiar CRI scale, or color-rendering index, is used to compare light from various sources to that of incandescent light. Again, this measure is not especially relevant for LEDs light sources, because LEDs sources have very narrow bandwidth emissions, highly dissimilar to the intent of the metric.

There are many debates and theories regarding vision and color. Unfortunately, the lack of a universal, simple way to describe light and vision does make comparing LEDs to other light sources very difficult. Determining their relative energy efficiency is similarly difficult, not the least because most LEDs are very small and emit light in a highly directional manner, whereas other light sources have a much broader pattern of emission, and are physically much larger, too. Due to these dissimilarities it might be more reasonable to compare clusters of LEDs to single lamps of other types.

**Development of LED Metrics**

One possible definition of LED efficiency could equal the total visible light output (in lumens) of the entire system, divided by the total input power (in watts). This would be expressed as lumens per watt. Or, efficiency — at least for luminaires — is more commonly defined as the total light output of the system, divided by the available light output from the lamps or light sources used in the system. This is expressed as a percentage. Either way, there are specific points of potential energy waste in an LED system, as follows:

- **Materials losses:** The integrity of the crystal structure of the LED chip layers determines the potential for the number of photons that could be emitted. Defects lower the light output.

- **Internal losses:** Some photons cannot escape from the LED chip; they convert back to heat energy. LED chip designers seek to increase the “extraction efficiency” of their products by introducing mirror layers, and by shaping or sculpting chips and reflective cups around the chips to better direct light out of the device. In some devices transparent substrates allow the light to escape in many directions.
- Thermal control: As the temperature at the p-n junction rises, the light output of the device declines. Good thermal control is very important for device and system efficiency.

- Encapsulants and optical elements: The materials in sealants, optical layers and lenses must be carefully matched to the emission of the chip to allow as much light as possible to pass through the encapsulating layers. If phosphors are added, they must also be “tuned” to maximize the conversion of excitation emissions to photon emissions.

- Solder or other contacts: Poorly soldered or bonded components resist the flow of electricity, and convert it to heat energy, compounding any thermal issues in the device.

- Controllers, drivers, transformers and other power supply components: Each of these devices can have its own power demand, and contribute losses to the system.

- Luminaire: The LEDs are usually integrated with one or more conventional luminaire components, such as reflectors, housing, or lenses, each of which has loss potentials.

Quantifying the losses at each of the above points would require additional research, and to be accurate should be done for a particular LED lighting system, or LED materials system.

**LED Rated Life**

One of the admirable qualities of the LED technology is that it has a long rated life of 50,000 to 100,000 hours. This is compared to other lighting technologies that range from 1,000 hours or less for an incandescent, 6,000 to 20,000 hours for fluorescent sources, to about 24,000 hours for a high-pressure sodium lamp. The rated life of LEDs is important to consider when analyzing the overall cost of an LED system as compared to the overall cost of a conventional system. The longer life of a LED system makes LEDs more attractive because it lowers the replacement frequency of the system and increases the time that a customer benefits from the energy savings.

In general, the life of a conventional lamp is defined and published by the ANSI/IES and IEC/CIE to be the time at which 50% of the test lamp population burned out. The use pattern that lamps are subjected to depends on the typed of lamp being tested. For example, incandescent lamps are required to operate continuously at their specified voltage until they burn out, whereas fluorescent lamps are operated under controlled
conditions cycling 3 hours on and then 10 minutes off until they burn out. Other technologies have other standard operational cycles to determine rated life.

Conventional lamps have some light output depreciation over the course of their life, which varies according to the types of lamp (Table 1). These percentages are not taken into account when bulbs are rated for longevity, and depending on the application, the bulb may require retirement before the end of its life because of decreased light output.

**Table 1: Rated Life and Lumen Output for Various Light Sources**

<table>
<thead>
<tr>
<th>Light Source</th>
<th>Rated Life (hours)</th>
<th>Lumen Maintenance @50% rated life</th>
<th>Lumen Maintenance @ 100% rated life</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incandescent</td>
<td>1,000</td>
<td>90%</td>
<td>78%</td>
</tr>
<tr>
<td>Tungsten-halogen</td>
<td>2,000</td>
<td>97%</td>
<td>93%</td>
</tr>
<tr>
<td>Metal Halide</td>
<td>15,000</td>
<td>80%</td>
<td>65%</td>
</tr>
<tr>
<td>Fluorescent (med load)</td>
<td>20,000</td>
<td>85%</td>
<td>75%</td>
</tr>
<tr>
<td>High Pressure Sodium</td>
<td>24,000</td>
<td>90%</td>
<td>72%</td>
</tr>
<tr>
<td>Mercury Vapor</td>
<td>24,000</td>
<td>75%</td>
<td>65%</td>
</tr>
</tbody>
</table>

LED lamps do not burn out in the same way that conventional sources do. Instead, their lumen output decreases over time. Currently, the definition of LED life is the point at which the LEDs reach 50% of their rated lumen output. If the lumen output for an application is initially overestimated, this might be a realistic place to set the benchmark. It is also possible that in certain applications, 50% lumen output near the end of the life of the LEDs is not going to be acceptable and they will have to be replaced sooner. There are also a wide variety of confusing claims on life and efficiency of LEDs.

The rate of degradation of the LEDs happens based on a number of factors. These factors include: the quality of the LED chip, the design of the LED package, and the design of the LED system. The most important factor here is heat dissipation within the LED. A quality chip without a heat sink in an enclosed channel letter sign, for example, is going to degrade much faster than a properly driven, properly cooled LED in the same channel letter sign.

Figure 5 below, shows the lumen depreciation of two white LEDs, as measured independently in 2002 by Narendran and Deng from Rensselaer’s Lighting Research.

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12 Note that fluorescent lamp life is predicted more by the number of switching cycles than total hours of operation, while LEDs’ lumen depreciation is driven by hours of operation, making them ideal for applications with frequent switching.

The red line (light gray in black and white printing) represents the high-powered white LED recently developed by Lumileds; the blue (dark gray in black and white printing) represents a traditional 5 mm LED. Notice that the traditional white LED package (5mm) depreciates considerably and is at 50% lumen output at about 6000 hours. The Luxeon LED, developed by Lumileds and representing the future of LED packaging, looks like it is on the way to long life, only losing 10% of its lumen output after 9000 hours.

Figure 5: Lumen Depreciation for Two White LED Packages.

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6. LED COST AND PERFORMANCE TRENDS

Much like Moore’s Law applies to semiconductors used in computing, a similar trend for LED has been dubbed Haitz’s Law. It states that the light output and efficacy of LEDs roughly doubles every 18 to 24 months, and that the future LED performance will likely follow a trend similar to that of the past 30 years. Figure 6 details the performance and cost data for the red LED, which have the longest history in the marketplace. Other colors of LEDs follow similar trends. Not only is the performance of LEDs improving, but the cost is also decreasing, making the technology more cost effective in the marketplace.

It is important to note that this law applies mainly to each single color of LEDs, and not white LEDs. As the development of white LEDs involves hybrid technologies, its performance trends are less predictable than that of colored LEDs. Nevertheless, technology roadmaps maintained by the U.S. Departments of Energy and Defense, in cooperation with manufacturers, forecast white LEDs bright enough for general illumination, displacing current sources in typical applications by 2010.15

The cost per lumen for red LEDs has been steadily falling in the past decade even as performance has consistently increased. Today, the cost per lumen for red LEDs had dropped to less than $0.10 per lumen, while performance has increased significantly during this same time period. At this price level, the LEDs in a typical 25-lm application contribute only about $1.50 to the cost of the complete unit, the remainder ($15 or more) being the costs of the driver and other components.

Even with the recent progress in price and performance, LED devices are still over two orders of magnitude more expensive than commercial incandescent light bulbs for general illumination. In particular, white LEDs are estimated to cost about $.20/lm

currently. Figure 7, below, shows a screw-in replacement for incandescent bulbs developed by Mule Lighting. Rated between 1.1 W and 1.9 W, it is intended for 25 W indicator, signal and marine applications. Pricing has not yet been determined, but is believed to be less than $40 depending on quantities.

Figure 7. “LEDison” Series Lamps from Mule Lighting.

If past progress of red LEDs can be taken as a guide, then we can expect the cost per lumen of white LED lamps to fall by a factor of 10 each decade. At this rate, white light produced by LEDs will cost about $.05/lm by around 2005 and $.01/lm by about 2012.

Figure 8. LEDs Past Performance and Cost Trends

Efficiency of white LEDs is currently better than incandescent and halogen technologies, but is still lagging fluorescent technologies. LEDs are not expected to reach 60 lm/W before 2020. However, if the technology is accelerated, projections indicated that white LEDs would be able to compete with fluorescent efficacy in the year 2010, surpassing

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fluorescent during the second decade of this century. Below, figure 9 illustrates these projections. Although this graph was created in 1999, the projections concerning efficacy that have been made are thus far accurate.

![Figure 9. Efficacy of Lighting Technologies](image)

How are the efficacy and cost projections of white LEDs expected to play out in the marketplace? Haitz et al. have made predictions regarding this complicated question that are useful to consider. The breakeven time associated with incandescent replacement of LEDs is a function of how long the lamp runs each day, the upfront cost of the LED, and the cost of the incandescent lamp. From these perspectives, the LED technology has surpassed the efficacy of the incandescent lamp, but has a higher up front cost. Further, LEDs often need fewer lumens to perform the same tasks under most conditions because their directional nature avoids waste light. A good estimate is that LEDs need about half the luminous flux of their incandescent counterparts to perform the same task.

Assuming that a lamp operates 12 hours a day and is replacing an incandescent lamp that is 100 watts and has an efficacy of 15 lumens/watt, the payoff time today for that kind of replacement is between 6.1 and 2.1 years, depending on the flux requirements of the application (Table 2). In 2010, with efficacies of white LEDs projected to be at 50 lumens/watt, this will be reduced to less than a year to two years. These payback periods, which cast white LEDs in a favorable economic light, strictly compare incandescent bulbs to white LED efficacies. It is important to note that this is in many ways an oversimplification. First, this analysis does not include installation costs of lighting systems (LEDs usually have lower installation costs). Nor are maintenance costs of the two systems taken into account. Maintenance for the LED system is virtually nonexistent compared to the maintenance for the incandescent system, so that actual savings may be larger.

Table 2. Payback Periods for Replacing Incandescents with White LEDs\textsuperscript{18}

<table>
<thead>
<tr>
<th>Year</th>
<th>LED Efficiency (lm/W)</th>
<th>Cost ($/kW)</th>
<th>Equal Flux Break-Even Time (Years)</th>
<th>Half Flux Break-Even Time (Years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002</td>
<td>30</td>
<td>100</td>
<td>6.1</td>
<td>2.1</td>
</tr>
<tr>
<td>2005</td>
<td>40</td>
<td>75</td>
<td>3.8</td>
<td>1.5</td>
</tr>
<tr>
<td>2010</td>
<td>50</td>
<td>47</td>
<td>2.2</td>
<td>0.9</td>
</tr>
</tbody>
</table>

There are also simplifications that make the above predictions look less favorable. The efficacy of an LED is not only dependent on the LED chip itself, but is also dependent on the design of the LED package, most particularly the heat sink and the current values, and also the design of the LED system that includes, among other components, a power supply and a driver. These components have their own efficiency values and power requirements that are not yet standard in the industry and therefore cannot be predicted.\textsuperscript{19}

With regards to LED-based lighting and fixtures, the trend for their penetration is much more uncertain, although certain elements can be gleaned from the recent development of fluorescent lighting, specifically compact fluorescent-based products. Screw-based CFLs finally transcended the bulky magnetic ballast in the mid 1990s, and have steadily gained market share in all sectors, especially in the residential sector for the latter part of the decade. This significant market share gain was helped along in part by utilities’ market transformation programs, and these products’ own quantum leaps in cost, size, variety and performance.

CFL-based fixtures, on the other hand, made more inroads in the commercial and industrial markets, where energy savings and low maintenance characteristics are much more important than others factors, such as first cost or usability. In the residential market place, where manufacturers compete on price points, CFL-based fixtures – especially hard-wired fixtures, have yet to achieve any prominence, especially with the dominance of the do-it-yourself retailers (such as the Home Depot and Lowes) who compete on cost. Even in areas of the country where there have been intervention by market transformation forces, CFL fixture sales have experienced some setbacks once the efforts were removed.

The take-away lesson from the progress of CFL-based products that can be applied to LED lighting products is that residential consumers are more particular about product costs and performance. Other factors such as ease of installation, simplicity, and design, may also play a large part in transforming the market for residential LED fixtures. The most prominent CFL fixture to have penetrated the residential market – the CFL torchiere

\textsuperscript{18} Roland Haitz, Fred Kish, Jeff Tsao, and Jeff Nelson 1999, Table 3.

\textsuperscript{19} While it is reasonable to assume that the semiconductor efficiencies of LEDs will continue to increase rapidly, other components such as heat sinks, optics, solders, may not be able to match LEDs’ spectacular gains due to their technological limits.
– entered the market helped not only by energy efficiency, but also by safety concerns (LED exit signs’ initial entry into the market was also helped by safety concerns). As a consequence of the difference in the commercial and residential market preferences, CFL-based fixtures are still struggling to get a foothold in the residential market while commercial and industrial fixture designs are much farther along in development. Thus, LEDs-based luminaires may experience the same path as CFL-based fixtures.
7. EFFORTS TO ADVANCE LED TECHNOLOGIES AND APPLICATIONS

In a highly competitive and technical market, there are two possible paths toward major advancements: individual manufacturers dedicate a significant percent of their funds towards internal, proprietary research and development, and/or manufacturers team up with government and academia in partnerships, or in consortia that share basic R&D burdens and benefits. To date, LED technical breakthroughs have emerged primarily from proprietary research efforts.

In fact, many of the key patents in the history of LED development have spawned intense industry confrontations, not lightly referred to as “the patent wars.” The confrontations were especially bitter surrounding blue LEDs. These legal stand-offs restricted some of the major manufacturers to producing only the colors of LEDs for which they held the critical materials and process patents. This entrenchment in production not only held back advances, especially with white LED (which requires blue as one of its possible components), but also was the reason why LED consortia have been less common to date.

Within the past two years, this trend has undergone a reversal. Many of the parties have settled and agreed to cross-licensing or other barrier-lowering deals and cooperative efforts. Some examples of collaboration and other combining activities by major LED manufacturers and other major players include:

- University-based collaboratives: The Lighting Research Center's Lighting Transformations Program (www.lrc.rpi.edu) helped overcome barriers to LED exit signs and LED traffic signals in the 1990s; and “ASSIST,” a more recently organized collaborative, includes several manufacturers.

- The National Electrical Manufacturers Association (NEMA) Solid State Lighting Section: this LED effort is industry-based, but it often includes other interested parties in its outreach activities. NEMA members can choose to pool funds for collaborative projects.

- Both OSRAM and Lumileds have shared the cost of systems’ R&D by partnering with driver and component manufacturers (BJB and Advance, respectively) to produce ballast-like devices that are compatible with their LEDs.

- Gelcore: Gelcore is one of the remaining major U.S. players. It recently took a different route to increased cooperation by buying an established LED traffic system manufacturer, Ecolux.

A more comprehensive list of manufacturers and products appears in Appendix A.
Sources of LED R&D Funding

In the past, some LED manufacturers have received substantial research funding from governments, especially from Japan’s Ministry of Trade and Industry (MITI), various agencies in Europe, and the US Department of Defense. Recent performance gains have increased the likelihood of additional funding. During the past year, the NEMA Solid State Lighting Section has intensively advocated for the Next Generation Lighting Initiative, a multimillion-dollar, multiyear R&D activity proposed within the Senate and House versions of the U.S. Energy Bill. The Optoelectronics Industry Association (OIDA) first pushed forward this Initiative, which was originally based on a white paper co-authored by Lumileds and Sandia National Lab.

If the above national legislation ever is approved, and the requested monies appropriated, it is likely that a third party will be named to set up and administer a competitive proposal process. Even if the legislation languishes, its promise has already inspired prospective bidders to get together to discuss collaboration. Most of the funds from this proposed initiative are planned for basic research and development to advance the technology needed to create lower cost, higher efficiency and higher quality white LEDs, with only a small portion earmarked for market and educational activities. Other sources of R&D funds are found at the state level, especially via the California Energy Commission and the New York State Energy Research and Development Authority. Each of these organizations offers competitive opportunities that are suitable both for small businesses and for teams of larger players. In fact, state-level funding might well be the catalyst and locus for a new generation of products.

While these above examples represent significant developments for LED R&D funding and bode well for the future of LEDs light sources, the focus of the majority of R&D efforts to date is still largely on innovative materials, device manufacturing and process improvements that would lead to higher yields and lower costs. It is still too early in the system development lifecycle to see much R&D devoted to LED “lamps” and luminaires. In particular, we expect that luminaire manufacturers will not devote significant R&D efforts to LEDs-based products until more standardized LED packages are available to them.

A few pioneering companies such as ColorKinetics and TIR Systems have put tremendous efforts into creating and marketing entire LED lighting systems. ColorKinetics has successfully raised venture capital for their efforts, while TIR Systems has recently won a Canadian government grant to further their LED systems R&D. They are the exceptions, however. Most manufacturers, especially manufacturers of residential lighting products, currently cannot afford the risks associated with single-source light sources. In the commercial/industrial arena, we expect that progress will come sooner, as LEDs economic and performance improve. In addition, some lighting manufacturers that have had previous experience and success with LED exit signs may have some impetus to expand their advantage and market over those companies that lack any solid-state systems experience.

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**LED Incentive Programs**

Along with R&D funding opportunities, we also examined other efforts to introduce existing LED-based lighting products into the market. To date, these efforts have been led by utilities, government, or consortia and alliances focusing on advancing energy efficiency through market transformation and other incentive programs. While the program targets have been mostly limited to exit signs and traffic lamps, they have helped these products achieve significant market penetration. Overall, these types of programs have compiled an impressive track record of reducing the time to market or sped up the typical market penetration process of products with significant energy savings potential. As more LED products become available, these types of programs will be instrumental getting them more quickly into the market place.

With two exceptions\(^{21}\), all of the LED incentive programs that were reviewed by Ecos Consulting for this report focused on LED traffic signal replacement. LED traffic signal incentive programs have run in all parts of the United States, with the highest concentration of these programs in the northeast and the west coast.\(^{22}\) Organizations operating programs in 2002 included state governments, utility consortiums, and non-profit groups.\(^{23}\) Program ranged from providing information about LED traffic signals (an example is provided in Appendix F), to giving significant rebates for these products. Other incentives include reducing the cost of signals to municipalities through large procurement contracts, and grants to purchase emergency battery backup systems.

There were wide ranges of rebate values, which are summarized in Table 3 below. Rebates are designated by the color of LED signal because of the varying cost of producing different colored light. Red LED lamps generally receive smaller rebates than green LED lamps. It should be noted that some programs also offered rebates for amber lamps and pedestrian signals. The amber lamp was not included in many programs due to the relatively short time that the lamp is in operation compared to the green and red lamps.

<table>
<thead>
<tr>
<th>Type</th>
<th>Range of Rebates</th>
<th>LED retrofit</th>
</tr>
</thead>
<tbody>
<tr>
<td>12&quot;Red</td>
<td>$12-$70</td>
<td>$60 - $125</td>
</tr>
<tr>
<td>12&quot;Green</td>
<td>$38 - $110</td>
<td>$160 - $250</td>
</tr>
</tbody>
</table>

\(^{21}\) These special cases will be discussed at the end of this section.

\(^{22}\) Specifically, we found incentive programs in the states of Minnesota, Wisconsin, Connecticut, California, Oregon, Massachusetts, New York, New Jersey, Vermont, Iowa, and Texas.

\(^{23}\) Information for 2003 is not yet readily available.
LED traffic light retrofit programs are being implemented around the country because of the large potential for energy savings, especially during peak demand. For example, according to *EPRI Journal Online*, Pacific Gas and Electric has saved 41,500 MWh of electricity and reduced peak demand by 5 megawatts. They achieved this by committing $15 million to a program that had 120 participating cities who save 80% - 90% on their traffic light bills. Statewide in California, the Consortium for Energy Efficiency says that the LED signal replacements have reduced state’s peak demand by more than 24 megawatts.24

**Non-Traffic Signal LED Incentive Programs**

**California**: A unique incentive program that offered a wide range of LED product rebates is the 2002 California Statewide Express Efficiency Program and included the utilities service territories of Pacific Gas and Electric, San Diego Gas and Electric, and Southern California Edison. This program is the only program that included incentives for signals, LED exit signs, and channel-letter signs. The focus was on retrofitting existing signage and traffic signals with LED alternatives that have the potential to save over 80% of the energy. The addition of rebates for other LED products is unique.

Rebates were given by the foot for the red channel sign LED and ranged from $2 to $6 a foot depending on the type of channel sign and the size of the sign. The utilities worked with the LED retrofit suppliers, so that the suppliers could include the rebate in their cost analysis for the customer and complete the paperwork for the rebate. 2002 was the first year that the program ran and was not as successful as was hoped because program restrictions prevented large multi-location corporations like fast food or convenience store chains from qualifying for these rebates. The 2003 program addressed this issue, and the response is expected to increase dramatically.25 Even though the absolute value of energy savings is small for these retrofits, the utilities see the huge number of retrofits that are available and the large percent difference in the power consumption of the signs. In 2003, they are also planning on expanding the program to include LED accent lights that replace architectural neon for additional savings.

**Pacific Northwest**: The Bonneville Power Administration sponsored the “Smart Choice Lighting Campaign” in the winter of 2002. The program provided a comprehensive marketing and incentive support for 80 of BPA’s member utilities. Utilities could select from a range of lighting products to promote with funding from their Conservation and Renewable Discount (C&RD) funds. Included in the selection of lighting products were 3rd generation LED holiday lights in 25, 50 and 75 light strings at prices ranging from $7.50 to $12.50 wholesale. Both BPA member utilities and consumers in the four NW states responded well to the program’s LED offerings, and the program sold out of its 68,000 strings that were reserved for utilities. In this case, consumer demand was unusually high, even with a two-fold price difference between LED and conventional holiday lights.

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24 CEE on line information, [www.ceeformt1.org](http://www.ceeformt1.org).

8. AVAILABLE LED PRODUCTS FOR NEAR-TERM APPLICATIONS

When mature, the LED-based lighting market will encompass the residential, commercial, and industrial markets. However, we expect products in the near term (one to four years), will first see application in specific niches in the commercial and industrial arenas before finding their way into more mainstream and residential applications. Even with the quickened pace of product development in recent months, we do not fully expect the residential market to see a large number of LED products within this near-term timeframe. However, the pace of product development has helped to bring more lighting products into the market, and a survey of known LED-based lighting products is presented in this section of the report.

For reasons mentioned, we first categorize LED lighting applications in this report into three general groups rather by markets. The first is group is direct-current LED systems, most of which are portable, battery-powered devices, and therefore do not directly draw power from the electrical grid. However, a subset of this group still uses AC power to charge their batteries and may have some effects on the overall power consumption, depending on their power requirements and market penetration. (In this case, it is their AC/DC power supplies that will have a significant impact on the grid.)

The other two groups include applications that draw power directly from the grid, and require a transformer or power supply unit. These products fit into two distinct groups: LED-based “appliances” – consisting of products that are not used directly for lighting or architectural applications, such as displays; and LED applications for the “built” environment, including buildings, public spaces, and transportation systems. Because developments are taking place rapidly in this field, the information presented here represents a snapshot of these markets at this point in time. The emphasis is more on products that are market-ready, or will enter the market in the near future. Moreover, we have attempted to focus the discussion on possible applications, and not the use of any specific technology or product.

LED Markets, Lighting Products, and Distribution Channels

Currently, the US general lighting and illumination market is estimated to be over $16 billion in volume, and consumes over 500 TWh (terawatt-hours) of energy annually. A combination of incandescent, fluorescent, and gas-discharge lamps (HID) dominate, with LEDs occupying a very small portion of the market. This market is expected to undergo continued growth in the next five years, averaging about 5% a year, with most of the growth in the lighting fixtures market coming from both commercial and residential replacement activities. Construction-related applications currently account for about two-thirds of all fixture sales in 2001. At this projected rate, the U.S. general lighting and illumination market will be at an estimated $21 billion in volume in the 2006-2007 timeframe, consuming over 600 TWh in energy.

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Various scenarios have been used to project LED-based products’ penetration of this market. LEDs’ success depends in part on their performance and users’ awareness of it. Users are less familiar with LEDs than with other lighting technologies that are, for the most part, white sources. This is true for all levels of user experience: lighting designers, business owners, residential and commercial users. The general public is used to thinking in terms of conventional white light design, instead of colored light design because colored light has been in general more expensive than its white counterparts. Not only are people unfamiliar with LED as a technology, but also they are not used to taking advantage of the LED as a colored light source, nor aware of its long-life and maintenance advantages. In addition, building inspectors, government codes, and installers are not yet familiar with LEDs and LED systems.

The Freedonia Group, for example, projects that demands will be driven by a shift towards products offering superior energy efficiency and performance, favoring products such as LEDs, electronic ballasts, low wattage HID, including ceramic metal halide (CMH). As a result of this trend, they expect double-digit growth for LED-based products in the next five years, with any increases in market share coming at the expense of incandescent lamps. Others have projected that LEDs will command up to 35% of lighting energy by 2020 if current progress can be sustained, creating a breakthrough in price and performance in the next five to ten years. If this happens, LEDs will have the potential to outpace fluorescent technologies in both cost and performance.

In the timeframe of this report, which examines LED developments and applications in the one- to four-year horizon, such penetration and saving estimates are not yet realistic. We expect any significant market penetration in this timeframe to be in the niche markets, even for the most mature products currently available. In fact, a significant finding from our survey of the market is that LED-based lighting products are available for a variety of applications, ranging from aviation to commercial signage and even retail lighting, around which marketing, promotion, and education efforts can be built (Appendices A and B contain additional information on LED products and retail applications).

Utilization in electronics (aside from indicator lights) is another active area for LEDs, most notably in the expanding flat panel monitors, displays, and TV markets. While liquid crystal displays (LCDs) have made significant inroads in the computer monitor market, their success has been much more elusive with televisions. The performance characteristics of LCD televisions with backlit fluorescent have not been competitive with the conventional cathode ray tube, especially given the enormous cost differences. Advances in LCD backlight technologies using LEDs are expected to vault the LCD over tube technologies as well as the current crop of fluorescent-backlit LCDs in both performance and efficiency in the near future.

In terms of distribution channels for these products, we expect that LED-based “replacement” products such as TVs and LCD displays may follow the traditional distribution and sales channel in these markets. For architectural accent and retail

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lighting, we expect that some products will enter the market through the established architectural route of specifications and installation (see Appendix B). We encountered a wide range of LED applications during our survey, but, because a number of the products discussed in details below are still niche products, the product distribution channel may just as likely happen through direct sales or other non-conventional routes. We describe below more fully those select applications that we believe would be of most interest in the next two to four years.

**DC-Powered LED Applications: Portable and Off-Grid**

Currently, this is a very active market, but because it is not very germane to the Alliance’s interests, we simply list commonly recognized LED product examples below, in the order of their maturity in the market.

- On-board vehicular lighting, for both exterior (brake lights, turn signals and headlights) and interior functions (indicators, vehicle electronics)
- Portable messaging systems (highway message signs, advertising signs); many are powered by photovoltaic systems
- Flashlights and other portable lighting applications, such as safety lights for bicycles and headlamps
- Cellular phones and other wireless devices such as geographic positioning systems
- Personal digital assistants and handheld electronic games
- Emergency signals and beacons (for example, for marine buoys and docks)
- Landscape and pathway lanterns
- Clothing and footwear

The advantage of highlighting these products is that while they may not result in direct energy savings, they can bring LEDs into the purchasing vocabulary of consumers. In addition, market penetration of some LED products may result in some indirect benefits. Examples include reduced battery consumption and disposal needs in the case of LED flashlights; or the technology transfer of improved manufacturing or production processes in the case of LED holiday lights. Other portable products where there may be some on-grid benefits with additional LED penetration include cellular phones, other wireless devices, and hand-held electronics such as geographic positioning systems (GPS) or personal digital assistants (PDA). Devices belonging in these categories tend to have rechargeable batteries drawing from wall sockets, and can benefit from the reduced power needs with LEDs. It still remains to be seen whether or not the use of LEDs in these products will result in decreased energy consumption, as their increase in popularity may outstrip any savings offered by the more energy-efficient technologies.

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28 According to REI (Recreational Equipment, Inc.), based in Seattle, LED flashlights currently command about 74% of flashlight sales, while LED “headlights” account for 88% of headlight sales. Sales in both categories are following an increasing trend in the past two years.
Even with the quickened pace of product development and introduction in recent months, we do not fully expect the market to overflow with DC-based LED products beyond the current range of offerings. With DC-based products, however, the potential also exists for off-grid applications to replace some current on-grid applications, especially in rural areas where infrastructure is expensive to maintain, is difficult and expensive to extend, or simply does not exist. Although currently not fully developed, the marriage of photovoltaics and LED technologies is a natural for these types of applications.

One company – Carmanah Technologies – leads this field with their off-grid applications that incorporate these two technologies. The company currently manufactures solar-powered LED units for a variety of applications, and has its roots in building navigation lights for port authorities and the US Coast Guard. Such applications require rugged, weatherproof products for use in isolated locations. Carmanah has taken this knowledge and translated it to other markets: one of their newest products is the “I-Stop,” an off-grid solar-powered bus stop that contains security, marker, and schedule lighting with LED-based lighting. This product has the potential to make public transportation safer and more convenient to use by providing passengers with a well-lit and informative shelter.  

While there is little potential to actually reduce the overall load with such a product, many of the bus stops currently do not have the lighting benefits of the I-Stop; adding such amenities with current technologies can result in increased electricity demands. A similar case seems to be the solar/LED combos used for perimeter lighting for buildings and landscapes. The cost savings result from not having to run wires to these products and eliminating the AC load they and their power supplies were responsible for.

**AC-Powered Appliances: Non-Architectural, Non-“Lighting” Applications**

Until very recently, very small-diameter fluorescent lights have been the only means of providing backlighting for liquid crystal displays (LCDs) in computer monitors, TVs, office equipment and appliance displays, and large-screen entertainment systems. The use of LEDs in these displays instead of fluorescent lamps has the potential to improve many aspects of the LCD performance. With current developments, it also might be possible to save a significant amount of energy by switching to this technology.

29 Full off-grid bus shelters are in the process of being developed by Carmanah, with prototypes now in use in London, England. In addition, the City of Oakland, CA and King County, WA have expressed interest in these full service bus shelters. Carmanah is looking to develop these new products in conjunction with buyers that have the potential to procure a large amount of the developed product. The main advantage of the Carmanah shelter technology is that it is maintenance free, and the LEDs used for illumination are said to last 100,000 hours.

30 Conventional LCD screens function as “shutters” for thousands of individual red, blue, and green subpixels. They allow light from behind to pass through, yielding illuminated spots that together comprise an image. Unfortunately, this shutter mechanism is not yet very efficient, with about 90% of the light still being absorbed even in the “on” position. As a result, about 60 to 70% of the total energy consumed by an LCD screen is in its fluorescent backlight system, which must be very bright and evenly distributed in order to deliver a high quality image. These fluorescent backlights also require inverters to convert the low voltage DC power from the screen’s power supply back into AC, compounding energy waste. LED
LEDs are currently being considered for LCD use due to the fact that LED-based liquid-crystal displays have the potential to provide approximately twice the brightness of conventional LCD monitors. Not only do the LEDs-based displays have the potential to be brighter than fluorescent displays, LEDs can provide a wider range of color and better color saturation for LCDs than is currently possible with fluorescent backlight technology. Furthermore, when coupled with advanced controls, LEDs can also help to reduce the motion blur that is typically associated with LCDs.

When LCDs switch from frame to frame in a motion sequence, the residual frame overlaps with the new frame for a split second, resulting in a blurred image. This overlapping occurs because LCDs can only switch frame every 16 to 50 milliseconds, which is slow enough to be seen by the human eye. Capitalizing on the quick response time of LEDs (in the space of nanoseconds), the LEDs used in LCD backlighting can actually be turned off and on in between frames in a ‘strobe’ effect. The backlighting can actually be synchronized to turn off when the LCD is switching from one frame to the next so that the blur can no longer be seen.

At this point, the power consumption of the fluorescent backlight and the LED backlight are roughly comparable, but the efficiency of the LED system is expected to increase in the near future. Efficiency of the light source itself is only one of the factors to consider when determining the power of the backlight. The power consumption of a backlight is inversely proportional to the product of the efficiency of the driver, the backlight efficiency, the transmission factor, and the efficacy of the light source (in lumens per watt). In addition, the power consumption is directly proportional to the flux of the display, which is related to the size, brightness, and viewing angle of the display.

LED backlight LCDs have the potential to create a product that is comparable, if not superior to the CRTs, but consumes a fraction of the energy in active mode. This is especially important when considering other display technologies entering the market that are extremely energy consuming, most notably the plasma display. Plasma displays, valued for their high quality, flat screens, and slim profile, currently cost between $6,000 and $15,000 per unit (sizes from 40 to 50 inches) and consume between 400 and 800 watts or more in active mode, perhaps 4 to 7 times the power use of a comparably sized LCD screen.

The most recent development in this display technology took place in December 2002, when Lumileds, Inc. unveiled to flat-screen display manufacturers a linear array of red, blue, and green LEDs in a strip, controlled by sophisticated light feedback technology. This new product was designed to expressively serve as a screen backlight for LCD displays, with the potential to offer improved color palette, wider viewing angle and increased brightness. The new control technology also offered better moving frame backlights promise to improve LCD screen efficiency and performance by increasing the vibrancy of colors, allowing customization of the shade of white light desired, eliminating the need for an inverter, and cycling rapidly on and off during periods of motion to improve clarity and cut power use.
resolution, and can be used in displays ranging from 5 to 20 inches in size, with Lumiled’s target being the 15 to 18 inch size range.

Figure 10. Effect of Blinking an LED Backlight

In Lumiled’s design, a linear strip of red, blue, and green LEDs light the LCD, replacing four or more fluorescent backlights typically used for an LCD screen. The strip produces 60-75 lumens/inch, with expectations that in one to two years it will increase to approximately 125 lumens/inch. To counteract the time degradation associated with LED technology, the system automatically maintains brightness and color levels with a brightness feedback system. In addition, these diodes generate 120% of the National Television Standards Committee (NTSC) color spectrum while conventional displays usually include about 70% of the spectrum.

Initial applications for this technology include monitors with wider viewing angles for use with medical consultations, high brightness monitors for viewing ease in high light conditions (for example, monitors in convenience stores), and monitors used by designers
who value the real-life saturated color rendition. Lumiled’s first products with this technology are expected to arrive in the display market in late 2003.

If this technology continues to advance as it has in the past, the potential for energy savings in the 3.9 million units a year LCD monitor market alone is significant. 31 Most of the power used by an LCD monitor is consumed by the backlight, so approximately 12.5 W of an average 30W LCD would be saved per unit during active mode. 32 If all LCD monitors were to incorporate LED backlight technology, the nation would have the potential to save over 38 GWh annually at current shipment volume. 33 Even more significant is the potential penetration of LED-backlight LCD TVs into the TV market, which according to Lumileds 34, should happen in two to three years, and can save up to 800 GWh per year at 25% market capture. 35 Market analysts are also predicting a bright future for OLEDs in the display market, due to their color reproduction abilities and the lower light output requirements for displays.

31 This 2001 annual sales estimate is according to Alfred Poor, “Flat-Out Brilliant,” PC Magazine, Feb 26, 2002.

32 This estimate assumes that a combination of improvements to the LED backlight system effectively halves the current power consumption of the backlighting system, which according to Mark Pugh of Lumileds, is a reasonable assumption.

33 Based on population, the NW accounts for about 4% of this amount, or 1.5 GWh. However, with the concentration of high-tech industries in the NW, this number may be higher.


35 There are other environmental benefits of the LED backlights. The lifetime of the LED backlight (50,000 hours) is more than the conventional backlight, leading to longer product lifetimes and less waste.
AC-Powered LED Lighting for the Built Environment, by Sector

The products discussed in this section are subdivided into three categories, and are listed in the columns below. In keeping with the convention set out earlier, we cover in details products that have near-term potential, with a summary matrix containing manufacturers, products, and their characteristics included in an appendix. With regards to market size, potential savings, price and penetration trends, this is the most difficult sector to develop estimates for with any certainty. This is because these products are entering the market at different entry points – some stay within their traditional distribution channel for their product categories and applications, while others are finding new routes.

<table>
<thead>
<tr>
<th>Industrial</th>
<th>Commercial</th>
<th>Residential</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aviation</td>
<td>Architectural</td>
<td>Outdoor pathway</td>
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<tr>
<td>Marine</td>
<td>Accent</td>
<td>Outdoor signage</td>
</tr>
<tr>
<td>Medical</td>
<td>Entertainment</td>
<td>Mini-signage and</td>
</tr>
<tr>
<td>Military</td>
<td>Health and Hospitality</td>
<td>decorative strings</td>
</tr>
<tr>
<td>Roadway</td>
<td>Outdoor</td>
<td>Security</td>
</tr>
<tr>
<td>Signals</td>
<td>Retail</td>
<td>Small plug-in</td>
</tr>
<tr>
<td></td>
<td>Merchantising</td>
<td>Task</td>
</tr>
<tr>
<td></td>
<td>Signs</td>
<td>Under cabinet</td>
</tr>
<tr>
<td></td>
<td>Signals</td>
<td>Showcase/hobby</td>
</tr>
<tr>
<td></td>
<td>Task Lighting</td>
<td></td>
</tr>
</tbody>
</table>

Industrial Opportunities

One area where LED-based industrial/commercial lighting products can make a significant impact in the near-term is airport, port, and roadway lighting. Traffic intersections, shipping, and aviation landing facilities use colored light sources as guidance signals. Conventional installations rely solely on incandescent lamps. These incandescent lamps have a very limited lifetime of only 2,000 to 4,000 hours for traffic signals, and up to 8,000 hours for airport applications. Due to their location, the use of incandescent lamps in these applications is a major maintenance burden. In addition, since the incandescent lamps are filtered to achieve particular colors suitable for aviation, shipping, and roadway needs, most of the input power is wasted.

Aviation (& Shipping)

Currently, there are about 14,000 airports as well as thousands of ports & shipping facilities in the US that require markers, numbers, signs, and other aviation-related, high duty-cycle lighting tasks, which are being met by incandescent lamps. The wholesale replacement of incandescent transportation-related lighting with more energy efficient and longer lasting LED units can result in significant energy and maintenance savings for shipping and aviation facilities, most of which are struggling to contain operating costs.
Viable LED alternatives for these applications are beginning to appear, one of which is manufactured by Dialight Corp. and recently approved for use for obstruction lighting by the FAA. The Dialight LED unit is a 19-LED, 12.5 watt unit with a rated life of 100,000 hours. This unit and other LED modules being developed are designed to replace 8,000 hours rated 126 Watt incandescent lamps that are typically found in these applications. Aviation facilities generally rely more on green, blue and white signal colors, so the energy savings with LEDs would be slightly less than for traffic intersections (~80% versus ~90%). To date, LED aviation lighting is being used in limited numbers only at 13 North American airports, including Anchorage, Phoenix, and Toronto.36

**Traffic Signals**

LED traffic signals offer a huge potential for energy savings and therefore have been successfully targeted by energy conscious organizations around the nation. Red LEDs have been used in this capacity for about a dozen years. Traffic signal retrofits take advantage of the colored nature of the LED light by replacing incandescent bulbs and filters. The luminous efficacy of the LED system far exceeds that of incandescent lamps in this application. LED traffic signals save between 80% and 90% of the electricity of conventional incandescent signals. By conservative estimates, there are 3 million traffic signals in the United States.37 If these were all converted to LED signals, the energy savings would be significant: 3 billion kWh saved annually, reducing overall peak demand by 340 MW. At this time, it is estimated that about 10% of the traffic signals in the US are LED traffic signals.

Energy savings is not the only area LEDs traffic signals excel. They last 5 to 10 times longer than conventional signals (up to 50,000 hours), and have little or no maintenance requirements. This means reduced safety risk for the work crews as well as reduced maintenance costs incurred by the municipality or state responsible for the signal. In addition, battery backup systems for important intersections can illuminate LED signals for much longer periods of time than they can illuminate incandescent signals in the event of a power outage.38

Currently, the most significant barrier to LED traffic signals’ market penetration is their initial cost, which is considerably more than incandescent traffic signals. An incandescent traffic signal lamp costs about $2 to $2.50, excluding reflector and cover. LED traffic signal modules costs vary, but they can cost 50 to 100 times more than the incandescent

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37 Based on population, the NW’s share is about 120,000 units and about 1.2 TWh in annual energy savings (or approximately 10,000 kWh savings per signal).

38 To illustrate, a 68-light intersection (4 lanes) with incandescent signal lamps consumes about 6.8 kilowatts, while the same intersection, configured with LED signals, consumes a tenth of that amount, or 680 watts. This has the potential to lengthen battery run time by a factor of ten, moving a system from being able to run 15 minutes to a system that would be able to run for over 2 hours. Other advantages of such low power consumption include the ability to reduce system and back-up battery size, thereby decreasing purchase and/or maintenance or battery replacement costs as well.
unit. For example, a 12” red LED signal can range from $60 to $125, and a 12” green LED module costs $160 to $250. Amber LED signals typically cost about $75 each.

Table 4. Typical Intersection and Airport Lighting Use

<table>
<thead>
<tr>
<th>Lamp Location</th>
<th>Traffic Signal Per Intersection</th>
<th>Aviation Per Airport - One Runway</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ball</td>
<td>Turn</td>
</tr>
<tr>
<td># Lamps Required</td>
<td>24</td>
<td>2</td>
</tr>
<tr>
<td>Incan. Watts/Lamp</td>
<td>150</td>
<td>125</td>
</tr>
<tr>
<td>Subtotal (Watts)</td>
<td>3,600</td>
<td>250</td>
</tr>
<tr>
<td>LED Watts/Lamp</td>
<td>15</td>
<td>10</td>
</tr>
<tr>
<td>Subtotal (Watts)</td>
<td>360</td>
<td>20</td>
</tr>
<tr>
<td>Savings (Watts)</td>
<td>3,240</td>
<td>230</td>
</tr>
<tr>
<td>Total Savings (Watts)</td>
<td>4,350</td>
<td>59,160</td>
</tr>
</tbody>
</table>

**LED Commercial Signage**

Signs are a high-profile energy users not only because they are used to attract public attention, but also because many are on 24 hours per day, consuming about 2% of the total electricity in the US. In 2001, the outdoor signs accounted for the larger sales percentage, with a majority of these sales going towards sports arenas. According to a survey conducted by the editors of *Signs of the Times* magazine, the US electric signs industry was estimated to be over $5.4 billion. Fluorescent signs account for about 48% of this market, with neon signs holding about 41%, the remainder of the market is occupied mostly by incandescent products.

LED signs are still relatively new to this somewhat conservative group of manufacturers. In the same period, LED sales showed a significant increase over the past year, reaching $380 million. Even with this increase, LED-based signs occupy less than 1% of this market. The trend that can be seen here is that larger companies in this industry tend to be the ones who offer LED signs first, based on their customers’ demands. The smaller manufacturers often specialize in neon signage, and tend to be protective of this aspect of their business (Appendix D contains the results of a survey of NW sign distributors on their awareness of LED signs).

A variety of LED products are now available for new or retrofit commercial signage and architectural lighting that could further reduce the electrical load, even for neon and fluorescent signs, especially during peak hours. These include the following:

- **Color Wash floodlighting** for variable color on interior and exterior walls in entertainment venues, and other high profile building facades. The LED products have been available for 7 months and feature 5 different colors. They are fully programmable to produce a variety of effects that are unachievable through other lighting methods.

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• **Channel Lettering replacement** products are available from a variety of manufacturers, including Osram/Sylvania, PermLight, and TIR Systems.

• **Replacement for MR-16 architectural halogen lamps** for exterior lighting.

• **Replacement Neon** polycarbonate tubing puts LEDs into a package that looks like a neon tube. Used for architectural neon accents on buildings and in entertainment venues (“architainment”). Available from PermLight and TIR systems.

Generally, LED companies cited that other performance benefits of their products were more important than energy savings to their clients. Special effects, such as programmable color changes, that are previously unachievable with other lighting techniques are important considerations. In addition, customers appreciate the flexibility, ruggedness, long life, and simple install aspects of the LED products. Users that are not associated with the entertainment (including casinos) and decorating industries are more likely to be interested in the energy savings aspects of the products.40

LED products also bring new considerations to the sign market. These products, in some cases programmable with ability to produce a rainbow of color, are changing old methods of sign construction and entertainment design. Because white has not penetrated this arena, these products require designers and business owners to ‘think in color’ when conventionally the design was primarily based on white light. Installation, although actually easier than conventional installation of sign products, is different than what electricians and inspectors are used to, and may not be adequately covered by building codes. This makes education an important aspect to the sale.

LED companies cited a number of concerns that were raised by customers about the products. Customers have yet to trust that the products that they are purchasing are going to last through their guaranteed lifetime, all the while maintaining their performance specifications. With the products being in their infancy, this can be a significant hurdle to the conservative customer. The upfront costs of the various products can be prohibitive. For example, the upfront cost for architectural neon replacement is 50%-100% more than conventional neon. The customer must be willing to consider the entire upfront cost, which includes cost of installation in order to make the sign products more favorable. Some customers don’t think that the products are bright enough; others are more interested in the conventional white signage options that are, as of now, virtually unavailable with LED technology.

**LED Exit Signs**

According to an estimate by the US EPA in 1999, there are about 100 million exit signs in the US, using about 4 billion kWh per year. Exit signs typically found in older buildings still use incandescent lamps, and each two-face sign can consumes about 30 to 35 kWh annually. LED-based exit signs currently use about one-tenth of the energy

40 The TIR neon replacement products system claims a range of 40% to 90% efficiency improvements over the neon, depending on the baseline dictated by the conventional product.
required by incandescent lamps, and last much longer. The luminous efficacy of the LED system far exceeds that of incandescent lamps (and CFLs) in these types of applications. Like traffic lights, new and retrofit exit signs also take advantage of the colored nature of the LED light, replacing the need for incandescent lamps and colored filters, and can save between 80% and 90% of the electricity of conventional incandescent exit signs.

Because of their energy saving potential, LED exit signs were the focus of a number of utility programs, and are now well established in the market, thanks in part to pioneering DSM incentive work done in the 1990s by BPA and other members of the Alliance. The introduction of the US EPA/DOE ENERGY STAR® Exit Sign program in 1996 further enhanced the market acceptance of LED exit signs, and established a national specification. LED exit signs have been proven as a full acceptable substitute for conventional incandescent exit signs. In fact, this is another case where LEDs not only hold an advantage over incandescent lamps, but also over CFLs as well in both energy consumption and lifetime.

**LEDs in Retail Food and Beverage Displays**

Another retail area where LED lighting has the potential to excel is in the grocery market, specifically in coolers and freezers. Currently, this market segment accounts for about 15% of all refrigeration energy use in the US, and is dominated by fluorescent lighting. However, LEDs have inherent characteristics that are much more suitable for this particular application: LEDs are more efficient at directional illumination, not adversely affected by cold temperatures, and do not require as much space. Other LED advantages include maintenance, energy-efficiency, longer life, and with advances discussed in the section on general retail, they can be “tuneable” to highlight particular colors in the products on display. In addition, LEDs can also reduce the amount of heat introduced into the display space when compared to fluorescents, yielding secondary savings.

While the technology exists, to date, no manufacturers have gone further than the concept stage with this particular application. Fluorescent manufacturers, on the other hand, are aggressively moving to keep their dominance in this market – several manufacturers have shown prototypes of cold-cathode fluorescent (same technology used in displays and LCDs) illumination systems for coolers, as well as more efficient systems based on T-5 fluorescent lamps. While these new fluorescent systems may promise incremental energy savings, LEDs may still offer important advantages over all of them.

**LED in Retail Lighting**

LED-based lighting in retail applications is a nascent, but potentially enormous market, as LEDs can and will displace incandescent products in a way that CFLs have never been able to do. LEDs offer unprecedented flexibility in colors and configurations to lighting designers in creating displays and display environment.

The potential for LEDs in retail and display markets may not be fully realized for some time, as designers and engineers explore and discover its possibilities. Nevertheless,
studies have been conducted to evaluate the feasibility of LEDs in this environment. For example, a study was designed to compare the performance of a conventional white light and colored LED light as used window display backgrounds. Some significant findings are summarized below:  

- Static colored (LED) light in combination with white light provided significantly more visual appeal than all-white light.
- Modulated colored (LED) light in combination with white static light provided significantly more attention capture than all white light.
- Colored (LED) light did not improve the viewer clarity of the display. The clarity was solely influenced by the luminance (quantity of light) on the display.
- When colored (LED) light is used on the background of the display, the accent light on the display can be decreased significantly preserving the attention capture and the visual appeal of the display.
- Energy savings with colored LEDs result in two ways – one, by producing efficiently a colored background for the display (without trashing light by color filtering), and two by being able to decrease (dim) the amount of accent light on the display objects.

Finally, with retail lighting, additional cost savings can be achieved through reduced labor costs, as the use of LEDs, especially programmable and “tuneable” products would eliminate the periodic need for lighting changes and updates.

**LED Holiday Lights and Other Applications**

LED-based holiday and “decorative” light strings have generated considerable consumer interest since their introduction several years ago. Manufacturers have been steadily improving product performance and quality. The most recent (3rd) generation of products is brighter and more reliable, with wider color variety. LED holiday and decorative light strings offer a magnitude reduction in energy consumption over current products (~4W versus ~40W or more per 100 light string). While the majority of applications remains seasonal, more are being used for decorative purposes (for example, the Portland Zoo, or a number of NW historic down-town districts), and stay lit year-round. Replacing these year-round decorative applications with LED light strings could yield additional savings on top of the savings achievable during the holiday season.  

41 “Use of colored LEDs in retail window display.” Master of Science Thesis, Milena Simeonova, Lighting Research Center, Troy, NY.

42 Per the Bonneville Power Administration’s Smart Choice Lighting Program, each 100 light LED strand saves about 8.6 kWh during their estimated 30-day holiday season service (at 8 hours per day).
In addition to holiday and decorative lights, LEDs have also made some inroads into several other consumer areas, including:

- Task lighting
- Pathway lighting (some with photovoltaic cells and battery ~4W per unit)
- “Rope” strings or light strips
- Nightlights
- Emergency lighting systems (not yet available commercially)

Each of the above categories has the potential for energy saving in the order of one magnitude or more when current products are replaced with LED-based alternatives.

Figure 11. LED Task Lamp (Courtesy TCP, Inc.)

In particular, the task lights that have recently been introduced by a number of manufacturers are worth noting for their combination of energy efficiency and light output. The latest products, rated at about 3W to 5W, are offering about 60% additional energy savings over CFLs (as compared to a 15W CFL), and over 90% savings over their incandescent counterparts (as compared to a 60W incandescent lamp). A number of these products use the high brightness LEDs that are currently found in commercially available flashlights and reading lights (Figure 11). As these LEDs are not yet capable of delivering true “white” light, manufacturers are using a combination of colored LEDs (for example, blue-white/yellow) to deliver light at the 2700°K to 3100°K color temperature range that users are familiar with. A number of these products are being designed into the new public library in Hillsboro, OR, scheduled to open in 2004, and promises to deliver significant savings over their 50,000 hours rated life.

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43 While these products are rated at 3W to 5W currently, they use the traditional (and energy inefficient) “brick” transformers as their power supplies. Advances in power supply designs can further reduce their power consumption by 50% or more.
9. LEDS: BARRIERS, OPPORTUNITIES, AND NEXT STEPS

LEDs bring many advantages to the lighting marketplace, and offer significant energy saving potential. Since the technology is so new and fundamentally different than the two dominating conventional technologies – incandescent and fluorescent, it faces significant challenges from several fronts. In the timeframe of this report, which examines LED developments and applications in the one- to four-year horizon, we expect any significant market penetration to be in the niche markets, even for the most mature products, and not without some external support.

A number of the challenges faced by LEDs – discussed elsewhere in the report – are summarized below (and further elaborated in Appendix C), along with near-term opportunities and next steps.

**Barriers**

- **Technological Barriers**: LEDs still have a number of technological hurdles to overcome. LEDs are currently more difficult to fabricate than their microchip cousins, though more improvements in production methods may be able to increase yield and help to further drive down prices. Additional work also remains to be done in the systems design and integration area before LEDs can fully compete as a viable light source in the general lighting market. There still is no consistent approach to creating an LED system to date. Finally, because it is a new technology, the upfront cost for LED-based systems is often more than conventional systems.

- **Comparing LEDs to Other Sources**: LEDs also face measurement hurdles as they enter the lighting market. Measuring LEDs’ performance with conventional lighting metrics, which are based on the incandescent standards, could actually hinder the process of using LEDs in applications. In addition, until LEDs are marketed in a more convenient assembly, it remains difficult to compare the output of different light sources to LEDs.

- **Educational Barriers**: LED-based lighting remains a new technology that is not well known in the marketplace. This unfamiliarity applies equally for users at all experience levels: lighting designers, residential and commercial users, installers, building inspectors, and government code officials. Most lighting designers are used to thinking, designing, and working with white light sources instead of colored light sources. They are also not accustomed to taking advantage of the energy-efficiency, long-life and maintenance characteristics of LEDs.

- **Infrastructure**: Because it is a new technology, manufacturers of LED luminaires, systems and controls are few, and some products have reached the market via different routes instead of the traditional distribution channels used by more established lighting products.
Opportunities

- **Design**: Because LEDs are an inherently colored light source, they present new design and application opportunities in a variety of areas where conventional lighting has dominated, as designers and specifiers become more aware of their qualities. In the near-term, however, there are quite a number of “niche” opportunities for LED technologies to become more established, displacing incandescent and even CFLs.

- **Applications**: LEDs excel in low temperature operations, rugged environments, and applications that require fast ‘on-time.’ LEDs systems also tend to be more compact, due to their generally small footprint, allowing for easier installations and smaller space and materials requirements (for example, a disk of LEDs that can be attached to the ceiling versus the need to install an 8 in deep downlight cylinder or box).

- **Safety**: LEDs’ lower power consumption provide some obvious safety advantages over incandescent lighting systems, including:
  - Easier system adoption and installation (low voltage, reduced component size and complexity)
  - Less electric shock risks
  - Lower fire risks

- **Technological, Environmental and Market**: Technological advances are taking place quickly, enabling LEDs to match the progress mapped out by experts. As LED technologies improve and displace current technologies, there is substantial opportunity for energy savings in both lighting and display areas. Estimates of the lighting savings potential alone is significant, as more efficient LED lighting technologies can substantially reduce the projected 600 TWh annual consumption by US general lighting needs by 2007.\(^\text{44}\) Similarly, LED penetration into the display market can yield huge energy savings.

Table 5 identifies both barriers and opportunities associated with a particular characteristic or related issue. For example, LEDs’ characteristic colored light output represents both an educational barrier and a design opportunity.

\(^{44}\) Ibid
Table 5. Summary of LED Characteristics, Barriers, and Opportunities

<table>
<thead>
<tr>
<th>LED Characteristics</th>
<th>Barriers</th>
<th>Opportunities</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Technological</td>
<td>Educational</td>
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<tr>
<td><strong>New Technology-Related Issues</strong></td>
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<td></td>
</tr>
<tr>
<td>Performance Trends</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>Led ‘Package’</td>
<td>V</td>
<td>Infrastrucure not in place</td>
</tr>
<tr>
<td>Lack of Components</td>
<td>V</td>
<td>Infrastrucure not in place</td>
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<tr>
<td>Installation</td>
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<tr>
<td>White LEDs</td>
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<tr>
<td>Colored Light Source</td>
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<td>V</td>
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<tr>
<td>Energy Efficient</td>
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<td>V</td>
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<tr>
<td>Long Life Time</td>
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<td>Reduced Maintenance</td>
<td>V</td>
<td>V</td>
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<tr>
<td>Performance-Related</td>
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<td>Measurement Metrics</td>
<td>V</td>
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<tr>
<td>Expensive to Measure</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>Directional Light Source</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>Lacks Common “Language”</td>
<td>V</td>
<td>R&amp;D focused on chips</td>
</tr>
<tr>
<td>Fast On-Time</td>
<td></td>
<td></td>
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<tr>
<td>Low Voltage</td>
<td>V</td>
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<tr>
<td>Simple System</td>
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<td>Low Temp Operation</td>
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<tr>
<td>Others</td>
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<tr>
<td>Cost</td>
<td>V</td>
<td></td>
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<tr>
<td>R&amp;D Connections</td>
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<tr>
<td>Off-Grid Possibilities</td>
<td></td>
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<tr>
<td>Photovoltaic Connection</td>
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<td></td>
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<tr>
<td>Disposal Issues</td>
<td>V</td>
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</tr>
</tbody>
</table>

Next Steps

As with any new technologies, especially one as visible, and has the potential to impact not only lighting designs, but also some fundamental ways on how lighting is quantified, a combination of new and old approaches may be needed to help LEDs-based products enter the market. As discussed earlier, available products currently range from market-ready to “vapor ware,” necessitating some degree of caution, applying lessons learned from CFLs. Finally, products and projects supported must also serve the Alliance’s mission as a market transformation organization, as well as meeting the specific needs of the Pacific Northwest.
Depending on potential impacts and savings, the Alliance has a variety of options to pick from in advancing LEDs technologies. It can choose to support some market-ready products with marketing and other assistance to shorten the market penetration time, study and invest in potentially promising technologies to help speed up the to-market time, and conduct pilot projects to ensure market-readiness of others.

With regards to which products to pair with what approach, some initial suggestions are covered in the table below, with additional discussions to follow:

Table 6. Available Program and Funding Options

<table>
<thead>
<tr>
<th>LED Product Status</th>
<th>Product</th>
<th>Possible Approach</th>
<th>Additional Approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>Market-Ready</td>
<td>LED Signage</td>
<td>Education/Marketing</td>
<td>Codes, Incentives</td>
</tr>
<tr>
<td>Market-Ready</td>
<td>Aviation/Shipping &amp; Roadway</td>
<td>Pilot</td>
<td>Demonstration, Group Procurement</td>
</tr>
<tr>
<td>Market-Ready</td>
<td>Traffic Signals</td>
<td>Code Development</td>
<td>Case Studies</td>
</tr>
<tr>
<td>Near-term/MR</td>
<td>Niche Products Group</td>
<td>Education/Marketing</td>
<td>Regional Promotion</td>
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<tr>
<td>Near-term</td>
<td>Programmable/combo</td>
<td>Research/Assistance</td>
<td>Market Assessment</td>
</tr>
<tr>
<td>Near-term</td>
<td>White LEDs</td>
<td>Research/Assistance</td>
<td>-</td>
</tr>
<tr>
<td>Developmental</td>
<td>LED-Based LCDs</td>
<td>Education/Demonstration</td>
<td>Pilot</td>
</tr>
<tr>
<td>Developmental</td>
<td>Retail Lighting (“visi-coolers”)</td>
<td>Demonstration</td>
<td>Pilot</td>
</tr>
<tr>
<td>Developmental</td>
<td>Retail Lighting</td>
<td>Designers Challenge</td>
<td>Demonstration</td>
</tr>
</tbody>
</table>

**Market-Ready**

Among the market-ready products, LED-based traffic signals, airport/port lighting, and signage are poised to become competitive with traditional incandescent and even CFL products. As is the case of many products that are on the cusp, some products may take more time to penetrate the market than others.

For example, with aviation, shipping, and signal products, the LED-based replacement modules’ initial costs are clearly a deterrent in their penetration of the market, despite their clearly superior lifetime, maintenance, and energy conserving characteristics. The Alliance could consider a program to replace the incandescent lamps with LEDs at a number of major NW airports, or initiate group procurement of these products for airport and shipping use. Based on information compiled for this report, an average airport with one runway draws about 69.6 kW with incandescent lamps, which can be reduced by 80% (to 10.44 kW) with LED lamps.

Table 7, below, lists the number of operating airports in each of the NW state, and possible savings:
Table 7. Estimated Energy Usage (in Watts) for NW Airports

<table>
<thead>
<tr>
<th>State</th>
<th>Estimated Number of Airports</th>
<th>Estimated Number of Major Airports</th>
<th>Estimated Incand. Watt per Airport</th>
<th>Estimated LED Watts per Airport</th>
<th>Estimated Savings Per Airport (W)</th>
<th>Estimated Annual Savings (MWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Idaho</td>
<td>119</td>
<td>6</td>
<td>69,600</td>
<td>10,440</td>
<td>59,160</td>
<td>3,109</td>
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<td>Montana</td>
<td>121</td>
<td>5</td>
<td>69,600</td>
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<td>Oregon</td>
<td>111</td>
<td>7</td>
<td>69,600</td>
<td>10,440</td>
<td>59,160</td>
<td>3,628</td>
</tr>
<tr>
<td>Washington</td>
<td>139</td>
<td>8</td>
<td>69,600</td>
<td>10,440</td>
<td>59,160</td>
<td>4,146</td>
</tr>
<tr>
<td>Total</td>
<td>490</td>
<td>26</td>
<td>69,600</td>
<td>10,440</td>
<td>59,160</td>
<td>13,474</td>
</tr>
</tbody>
</table>

In the case of LED traffic signal modules, market transformation organizations, utilities, and some local governments, including the City of Portland, have invested sizeable efforts and funding to help increase their exposure and use. There are now sufficient “success stories” that can be used to further increase awareness and promote the use of LED traffic signals in the NW.

In 2002 the State of California updated its Title 20 energy-efficient legislation to include a mandate for the exclusion of incandescent exit signs from sale in California, beginning in 2005. This legislation was based on evidence that this was in the public interest by the sponsoring utilities. A similar case can be made here in the NW. We recommend that the Alliance and its members consider initiating similar actions as next steps for exit signs. Such a move would aggregate the market for LED exit signs for the entire west coast of the U.S., further reducing first costs for LED exit sign products. It would also capture permanently the lower input power demand and higher energy savings for this segment.

With regards to the signage market, LED-based signs are now being offered by manufacturers and starting to gain some footholds. In fact, our survey for this report indicated that LED signs are available from a number of sources in the NW. The level of awareness and demand for LED signs, especially outdoor signs, is still minimal. Possible next steps for the Alliance can include programs encouraging potential customers to consider LED signs over neon or even fluorescent signs. While the promotion of new signs may not result in energy savings, as they represent new loads, a successful campaign targeting replacement signs can yield significant savings, as a majority of business signs can be on for 12 hours a day or more.

**Near-Term**

Near-term LED products opportunities include a mix of products in both the grid-connected and the off-grid categories. Of interest among them is the group consisting of niche LED product categories whose savings potential by each may not appear to be significant, but collectively, they can yield significant savings. Among these are LED-based task light, nightlights, holiday lights, light strips, pathway lighting, and possibly emergency/backup lighting.
The replacement of current systems with LEDs through a comprehensive market transformation effort, building on earlier work by NW utilities can yield significant energy savings. This is especially true for nightlights (average of 2 or more per households at 8 to 12 hours per day), holiday lights (which are more routinely used as decorative rather than seasonal), as well as pathway lighting. Of particular interest is the new task lights that are just beginning to make their way into the market, with the latest products offering about 60% additional energy savings over CFLs, and 90% savings over their incandescent counterparts.

As in the case with LED signs, the promotion of some of these above lighting systems, such as decorative lighting or pathway lighting can have the effect of load-building rather than reducing energy consumption. However, a well-designed program focusing on transforming the market for these products can minimize such overlap while reducing future energy needs.

**Developmental**

Opportunities to further help the development of LED technologies include a mix of program design options, ranging from research assistance (an option less aligned with Alliance mission), and educational/marketing efforts for new products with great energy-savings potential, to additional market assessment, or participation/initiation of regional or national efforts. For example, the development of the nascent white LED market remains uncertain, and still requires additional investment in R&D as well as lighting systems. The most cost-effective way to leverage Alliance resources here may be in the form of a design competition, or even a regional forum or demonstration project to highlight the issues of applications for LEDs and LED-lighting systems.

LED-based displays hold the most energy-saving potential. While the development of this market has been rapid, options remain for the Alliance to significantly affect energy consumption in this area. For example, in the TV market, plasma displays are beginning to make significant in roads, including usage as monitors in public spaces, such as the Portland International Airport. LED displays’ two significant advantages over plasma technology – energy consumption and lifetime – are not well known. A small, well-focused program to address these factors can result in significant energy savings. This effort lends itself well to regional and even national cooperation, such as working with the Consortium for Energy Efficiency. Other small Alliance efforts in this area can include sponsoring additional studies or evaluation of retail and viscooler lighting.

**LED Lighting System Metrics**

Finally, one area that the Alliance may consider a leadership role is helping to identify metrics with which to better measure LED-based lighting system performance. This will entail working with other Market Transformation organization, such as the Consortium for Energy Efficiency, and perhaps others interested in product performance and efficiency.
Summary of Savings Potential
Table 8 below summarizes the savings potential of a number of LED products in the US, their status, major barriers, and the potential for the NW.

Table 8. Estimated Energy Savings Potential for the NW

<table>
<thead>
<tr>
<th>LED Product Category</th>
<th>Current Product Status</th>
<th>Est. US Potential</th>
<th>Est. NW Potential</th>
<th>Major Barriers</th>
<th>Basis for NW Estimates</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Lighting</td>
<td>Long-term</td>
<td>500 TWh/yr</td>
<td>20 TWh/yr</td>
<td>Technological</td>
<td>~4% of US Estimates</td>
</tr>
<tr>
<td>Aviation &amp; Shipping</td>
<td>Market Ready</td>
<td>~59+ kW/Airport</td>
<td>13.4 GWh/yr</td>
<td>Price, Awareness</td>
<td>Savings only from 26 major NW airports</td>
</tr>
<tr>
<td>Roadway/Signal</td>
<td>Market Ready</td>
<td>30 TWh/yr</td>
<td>1.2 TWh/yr</td>
<td>Price, Awareness</td>
<td>120,000 in NW @ 10,000 kWh/yr ea</td>
</tr>
<tr>
<td>Exit Signs</td>
<td>Market Ready</td>
<td>3.6 TWh/yr</td>
<td>120 GWh/yr</td>
<td>Awareness</td>
<td>~4 million in NW @ 30 kWh/yr ea</td>
</tr>
<tr>
<td>Commercial Signage</td>
<td>Market Ready</td>
<td>16 GWh/yr</td>
<td>600 MWh</td>
<td>Awareness</td>
<td>~2% of commercial electricity</td>
</tr>
<tr>
<td>LCD Monitors</td>
<td>Near-term</td>
<td>38 GWh/yr</td>
<td>1.5 GWh/yr</td>
<td>Technological</td>
<td>~4% + of US Estimates</td>
</tr>
<tr>
<td>Niche Products</td>
<td>Ready/near term</td>
<td>Varies</td>
<td>Varies</td>
<td>Availability</td>
<td>-</td>
</tr>
<tr>
<td>LCD TVs</td>
<td>Developmental</td>
<td>800 GWh/yr</td>
<td>32 GWh/yr</td>
<td>Technological</td>
<td>~4% of US Estimates</td>
</tr>
<tr>
<td>Food &amp; Beverage</td>
<td>Developmental</td>
<td>NA</td>
<td>NA</td>
<td>Awareness</td>
<td>-</td>
</tr>
<tr>
<td>Retail</td>
<td>Developmental</td>
<td>NA</td>
<td>NA</td>
<td>Technological</td>
<td>-</td>
</tr>
</tbody>
</table>
## APPENDIX A

### Product Summary Matrix

#### Exterior Architectural

<table>
<thead>
<tr>
<th>COMPANY: PRODUCT TYPES</th>
<th>ADVANTAGES</th>
<th>POSSIBLE DISADVANTAGES</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Color Kinetics</strong>&lt;br&gt;www.colorkinetics.com</td>
<td>Products use red, green and blue LEDs to achieve multiple colors and dynamic effects.&lt;br&gt;Wide variety of architectural wall-wash, accent, and feature lighting for outdoor applications. Trademarked product line names include Chromacore, ColorWash, and iPlayer. The company aggressively develops and markets new products. Color Kinetics products and installations have been widely recognized by the media and by the design community.</td>
<td>Products do not have much optical control. “White” light products are not yet available, but may be forthcoming. Several basic fixture types can be combined to achieve many architectural and decorative effects. Thermal management is incorporated in the fixtures. State of the art software and digital controls. Controls and drivers can be interchanged between products; some interface with other manufacturers’ controls, too. The products are marketed as a fully integrated system. Product warranty of one year. Good customer support.</td>
</tr>
<tr>
<td><strong>TIR Systems Ltd.</strong>&lt;br&gt;www.tirsys.com</td>
<td>Products use red, green and blue LEDs to achieve multiple colors and dynamic effects. Light distribution from and within the fixtures is carefully designed and well-controlled. Company has in-house expertise to design customized fixtures. On/off control, dynamic color control.</td>
<td>White light LED applications are presently under development. Limited number of off-the-shelf fixtures. Dimming not available as standard option. Dynamic color must be programmed by computer. The products are marketed as a fully integrated system. Good customer support.</td>
</tr>
</tbody>
</table>
**Flexible Linear Lighting**

<table>
<thead>
<tr>
<th>COMPANY: PRODUCT TYPES</th>
<th>ADVANTAGES</th>
<th>POSSIBLE DISADVANTAGES</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>GelCore</strong>&lt;br&gt;www.gelcore.com&lt;br&gt;“Tetra”</td>
<td>Can replace most common colors of channel letters. Sturdily engineered components; wide, even beam angle from each LED package.</td>
<td>Single color: cannot mix colors on one strip.</td>
</tr>
<tr>
<td></td>
<td>Good heat control via heavy gauge wire: the individual LED reflector packages have punch-through contacts into the wire.</td>
<td>Strip is bulky and not aesthetic for direct view applications.</td>
</tr>
<tr>
<td></td>
<td>Very easy to install.</td>
<td>Needs to be screwed onto backboard or substrate.</td>
</tr>
<tr>
<td></td>
<td>Power supply is designed to fit inside a standard box.</td>
<td>Bulky power supply must be hidden behind luminaire or sign.</td>
</tr>
<tr>
<td></td>
<td>The products are marketed as a fully integrated system.</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>Offers two or three levels of light intensity.</td>
<td>Intensity dip switch hidden inside power supply; no continuous dimming</td>
</tr>
<tr>
<td></td>
<td>UL-listed retrofit system.</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>Reasonable costs.</td>
<td>--</td>
</tr>
</tbody>
</table>

**TIR Systems Ltd.**<br>www.tirsys.com

Marketing a neon-replacement product originally developed and still manufactured by Lumileds: “Chip Strip.”

- Strip of LEDs mounted on a slightly flexible board that is capped with a half-round, thick lens.
- Applications limited to thin strips.

**OSRAM Sylvania**<br>http://www.osram.os.com/products/lampmodules/

Several versatile product lines, including “LINEARlight” and “LINEARlight Flex.”

- LEDs are surface-mounted on very flexible, thin circuits. The strips are self-adhesive, but may need additional anchoring on strongly curved surfaces.
- The thin strips flex only bend in two dimensions, not three.
- The product is compact, with small LEDs that allow a pleasing direct view.
- The relatively low light output from each LED may force designer to use several strips in parallel, or more modules than other manufacturers’ products would require.
- Different color LEDs and multi-chip LEDs can be driven from the same power supply.
- --
- Thermal control via copper circuit material.
- Should consult manufacturer regarding thermal heat sink requirements for each application.
<table>
<thead>
<tr>
<th>Company</th>
<th>Description</th>
<th>Connections must be carefully soldered. Drivers must match requirements of the strips.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Customer support available for novel applications.</td>
<td>Technical support needed for most applications, due to lack of system packaging.</td>
</tr>
<tr>
<td></td>
<td>Reasonable costs. Purchase through distributors.</td>
<td>No system warranty available.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Company</th>
<th>Description</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>LEDTronics</strong></td>
<td>Huge variety of LED package types available: surface mount and also standards 5mm and 3mm</td>
<td>Designers must choose appropriate product for their applications.</td>
</tr>
<tr>
<td></td>
<td>Variety in spacing of LEDs available</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>Single and bi-color strips available</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>3 year warranty</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>Whole system package</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>Relatively low costs. Purchase small number of units through distributor network, large numbers direct from factory.</td>
<td>Not much customer support for small orders.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Company</th>
<th>Description</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Permlight</strong></td>
<td>Can replace most common colors of channel letters and neon. Plans to introduce purple soon.</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>Easy to install, self-adhesive modules.</td>
<td>Not as sturdy as some other manufacturers’ products.</td>
</tr>
<tr>
<td></td>
<td>UL-listed power supplies.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Focus is on thermal management to maintain good light output over time.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Reasonable costs. Purchase through distributors or directly from company.</td>
<td></td>
</tr>
</tbody>
</table>
### Individual, small fixtures for steps, walls and pathways

<table>
<thead>
<tr>
<th>COMPANY: FarLight LLC</th>
<th>ADVANTAGES</th>
<th>POSSIBLE DISADVANTAGES</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;ped.X&quot; and &quot;uniLight&quot;</td>
<td>Excellent use of optical technologies for control of light distribution.</td>
<td>Full range of colors.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Long run of up to 600 feet from driver.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Flush installation, very solid hardware.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3 year warranty.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Whole system package.</td>
</tr>
<tr>
<td></td>
<td>Purchase directly from manufacturer.</td>
<td>Relatively high cost.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>COMPANY: ERCO</th>
<th>ADVANTAGES</th>
<th>POSSIBLE DISADVANTAGES</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;Orientation luminaires&quot;</td>
<td>Several colors and multi-colors available.</td>
<td>No red standard color.</td>
</tr>
<tr>
<td></td>
<td>Dimming and blinking via compatible control system.</td>
<td>Must purchase controllers.</td>
</tr>
<tr>
<td></td>
<td>Excellent detail and aesthetics.</td>
<td>Flange, no flush mounting</td>
</tr>
<tr>
<td></td>
<td>Limited run 100' to first LED, 200' to the last LED.</td>
<td>May need several lengths to complete installation.</td>
</tr>
<tr>
<td></td>
<td>Order controls and luminaires separately.</td>
<td>Special tools needed for installation.</td>
</tr>
<tr>
<td></td>
<td>Good support service.</td>
<td>--</td>
</tr>
</tbody>
</table>

### Screw-Base Bulbs

<table>
<thead>
<tr>
<th>COMPANY: Boca Flasher</th>
<th>ADVANTAGES</th>
<th>POSSIBLE DISADVANTAGES</th>
</tr>
</thead>
<tbody>
<tr>
<td><a href="http://www.bocaflasher.com">www.bocaflasher.com</a></td>
<td>Bulb casings have option of teflon coating to contain shattering.</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>Discrete LEDs are visible through bulb. Several single colors.</td>
<td>May not be an aesthetically satisfying replacement. Not many color options.</td>
</tr>
<tr>
<td></td>
<td>Recommended for replacing 25-watt incandescent lamps for direct view applications.</td>
<td>Limited applications. (Cannot be used effectively for illuminance)</td>
</tr>
<tr>
<td></td>
<td>Offers directional light distribution patterns.</td>
<td>Optics not optimized for light source.</td>
</tr>
<tr>
<td></td>
<td>Established manufacturer, relatively small company.</td>
<td>Limited distributor options. Cannot purchase online.</td>
</tr>
<tr>
<td></td>
<td>Claim of 100,000-hour lamp life.</td>
<td>No light output over life shown.</td>
</tr>
<tr>
<td></td>
<td>Relatively inexpensive cost.</td>
<td>--</td>
</tr>
</tbody>
</table>
| **Ledtronics Inc.**  
**www.ledtronics.com** | Wide array of products to suit many application needs. | Can be confusing if specifier is not familiar with LED nomenclature and devices. |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Myriad combinations of color, shape, size, base type and configuration.</td>
<td>Offers so-called “spot” lights and other narrow beam options.</td>
<td>These really are not direct replacements for similarly shaped incandescent lamps, because light output is too low.</td>
</tr>
<tr>
<td>Brand names include “DecorLED”</td>
<td>Offers several color temperatures of white LEDs.</td>
<td>Color rendering is not as high as incandescent or fluorescent.</td>
</tr>
<tr>
<td>Marketing heavily to the entertainment industry (theatres, casinos, amusement parks, etc.)</td>
<td>Costs reasonable for large quantities.</td>
<td>Not as easy to obtain in small quantities.</td>
</tr>
<tr>
<td></td>
<td>Claim of 100,000-hour lamp life.</td>
<td>No light output over life shown.</td>
</tr>
</tbody>
</table>

| **Mule Lighting Inc.**  
**www.mulelighting.com** | Discrete LEDs are visible through many of the bulb options. Several single colors. | May not be an aesthetically satisfying replacement. Not many color options. |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Myriad combinations of color, shape, size, base type and configuration.</td>
<td>Offers some frosted bulbs.</td>
<td>Light output is much lower than with clear bulbs.</td>
</tr>
<tr>
<td>Brand names include “dynaLUX,” “LEDelier,” “FlameTip,” “LED-A19” and “LEDison.”</td>
<td>Offers cool white and warm white.</td>
<td>Color rendering is not as high as incandescent or fluorescent.</td>
</tr>
<tr>
<td></td>
<td>Offers specification sheets with performance data for some LED products.</td>
<td>Not available for all LED bulbs.</td>
</tr>
<tr>
<td></td>
<td>Costs reasonable for large quantities.</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>Catalog notes that company is an ENERGY STAR Partner [n.b. for exit signs].</td>
<td>--</td>
</tr>
</tbody>
</table>
APPENDIX B

A LED Lighting Designer’s Perspective

LEDs in The Retail Market Place
The potential for LEDs in retail and display markets may not be fully realized for some time, as designers and engineers explore and discover its possibilities. Nevertheless, studies have been conducted to evaluate the feasibility of LEDs in this environment. For example, a study was designed to compare the performance of a conventional white light and colored LED light as used window display backgrounds. Some significant comments regarding the use of LEDs in retail lighting derived from experimentation, observation, and research include:

- There is a delicate balance to be preserved between attention capture and visual appeal (pleasantness). The modulated colored light quickly captures attention, but then when it is observed for a longer period of time it is perceived as unpleasant. Amplitude of modulation as well temporal frequencies (rate of change) determine the final effect of the modulated light.

- Changes from color to white light and then to another color are more attention capturing than changes simply from one color to another color. This “bleaching” in between the color changes is important.

- Red colored light improves slightly the clarity of seeing. At the same time red colored light is more “jumpy” when modulated in lightness. This means at high lightness the red colored light appears brighter than the blue colored light. At lower lightness, the red colored light suddenly shifts to below the brightness of a blue colored light at the same level of lightness.

- The blue colored light is very sensitive to content of lightness. Blue is perceived negatively as gloomy and depressing at low lightness level. (Each color is expressed through 3 dimensions: value or saturation, hue, and lightness or luminosity. The saturation and the lightness dimensions are somewhat related. The brightness perception for a specific colored light comes from these two dimensions).

- 75% of people’s color preference is based on saturation and the rest on the lightness. Practically, individuals like all colors if presented in the right saturation (or brightness).

- Colored light has significant effect on the performance of retail window displays. However, this effect is up to a certain luminance (available light intensity) lowest threshold. Luminance level is critical for seeing, seeing is directly related to liking. If there is not sufficient light on the display objects to carry the information to the brain, the display is ineffective.
Colored light cannot compensate for the lack of light under a certain threshold. This threshold varies with the characteristics (size and contrast) of the display objects. If the path of information to the brain is degraded by low luminance or distorted by a low color-rendering index, color will not compensate for this.

Colored light adds to the perception of brightness. Colored light effects add to the luminance effect: they work together. When using colored light, the luminance (or white light quantity) can be decreased without a change in the perception of brightness.

Colored light generates a complex response in people. Colored light brings associations, is measured against expectations, and against the context of the display. People exhibit a wide variety of color preference.

Modulated colored (or white) light on the background distracts from the display object and is annoying.

**Future trends in retail and features of LED lighting**

Due to the nature of the interaction between conventional light and LED light, optical control of the conventional lighting becomes very important so as not to wash out the effect of the LED colored light. Retail will become much more virtual oriented and much more accessible from the street (or exterior) side of the window displays. Further, advances in interactive technologies will allow much more interaction than is currently possible.

A possible scenario for the future of retail lighting may play out as follows: Customers are walking along the window displays. A camera connected to the lighting in the window display monitors the movement of the customers. While they are walking by, the window display captures their attention by modulating colored light (or cycling). Once the customers approach the window display, the command is given to the lighting to stop changing and modulating. Now the lights are static, all white, and all at full intensity, with excellent CRI, and with sparkle effects overlaying the white light.  

This above scenario, while possible, will be dependent on additional developments or improvements on current products, including:

---

45 The whole window display is intended to be achromatic, like a white canvas ready to receive the colors of a paintbrush. In this case, the LED lighting fixtures provide the colors. These fixtures are controlled and operated by the customers on the outside of the window display. The white light can be automatically dimmed down while the customer “paints” the same sweater in several tonalities (colors) and decide which one he/she likes best. Or the customer can determine what chair to buy at a furniture store, by setting the background color to match his/her house settings and then “painting” the chair through an array of colors. This helps the customer to decide which chair and what color work the best in his/her particular case. By giving control to the customer and the possibility to visualize the display in specific context the retailer will realize a higher number of finalized purchases.
- Availability of RGB type LED fixtures: these are more suited to provide the customer with an array of colors. Not only the hue but the saturation of the colors can be controlled by the customer.

- Individually addressable LED fixtures: with these, it will not only possible to set the color, but also physically move the heads of the LED fixtures with automated controls (much like theatrical lighting). The need to re-aim fixtures comes from their tight optical control.

- Precise optical controls of the LED fixtures: these will enable scene framing with color. The same LED fixture head will have interchangeable accessories for the optics.

- Because white LEDs (blue with phosphor coating) presently have low CRI, it may be necessary to develop hybrid fixtures containing RGB LEDs and conventional white light bulbs (in order to decrease the visual clutter of fixture heads).

- Even if no hybrid fixtures are produced, still for some time the conventional light will operate side by side with the LED fixtures. Compatible controls will be required, with simultaneous controls for the LED and the conventional lighting.

**Status of LED Products, from a Lighting Designer’s Perspective**
*(Contributed by Milena Simeonova, MS, LC, President of Milena Lighting Design)*

LED modules are lightweight. Consequently the method of attaching them in an application is much easier and faster than the conventional mechanical attachments. Manufacturers offer various adhesives, Velcro, and bonding tapes, in addition to some novel snap-connect or snap-in mechanisms. LED modules are also small in size, and can used in clusters or arrays, and easy to rearrange. Therefore, the same manufacturer often produces a wide variety of fixtures for interior and for exterior use. In contrast, the conventional lighting fixture manufacturers are more narrowly specialized (with a few exceptionally large companies).

There seems to be a reciprocal correlation between the variety of LED products that one manufacturer provides and the level of light distribution control that they incorporate in their products. The more interchangeable the LED modules are that are used in a variety of products, the less variety there is in light distribution patterns between these products. Specifically designed reflectors and optics result in better light control, but at the same time limit the number and range of possible applications.

All LED products work with low voltage. Therefore, the same constraints as for conventional low voltage lighting apply. This means that there is always a limit to the maximum “run,” or distance from the driver/power supply to the first and last units in the system. This also limits the quantity of fixtures that can be supported by one driver or power supply. So, applications may require multiple drivers, and thus multiple electrical junction boxes and controls. LED controls can be selected to work together with
conventional controls, such as photocells, time clocks, motion sensors, sequencers, and preset lighting scenes controls. Changing the color of LED light from a luminaire does not occur with physical devices such as color filters, gels, etc. because of the narrow band light emitted from the LED. The conventional devices used with incandescent, fluorescent and HID sources are inefficient because they absorb a great deal of light energy.

The mall size of the LED modules results in small, flat fixture housings. This is encouraging new lines and aesthetics in fixture design. The products tend to blend well with architecture, especially where the fixtures are flush with surfaces, or can be slightly recessed in sleek structural features. Due to lower intensities of light compared to HID sources, most individual LED luminaires cannot produce grazing light on large surface areas. LED luminaires usually need to have a slight set back from the lighted surface. This applies to cove lighting as well as to valences.

There is no established nomenclature for specifying LED products. This is a major barrier and expense for the lighting and designer and architect, since time is billed on an hourly basis, and lighting budgets are always limited. With the exception of a couple of LED fixture manufacturers, standard luminaire photometrics are not provided. Instead, beam angles keyed with degree numbers are given. Traditionally, the performance of luminaires is presented via photometrics, labeled by lighting specifiers as the “fingerprints of a fixture”. Therefore, there is confusion about the performance, spacing, set backs, and other requirements for the LED luminaires. Specifiers feel helpless when selecting products. They must seek cooperation and customized help from the manufacturer for each application.

 Apparently there are two venues for developing new LED products. Each must address the challenge of providing good thermal design, assembling with drivers and controls, and providing any other accessories such as reflectors. By approaching existing small manufacturers of conventional lighting fixtures, designers can request that they retrofit or install the LED modules in standard reflectors and luminaire housings. These manufacturers should be asked to provide a warranty for the LED product. The other method a designer can follow is to request that the LED system components be assembled by an electronics workshop that is qualified to take care of the connections and soldering between the components. The workshop should be asked to provide a warranty, too.

LED products are unfamiliar to risk-averse designers. The LED manufacturers themselves are new and relatively unknown in the lighting market. They must provide heavy-duty customer support, educating the lighting specifiers, installers, and end users with wiring diagrams, controls, and other technical support. Although many have excellent technical documents on their websites, others have little or nothing to offer the designer. At this stage, it is crucial for them to provide samples so that designers can see, measure and handle the new devices.
The highest demand and the ease of market penetration with LED products seem to be in specialty lighting, especially where the narrow bandwidth emission of an LED is an advantage. Applications include dental treatments, darkrooms and photo laboratories, color therapy salons, and other novel venues.
APPENDIX C

Summary of LED Barriers and Opportunities

Barriers

Technological Barriers
While many industry experts are optimistic about LED progress, the technology must still overcome a number of hurdles related to light output and efficiency to fulfill its promise. As discussed in the technological overview section, LEDs are currently more difficult to fabricate than their microchip cousins. At best, they can be fabricated in 6-inch diameter wafers, whereas the microchip industry fabricates their chip with 12-inch diameter wafers. Some of the more exotic wafers required for LED production are manufactured with a 2-inch diameter. More improvements in production methods may be able to increase yield and help to further drive down prices.

Also, as discussed in the lighting technology section, the performance and efficiency of an LED as a light source is a function of the configuration of the LED package and also the configuration of the LED system as a whole. If the supporting system is not efficient, the energy and performance benefits of the LED technology will not be fully maximized. Additional work remains to be done in this area before LEDs can fully compete as a viable light source in the general lighting market. In addition, because the main focus of current LED R&D efforts is on creating more innovative materials and lowering chip-manufacturing costs, there is less of a research focus on the LED package, LED system research and potential applications. There still is no consistent approach to creating an LED system to date. Finally, because it is a new technology, the upfront cost for LED-based systems is often more than conventional systems (although the upfront costs of red neon are now comparable to red LEDs).

Going forward, technological barriers that need to be the focus points for LED research and development include:

- LEDs fabrication improvements
- Maximizing the configuration of the LED package and the configuration of the LED’s supporting system
- Consistent approach to creating LED systems
- Cost improvements

Barriers to Comparing LEDs to other sources
Along with the technological challenges associated with manufacturing and production of components, LED lighting technology also faces another technological hurdle as it enters the conventional lighting market. Currently, the well-established technique for measuring light output in lighting applications does not easily lend itself to measuring LEDs light output. Designers and specifiers still need a useful measure by which to compare LEDs lighting to conventional light source, as the familiar lumen may not be an
accurate way to describe LEDs. Is it also difficult to apply the common concepts of Correlated Color Temperature and Color Rendering to LEDs, because there is a very narrow bandwidth of emission for the LED. These conventional metrics, which is based on the incandescent standards, could actually hinder the process of using LEDs in applications.

Until LEDs are marketed in a more convenient assembly, it remains difficult to compare the output of different light sources to LEDs. This is because LEDs are very small, and emit light in a directional manner, whereas other light sources are larger and emit light with a broader pattern. As a result, expensive equipment is usually needed to accurately measure LED light output. In addition, as it is a relatively new industry, there are few standards available, making it difficult to even compare LEDs to other LEDs.

For LEDs and LED lighting systems to be able to compete with conventional lighting, the barriers remain to be addressed include:

- Establishing a technique for measuring light output of LEDs in lighting applications.
- More convenient assemblies that permit comparison of technologies.
- More inexpensive methods to accurately measure LED light output.
- A measure with which to compare LEDs to conventional light source.
- Industry-accepted method comparing LEDs to other LEDs.

Educational Barriers
Although the technology has come a long way since its first popular introduction to the public in the form of luminous watches, LED-based lighting remains a new technology that is not well known in the marketplace. Consumers are less familiar with LEDs, both in terms of technology as well as a light source. This unfamiliarity applies equally for users at all experience levels: lighting designers, residential users, and commercial users. Most lighting designers are used to thinking in terms of conventional white light design and working with white light sources instead of colored light design, because colored light has been in general more expensive than its white counterparts. By extension, the general public has been exposed to designs using only white sources for the most part.

In addition to lack of exposure to LED technologies and color applications, the proliferation of different LED systems and components currently available for the same application may also contribute to the slow pace of adoption. This especially true in the commercial arena, where building inspectors, government codes, as well as installers are not familiar with the LED systems and the components. While the aspects of these systems are not more difficult, they are just different than conventional systems, and may require changes and adjustments to existing practices and codes. Finally, lighting designers and specifiers who consider light installations are not yet used to taking advantage of the energy-efficiency, long-life and maintenance advantages of LEDs. To compound this situation, there are also a wide variety of claims on life and efficiency of LEDs, making it confusing to potential users.
Additional awareness and education to familiarize users, and a consistent systems approach can help LEDs make further inroads into the current marketplace. Barriers that any LEDs awareness and education campaigns will need to address include:

- Familiarization of LED lighting technologies and component
- Identification of the advantages of LEDs as a colored light source
- Identification of the efficiency, life-time and maintenance advantages of LEDs
- Clarify confusion regarding competing claims
- Familiarization of building inspectors, government code officials, and installers with LED systems and the components.

In many arenas, there also is a lack of connection between different players who are trying to advance this technology. This includes the energy efficiency leaders, R&D think tanks, and system developers. Additional education and outreach efforts will be needed to address these issues as well. For example, not much attention has been focused on the fact that single color LEDs have the potential to change the way that lighting designers and safety experts think about color and the perception of color by the human eye, possibly opening doors for more effective low-level night illumination that is also more energy efficient.

**Opportunities**

**Design and Applications Opportunities**

Because LEDs are an inherently colored light source, they present new design and application opportunities in a variety of areas where conventional lighting has dominated. For example, LED’s light output is perceived differently by the human eye under certain conditions. Results from research into these biological characteristics can help lighting designers and product developers make informed decisions about the applications of LED technology.

In more “conventional” applications, LED-based lighting in commercial areas is still a nascent field, but is a potentially enormous market, as LEDs can and will displace incandescent products in a way that CFLs have never been able to do. LEDs offer unprecedented flexibility in colors and configurations to lighting designers in creating displays and display environment. The potential for LEDs in retail and display markets may not be fully realized for some time, as designers and engineers explore and discover its possibilities. The advent of programmable color change controls by LEDs will also give designers new options for lighting techniques. This includes mixing red, green, and blue LEDs to make a ‘tunable’ white as well as programming color wash effects for theatre, building design, and large-scale entertainment venues.

In the near-term, however, there are quite a number of “niche” opportunities for LED technologies to become more established, displacing incandescent and even CFLs. Because of their low power requirements, LEDs work well in a number of areas, such as emergency lighting in hallways and stairways that can run off of battery storage when
grid is down. Here, LEDs’ advantage extends beyond just low power consumption – the reduced power requirements for these emergency systems allows for smaller batteries, power supplies, and simpler overall systems that may be easier to install and maintain. LEDs’ extremely long service life also lends itself to areas such as airport, traffic, and exit signs, where it can effectively out-compete even CFLs in terms of performance. In addition, LEDs’ low power requirements match well with devices that spend time both on and off the grid, such as computers (both laptop and hand held), cell phones, and other displays.

Another advantage is that LEDs are extremely rugged and are less sensitive to operational environments that include regular vibration and shock. This makes LEDs suitable for a variety of locations and applications, including industrial and automotives. In addition, LEDs have a fast ‘on-time’ (typically 60 nanoseconds vs. 10 milliseconds for incandescent). This characteristic, coupled with LED’s insensitivity to shock and vibration combined to make LEDs very attractive for automotive designers.

Because LEDs operate on direct current, there is a natural match with electronic devices that incorporate microchips. This and the fast response time provide designers with opportunities to integrate LEDs into backlighting displays on all sorts of electronic office and entertainment equipment. Eventually, LEDs could be integrated into "system on a chip" designs, if thermal challenges can be met. In addition, because of its low power, LED technologies couple well with solar cell technologies for potential off-grid replacement for applications that are currently on-grid. LEDs also operate well in cold environments. This opens market opportunities where other technologies, such as fluorescent, have not performed to their potential because of temperature constraints.

To summarize, near-term design and application opportunities for LEDs can take advantage of the following LED characteristics:

- Single color output
- Low power requirements
- Programmable color change and controls
- Matched applications with battery storage
- Matched applications with solar cell technologies
- Matched applications with other direct current electronic devices
- Low temperature operations
- Ability to function in rugged operational environments that include regular vibration and shock.
- Fast ‘on-time’ (60 nanoseconds vs. 10 milliseconds for incandescent) [Need to highlight their great match with applications that incorporate rapid cycling]

Safety Opportunities
One unique feature that can place LEDs ahead of other lighting technologies is the fact that it is an inherently low-power technology, requiring about an order of magnitude less in power for the same task in certain applications. As such, the low voltage and DC nature of LED systems can provide easier installation and safety benefits to the user. It
might be possible that businesses can get reduced rates on fire insurance if LEDs lighting replace systems such as neon in areas with higher-fire hazards.

Such low-power systems can also reduce the risks of electric shocks traditionally associated with AC systems, and may allow for more rapid adoption as users learn of this safety aspect (a similar example is the rapid consumer acceptance and use of low-voltage halogen systems). Another area that LED can excel with these advantages in the near-future is lighting for clean rooms and other sterile environment, where it can provide superior maintenance and lifetime over fluorescent and high-intensity discharge technologies. To summarize, the following LED characteristics can provide opportunities for LEDs to compete on safety-related aspects:

- Low voltage, easier system installation
- Less electric shock risks
- Lower fire risks

**Technical, Environmental and Market Opportunities**

Technological advances are taking place quickly, enabling LEDs to match the progress mapped out by experts. Single color LED performance trends are likely to follow a trend similar to Moore’s Law for microchips, reaching higher brightness levels in the next few years. Performance trends for white LEDs are harder to predict because of the hybrid nature of the technology, but the Departments of Energy and Defense predict that white LEDs will be bright enough for general illumination by 2010, this will enable LEDs to displace current incandescent and even compact fluorescent technologies.

As LED technologies improve and displace current technologies, there is substantial opportunity for energy savings in both lighting and display areas. Estimates of the lighting savings potential alone is significant, as more efficient LED lighting technologies can substantially reduce the projected 600 TWh annual consumption by US general lighting needs by 2007. Similarly, LED penetration into the display market can yield huge energy savings. An 80% market penetration by LED-based monitors in the US television market can result in an estimated 800 GWh annual energy savings.

Other benefits to advances in LED lighting systems include long-term savings. As LED retrofits are system based, they are less likely to be replaced with less energy efficient technologies later on, after initial investment has been made. Combined with their long service life, the duration of energy savings will be much longer than is currently achieved with compact fluorescents lamps, or even CFL-based fixtures. Additionally, as more outdoor LED lighting products enter service, they offer the potential to reduce the “overglow” from light pollution in cities, due to the fact that they are an inherently directional light source.

Finally, although toxic substances are used in the LED manufacturing process LED materials researchers claim that any toxins in the devices are tightly bound chemical molecules, or are encapsulated in epoxy. Thus, the disposal of used LEDs in the landfill is not an anticipated problem. There can be less environmental exposure because toxic
substances used in the manufacturing processes are regulated and controlled through rules and regulations that are similar to the regulations of the microchip industry.

Technological and environmental opportunities for LEDs are many, and the pace at which they can be utilized depends on a number of factors, but some near and longer-term factors affecting LED lighting technologies to consider include, but not are limited to the following:

- There is substantial opportunity for energy savings as LED technologies improve.
- Single color LED performance doubles every 18 to 24 months
- The Departments of Energy and Defense predicts that white LEDs will be bright enough for general illumination by 2010.
- LED retrofits are system based and are less likely to be replaced with less energy efficient technologies later on.

Finally, as the market is still developing, and the actors include both manufacturers and research and development organizations, there currently exist valuable resources in the LED community that are willing and able to participate in educational activities related to LED market transformation. In addition, because of new nature of market, LED product developers are willing to work with municipalities and other players with the ability to requisition large contracts in order to develop products “on-request.” This gives a lot of opportunity for large customers and for procurement groups to influence the direction of the market.
APPENDIX D

Are Local Sign Companies familiar with LED Sign Products?

In order to obtain an estimation of the current penetration of LEDs into the sign market in the Northwest, Ecos interviewed 15 sign companies, 8 of which were certified to offer electric signage, and 7 of which were sign companies that had other specializations. 5 of the companies were located in Oregon, 5 in Washington, 2 in Idaho and 3 in Montana, with the same electric and non-electric distribution of each, with the exception of Idaho where we interviewed no non-electric sign companies. The purpose of interviewing the electric and non-electric sign companies is that the LED product operates at a low voltage and doesn’t always require a certified electrician to install the signs, although in some cases an electrician is needed. In addition, we wanted to determine to what extent knowledge of the LED technology was present in those companies that did not offer the technology themselves. The companies were randomly selected out of the yellow pages in the phone book under the heading for signs.

The region can be broken up into two sub-regions based on the relative level of knowledge related to LEDs. The first region, which includes Oregon and Washington had a strong knowledge of the LED sign products that were offered, and offered a wide range of products, including products that were designed to replace neon in channel lettering signs, and elsewhere, including decorative neon on buildings and awnings. The second region includes Montana and Idaho. In this region, sign companies were not offering LED products other than the reader board signs and were not convinced of the benefits and claims of the LED technology.

In Washington and Oregon, we talked to 5 sign companies that offered some form of LED signs. Only one electric sign company that we talked with did not offer LED signs because this company specialized in resale of electric signs and LED signs are not in the market to yet be resold, as they are such a new technology. There was one sign company that was not a company that specialized in lighted signage, but offered LEDs in interior and specialty design exterior application. (One of their projects including making a candle look like it was glowing for a local candle shop.)

Sign types that are currently being offered are LED channel letter signs, and LED architectural neon replacement. The available colors run through all shades of the rainbow, although not all of the colors can be used in all applications because the lumens output and the cost vary with the color. The colors available include red, blue, green, orange, yellow, amber, turquoise, and white. Red is the color most often used because it is the least expensive and also has the highest lumen output. One company mentioned that LED channel lettering was more likely to be attractive to larger companies and businesses because they have the capital to make the upfront purchase of the signs, which can cost 2-3 times their neon counterparts. Few customers come to them with LEDs signage in mind and the companies are responsible for educating their clients about the advantages of LEDs.
Customers that are interested in LEDs are attracted by the entire benefits package of the LED system, rather than only attracted by the energy savings. The benefits sighted as being most important to the customer include low-maintenance, longer life expectancy, improved safety for service people, lower fire hazard, and lower installation costs. In addition, they are attracted by the red LED signs because by some accounts, they outperform red neon. One sign company reported that their customer was able to get an insurance deduct as a result of changing from Neon to LED signage simply because of the reduced fire hazard.

As a side note, when companies were asked about LED signs, some of them talked about the LED reader boards, or message centers in addition to these other products. Although these LED signs don’t have large potential for energy savings, they are an LED product that people are familiar with and can relate to.

In Idaho and Montana, there is a very different picture. Five total companies were interviewed, 3 in Montana and 2 in Idaho. Four were electric and two were non-electric sign based companies. Only one company out of four electric sign companies offered LEDs signage, which included channel lettering and reader board signs. The and the majority of their sales were in LED reader board signs. The colors were more limited than in the other region and included red, amber, yellow, blue, green and white. One store that specialized in non-electric signs offered indoor reader boards that required little or no installation. This was the extent of the products offered.

In this region, people were less knowledgeable about LEDs being used for anything but LED reader board signs. The companies contacted in this region were not able to refer the interviewer to other companies that potentially offered LED signage. Most companies, when they were asked about LED signs, assumed the reference was to reader board signs or needed to ask for clarification. Some had never heard of LEDs being used in channel letter signs or replacement neon. One company expressed a reluctance to trust the LED products, stating that the claims about life and maintenance were exaggerated. Another company stated that they were holding out to see if the claims made by the manufacturers proved sound.

What LED Products do major lighting distributors have available?

In the course of doing informal interviews with regional sales representatives and searching the product catalogues of the three major lighting distributors in the U.S., only one company was discovered to have LED products, Osram-Sylvania. Neither GE nor Philips carry any LED products.

Osram-Sylvania sold a linear strip that was applicable for replacing channel neon signs, cove lighting, and theatre safety lighting. They have all colors available. A further discussion of the feedback from the Osram-Sylvania commercial engineer is included with the other LED specialty companies.
APPENDIX F

Useful Examples of LED Informational Tools

Because LED lighting is relatively new and is fundamentally different than the incandescent and fluorescent lighting that it replaces in retrofit programs, education about the differences and advantages to LED technology is key to incentive programs success. We came across some examples of this educational material in our search. Figure F1 below, is an example of a cost comparison tool found on the web. This calculator, available on New York State Energy Research and Development Authority’s (NYSERDA) website\(^{46}\) allows the municipalities in New York to easily get a sense of how LED signals can save them money. After inputting the number of intersections and signals per intersection, the Costs and Savings of the retrofit are displayed.

Figure F1: NYSERDA Cost Comparison Tool for LED Traffic Lamps

![Cost Comparison Tool](http://www.lrc.rpi.edu/ltgtrans/nysled/)

\(^{46}\)http://www.lrc.rpi.edu/ltgtrans/nysled/
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<table>
<thead>
<tr>
<th>Acronym</th>
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<tr>
<td>AlGaAs</td>
<td>Aluminum Gallium Arsenide</td>
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<td>AlGaP</td>
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<td>AlInGaP</td>
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<td>ANSI</td>
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<td>CCFL</td>
<td>Cold Cathode Fluorescent Lighting</td>
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<td>Correlated Color Temperature</td>
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<td>California Energy Commission</td>
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<tr>
<td>CFL</td>
<td>Compact Fluorescent Lamp</td>
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<td>CIE</td>
<td>Commission Internationale de l’Eclairage (International Commission on Illumination)</td>
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<td>COB</td>
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<td>MITI</td>
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<td>mm</td>
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<td>MOCVD</td>
<td>Metal organic chemical vapor deposition</td>
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<td>Metal organic phase epitaxy</td>
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<td>NEMA</td>
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<td>NYSERDA</td>
<td>New York State Energy Research and Development Authority</td>
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<td>OIDA</td>
<td>Optoelectronics Industry Association</td>
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<td>RPI</td>
<td>Rensselaer Polytechnic Institute</td>
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<td>YB</td>
<td>Yellow, blue</td>
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LED PRODUCT MANUFACTURERS

Agilent Technologies
P.O. Box 10395
Palo Alto, CA 94303
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Aero-Tech Light Bulb Co.
534 Pratt Avenue
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Action Media Technologies Inc.
9400 Lurline Avenue, Unit-B
Chatsworth, CA 91311
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American Opto Plus LED Corp.
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San Dimas, CA 91773
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Ad Art Electronic Sign Corp.
3133 N. Ad Art Road
Stockton, CA 95215
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e-mail sck@adartesc.com
tax 209-931-5706
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