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EXECUTIVE SUMMARY

DOE's Office of Energy Efficiency and Renewable Energy (EERE) has identified solid-state lighting (SSL) technology as the primary candidate to displace most conventional incandescent and fluorescent lighting applications throughout U.S. commercial and residential sectors over the next 10 to 25 years. SSL refers to lighting applications that use semiconductor materials, including light-emitting diodes (LEDs), organic light-emitting diodes (OLEDs), or light-emitting polymers to convert electricity into light. Traditional incandescent and fluorescent lighting technologies are based on vacuum tubes, which use black body radiation or glow discharge for illumination. Once fully developed, SSL is expected to produce many energy-related and economic benefits, cutting energy consumption for lighting by at least half. In addition, the creation of a new lighting industry of more than $50 billion per year worldwide is anticipated.

SSL is the first new electric lighting technology to emerge in the last half-century. As a semiconductor technology, SSL lends itself to product methods and designs that differ fundamentally from those of the Edison, screw-in-the-bulb system that has dominated lighting. Compelling consumers to shift away from this traditional paradigm will require an understanding of how they might value and what they might expect from SSL. Products must be developed that take advantage of SSL's unique capabilities to meet consumers' needs, such as ability to control color [with red/green/blue (RGB) sources] and intensity of light. Though much can be learned from what consumers currently value about conventional lighting, new lighting applications through SSL will produce new consumer values and expectations for lighting.

Most current SSL market activity is focused on niche applications within the lighting industry for commercial and industrial use. These applications support transportation (all mobile platforms for land, sea, and air transportation), retail display, entertainment, traffic signal, and outdoor lighting. Major market players have researched these markets extensively. Some exploratory market characterization is also being conducted for the illumination market overall. Most of this analysis is proprietary and not publicly available. Assessment of the general illumination market's adoption of SSL is still very speculative.

Recognizing the tremendous opportunity afforded by SSL, as well as the volatility of this emerging technology market, EERE, the Optoelectronics Industry Development Association (OIDA), and other essential players have teamed to develop strategies for moving SSL into the general illumination arena. These strategies are outlined in technology roadmaps developed in 2001 and updated in 2002 and 2003. Though these documents are considered the primary framework for SSL to penetrate the general illumination market, they focus mainly on technology development and techno-centric parameters for determining consumers' preferences. They also assume a major R&D program leading to breakthroughs that have not been realized. In any case, a framework that focuses on what would motivate consumers to adopt SSL over traditional lighting sources is critically needed, particularly one that considers consumers' preferences for lighting performance.

This report provides an analysis of the status of the SSL market environment, focusing on understanding consumer values and preferences for lighting. The supply-chain relations involved in delivering lighting products to the market, including the role of R&D, and proposed strategies to ensure that SSL is successfully integrated into the general illumination market are also covered.

Key recommendations for EERE supported through this analysis include:

- The SSL roadmapping process, as the key framework for general illumination lighting strategy, must be updated, and it needs to expand activities beyond technology development. Other critical areas that need assessment include:
  - Market characterization for SSL that considers consumer preferences for attributes of this technology. Currently, most assessment speculates on how SSL compares with consumer preferences for conventional lighting attributes. One aspect would be determining consumer willingness to pay for various SSL attributes. Market studies reveal that consumers are generally unwilling to pay significantly higher prices for lighting, even though they would eventually recover cost through attributes of longer product life and long-term reduction in energy use.
  - Development of appropriate metrics for SSL that will reflect consumer preferences as well as support moving this technology into the general market. Current metrics, such as lighting output and color rendering index, which are used to compare SSL with conventional lighting, have not proven useful in understanding the drivers for this market. These metrics are based on engineering parameters for successful performance rather than actual consumer-based preferences for success.
  - Infrastructure planning and development needed to support the shift to a new lighting economy. This will include taking advantage of all the unique attributes offered by SSL as an electronic technology.
- The key LED manufacturers are focused on niche markets within the lighting industry, rather than the overall market penetration of interest to EERE. In addition, the top LED manufacturers have vested interest in maintaining market share in conventional lighting sources. EERE needs to support greater exploration of general SSL applications for major commercial and residential sectors by engaging more supply-chain participants in the roadmapping and product-development process. This includes:
  - Bringing important participants to the table, specifically lighting-fixture manufacturers, architects and lighting designers, lighting distributors, building industry representatives, and consumer advocate groups.
  - Offering opportunities for some of these players to be more involved in innovative product development through incentives, partnerships, etc.
  - Focusing on some of the key market segment opportunities for commercial lighting (hospitals, schools, retail industry, food service) and residential lighting (kitchens, bathrooms, and other remodeling) investments.
- Visible and widespread demonstrations of SSL will help consumers understand its attributes. Approaches might include:
  - Showcasing commercial and residential applications in federal buildings.
  - Sponsoring the development of relevant general illumination applications for SSL through rapid prototyping, manufacturing, and distributing. Offering products that can be made available for minimal cost.
- Energy Star labeling can provide a market edge for SSL. In addition, integrating Leadership in Energy & Environmental Design (LEED) certification standards into SSL technology can support marketing efforts in the construction sector. EERE should:
  - Pursue Energy Star certification for SSL products.
  - Explore opportunities to integrate LEED certification standards with SSL technology.

- More research is needed on lighting's effect on human performance and well-being with emphasis on color variations and brightness. SSL offers tremendous potential to control output and temperature of lighting. Gaining greater correlation between enhancing behavior and use of SSL will support general market adoption. EERE needs to:
  - Increase support for research on lighting and human performance, such as that being initiated through the Light Right Consortium, which brings together interested parties and researchers to use research as a basis for market transformation towards ergonomic lighting and publicizes the potential benefits of lighting to general consumers.
- Integrating the marketing of SSL technology with compact fluorescent lighting (CFL) will negatively affect the general illumination market's adoption of SSL. The introduction of CFL into the general illumination market was not a positive experience, and lessons learned from this and from continuing consumer resistance to CFLs must be incorporated into SSL's transition into the general market. This includes:
  - Consumer values and expectations regarding lighting need to be translated into products people will buy.
  - It is imperative that products on the market perform well and do what they are supposed to do.
- More publicly available information on consumers preferences for attributes of SSL is needed (most existing information is proprietary). This requires investing in a market analysis of consumer values and expectations for SSL and publishing that information.

Our analysis of the SSL marketplace environment confirms that now is the time to move forward with these recommendations. The market is still evolving, and key market players are excited and enthused about the possibilities for the future. EERE has already learned that waiting until a technology is "market ready" before assessing and considering consumer preferences for market adoption is ineffective and wasteful of development dollars (CFL is a prime example). One participant at the most recent DOE-sponsored review of the SSL roadmapping process noted that development and engineering of near-term critical market entry products is essential and that SSL is "good enough" to "get going" through an integrated product-team culture (Kilpatrick 2003).

ACRONYMS

CFL	compact fluorescent lighting
CRI	color-rendering index
DOE	Department of Energy
EERE	Office of Energy Efficiency and Renewable Energy
EIA	Energy Information Administration
HB LEDs	high-brightness light-emitting diodes
HID	high-intensity discharge
IALD	International Association of Lighting Designers
IR	infrared
LCD	liquid crystal display
LEDs	light-emitting diodes
LEPs	light-emitting polymers
LEED	Leadership in Energy and Environmental Design
LPW	lumens per watt
LRC	Lighting Research Center (at Rensselaer Polytechnic Institute)
NEMA	National Electric Manufacturers Association
OEM	original equipment manufacturers
OIDA	Optoelectronics Industry Development Association
OLEDs	organic light-emitting diodes
R&D	research and development
RPI	Rensselaer Polytechnic Institute
RGB	red/green/blue (color spectrum)
SSL	solid-state lighting
UV	ultraviolet

1. INTRODUCTION

The Department of Energy's (DOE's) Office of Energy Efficiency and Renewable Energy (EERE) is responsible for developing energy-efficient technologies for the future, promoting the purchase and efficient use of these technologies, and transforming markets to be more accepting of energy-efficient technologies, leading to energy savings. EERE is focused on market adoption of more efficient technology applications in sectors that consume the most energy. For buildings, these include systems for space heating and cooling, water heating, and lighting. Among these, solid-state lighting (SSL) has emerged as a top priority for technology advancement because of its great potential to save energy as well as create new markets for lighting.

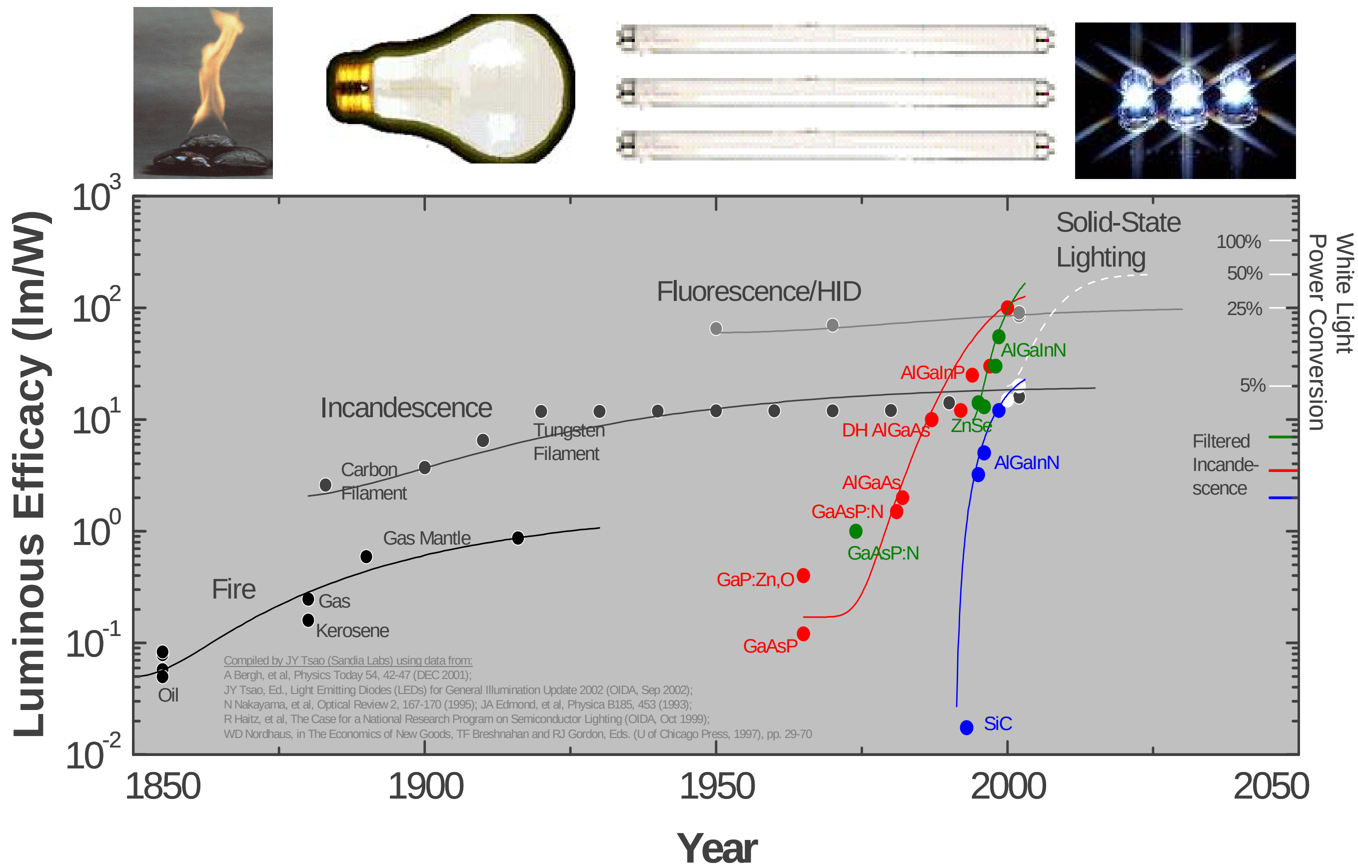

Fig. 1. 200-year evolution of luminous efficacy for various lighting technologies. Source: IEEE Circuits and Devices, Vol. 20, No. 3, pp. 28–37, May/June 2004. Note: Roadmap targets plotted as dashed white lines assume significant government research and development investment.

SSL, the first truly new electric lighting technology to emerge for nearly a half-century, produces white light from solid-state or semiconductor devices. Traditional white lighting markets refer to white light produced by incandescent and fluorescent lamps. Our traditional incandescent and fluorescent lighting technologies are based on vacuum tubes, which use black body radiation and glow discharge for illumination. SSL devices are described as "disruptive" technologies because they will permit nontraditional optoelectronics industries to enter and displace traditional lighting markets (Bingaman 2002).

In addition, as costs fall, efficiency rises, and the quality of the light improves, white LEDs should expand from the present niche applications and displace billions of conventional light fixtures in factories, offices, and homes. “It’s not going to just change the light bulb; it will change the lighting paradigm,” says Arpad Bergh, President, Optoelectronics Industrial Development Association (OIDA), a Washington, DC-based industry group (MIT 2003). Figure 1 is an illustration of the historical evolution of lighting technologies and their power-conversion efficiencies (Tsao 2003). This figure shows that SSL is projected to greatly surpass conventional lighting efficacy within the next 10 to 20 years. This projected scenario supports the possibility of a major lighting transformation. SSL’s ability to displace conventional technologies requires a major paradigm shift from our current Edison-based systems. One of the most important factors for successful market adoption of SSL is understanding what will motivate consumers to use it.

Recognizing the need for uniform strategy in the volatile, rapidly changing SSL market, EERE’s Office of Building Technologies, State, and Community Programs, has initiated important partnerships with key marketplace players through a technology roadmapping process. EERE, in collaboration with OIDA, has produced a technology roadmap for SSL, *The Promise of Solid-State Lighting for General Illumination: Light Emitting Diodes (LEDs) and Organic Light Emitting Diodes (OLEDs)* (OIDA 2001). Another collaboration of OIDA and the National Electrical Manufacturers Association (NEMA) is *Light Emitting Diodes (LEDs) for General Illumination: An OIDA Technology Roadmap Update* (OIDA 2002). The OIDA roadmap on LEDs was designed to complement a Senate authorization bill for SSL. The bill was to provide $1 billion (with industry matching) over 10 years for SSL R&D. Based on the current uncertainty of government funding, OIDA is recommending that the timetable for performance and cost targets as well as the implied energy savings mentioned in this roadmap are no longer valid and must be updated (Bergh 2004). See Appendix A for further recommendations from OIDA.

These roadmaps continue to provide a basic framework for supply-side companies to partner effectively with government and R&D organizations in the market adoption of LEDs. The focus of these documents is on the technology development needed to achieve consumer cost/benefit acceptance of SSL for general illumination applications. They provide very limited discussion about the consumer’s role in effecting lighting transformation.

This study goes beyond the roadmap to examine the impact of consumer values and supply-chain relationships on the effective market adoption of SSL for general illumination. Through examination of the available literature and in discussions with key marketplace players, this study attempts to gain a more in-depth awareness of

- the supply-side understanding of consumer values for lighting and
- how this understanding influences R&D and the introduction of new SSL products into the marketplace.

Government’s role in positively influencing market acceptance of SSL is explored, as well as the influence of branding, including Energy Star labeling, on the market adoption of products using LEDs. Results of this analysis are used to make recommendations to EERE for conducting a broader and more effective market transformation process for SSL.

2. STATUS OF SOLID-STATE LIGHTING IN THE MARKETPLACE

2.1 TECHNOLOGY OVERVIEW

SSL offers a range of new lighting attributes as a semiconductor technology. It produces illumination by passing an electrical current through a certain type of semiconductor material, causing the material to emit light. The type of semiconductor used determines the color of light produced. Because much of the energy goes toward generating light, rather than heat, the production of light through this process is extremely energy efficient. This contrasts sharply with incandescent light bulbs, which emit light essentially as a by-product of the high heat generated in the filament, and with fluorescent bulbs, which produce a low level of heat to excite a phosphor that then emits light. SSL devices include LEDs, semiconductor chips impregnated with impurities, and OLEDs, a semiconducting, carbon-based film. More detailed information about SSL technology is found in Appendix A.

2.2 POTENTIAL COST SAVINGS AND OTHER BENEFITS

SSL's initial attractiveness as a replacement for conventional lighting is its significant and widely recognized potential for energy efficiency and economic and environmental savings when compared with incandescent and fluorescent sources (Bergh et al. 2001). In the United States alone, producing electricity costs at least $60 billion per year. This does not include environmental costs of smog and carbon dioxide pollution associated with electricity production. About 22% of electricity generated is used for lighting.

Some experts estimate that widespread use of SSL could reduce U.S. lighting-related energy use by 50% to 90% (Becker 2003), reducing energy costs by $30 to $50 billion per year by 2020 (Chipalkatti 2003). Reduction in energy use would spare the atmosphere 28 million metric tons of carbon emission annually (DOE 2001a; Drennen, Haitz, and Tsao 2000). OLEDs alone may replace 50% to 70% of fluorescent lamps, thus saving one quad of energy in the nation (Duclos 2003), the equivalent of 12% of the current electricity consumption for lighting (Bergh et al. 2001).

Other projections show even greater gains. According to DOE, SSL has the potential to more than double the efficiency of today's lighting systems (see Fig. 1) and could save more than $98 billion in energy costs over the next two decades (Rensselaer Magazine 2002).

In addition to energy efficiency and cost savings, other acknowledged benefits of SSL include:

Physical Benefits

- Extremely long life and low maintenance—can be a permanent installation, requiring no replacement and reducing the need for routine maintenance.
- Cool light source—LEDS emit little heat, allowing installation of SSL within walls, floors, ceilings, and other architectural elements, potentially becoming an inherent part of an architectural feature. Low heat output also minimizes HVAC usage.
- Durability—resistant to shock and vibration with no filament or thin glass bulb to break
- Smaller, flexible light fixtures—useful for lighting in tight spaces.
- Good directional lighting source—output is flexible, providing both broad and narrow range of illumination.
- Technologically compatible with digital—can be easily coupled to digital control or sensing and can be integrated into digital networks.

- Reliability—Resistant to cold environments where fluorescents cannot cold start.

Visual Benefits

- Truer color
- Programmability for dimming and color variation (through digital control)
- Improved visibility

Safety and Environmental Benefits

- Better quality light output—minimum UV emissions and IR radiation
- Intrinsically safe—low voltage
- Reduction in carbon dioxide pollution—less burning of fossil fuels means reduced carbon emissions and reduced hazardous materials from spent lamps (unlike fluorescent bulbs, which contain mercury)
- Resistance to attracting insects as UV sources do

Other Benefits

From a product or marketing standpoint, LEDs provide the designer a whole new field of opportunities to integrate illumination in new ways and the consumer many new ways to experience light. Cars are the best current example of SSL providing entirely new ways of controlling interior and exterior lighting. As indicated previously, SSL represents a paradigm shift in lighting that could create an SSL industry of more than $50 billion per year worldwide.

2.3 PRODUCT ATTRIBUTES AND CONSUMER VALUES

Significant market penetration will be required if SSL is to achieve its potential for reducing national energy consumption through general illumination applications. This penetration will depend largely on how consumers' expectations and values about the benefits and attributes of SSL compel them to adopt this new technology over conventional lighting sources.

As indicated previously, the attributes of SSL must be significantly attractive to support a general market shift away from the current Edison system. SSL has the capacity to provide totally new approaches to and capabilities for lighting, creating new consumer values and expectations. Publicly available studies of consumers' values related to current and potential attributes of SSL are almost nonexistent. However, literature describing what consumers value about current incandescent and fluorescent lighting is extensive. Current consumer preferences for conventional lighting attributes include long life of lamps, suitable light color, good illumination of colored objects, reasonable cost, and energy efficiency. Most current values for lighting can be supported by SSL capabilities. However, most industrial and research developers of SSL believe that the new and potential capacities of this digital technology will likely drive consumers to embrace it over conventional approaches. How consumer values for conventional lighting compare with attributes of SSL is described below.

Long Lamp Life. According to Steven Goldmacher (1999, 2001), Director of Public Affairs for Philips Lighting Co., longer life is consistently "the number one attribute demanded by consumers in all lighting research." He notes that, in addition to increasing the economic value of the product, longer life means the consumer doesn't have the inconvenience of changing the device as often.

SSL devices have tremendous potential for meeting consumer desires regarding longevity. [Some current LEDs claim to last more than 100,000 hours, equivalent to more than 10 years of normal use. White LEDs, which have shorter wavelengths and higher energy (blue and UV) sources, can experience shorter lifetimes, however, and material degradation can affect lifetime length.] In addition, the devices are quite rugged, being much less subject to breakage than incandescent and fluorescent lamps (Chipalkatti 2003). While OLEDs are in an early stage of development compared to LEDs, eventually they are expected to last for similarly long periods (Thompson 2003).

It is also notable that SSL devices do not fail suddenly the way conventional lighting sources do. In solid-state devices, the light output gradually diminishes over the life of the product. Lighting developers believe this quality will add to the products' appeal to consumers since it will eliminate the sudden loss of light, which requires immediate action to restore it. On the downside, there may potentially be some consumer frustration if control adjustments are periodically required to compensate for the declining output of the solid-state device. (The longevity estimates in the previous paragraph are based on a convention commonly accepted among LED developers that a lamp has reached the end of its useful life when its output declines to 30% of its initial value.)

Light Color. Light used for illuminating interior spaces has two color attributes: the color of the light source itself and the ability of the light to accurately render the color of the objects it illuminates (color rendering). This section is concerned with the color of the light source; the following section addresses the light's color-rendering ability.

Virtually all light used for general illumination purposes is considered "white" light. However, there is considerable variation within this general term, roughly corresponding to the difference between the soft, warm, yellowish white of raw cotton to the hard, cool, bluish white of fresh snow. Incandescent bulbs produce a warm light. Early fluorescent tubes produced a light that was quite cool in color, although later developments increased the range of light colors available from fluorescent lamps.

The color of interior light preferred by consumers varies depending on a number of factors, with a principal consideration being the use of the illuminated space. Cool light sources are normally preferable for offices where a feeling of alertness is desired. People usually like warmer light sources in homes, restaurants, and retail businesses to encourage a sense of relaxation and comfort (interLight, Inc. 2000). The colors used in the space are also significant—warm colors (reds, yellows, and browns) tend to appear more natural and appealing under warm light sources, while cool colors (blues, greens, and violets) usually look better under cool light sources (Retrofit Design Lighting 2003).

The intensity of light in the space also influences the desired light color. Dimly lit spaces are usually more appealing and comfortable when lit with warm light sources. Brightly lit spaces, on the other hand, seem more natural when the light color is cooler, similar to that of daylight (Retrofit Design Lighting 2003). As one source explains, a dimly lit interior appears gloomy and overcast under cool lighting, but pleasant and comfortable under warm lighting (Weintraub 2000).

Lighting preferences vary by season and over the course of a day. Some lighting experts maintain that warmer light sources are preferred in winter while cooler sources are desirable in summer to counteract ambient temperatures (Chipalkatti 2003). One study (Morita et al. 2003) has shown that a person's light color preferences change over the course of a day. When five women were given precise control over the intensity and color of light in their individual environments, they increased the light intensity gradually over the first five hours after waking and increased the coolness of the light color over the first two hours. During the last five hours before retiring, they progressively decreased the intensity of the light and made it warmer in color. It is interesting to note that some researchers claim that cool white lighting, such as that produced by many fluorescent lamps, is stressful to people, particularly to children and others who are especially sensitive to environmental stress (Basso 2001).

SSL promises to provide consumers with an unprecedented ability to control the color of interior lighting. Depending on the LED technology employed, users may be able to adjust the light color to match the use being made of the space and the intensity of illumination. The same source could provide bright, moderately cool light for a cocktail party and dim, warm light for an intimate dinner. Furthermore, since SSL is digital, it is ideally suited for automatic control. Digital controllers could continuously change the color of light as appropriate for the time of day and season of the year (Chipalkatti 2003, Feder 2003).

Quality of Light/Illumination. The current technical measure of how a light source accurately renders the colors of an illuminated object compared to a reference light source of similar color temperature is referred to as color-rendering index (CRI). The "ideal" color-rendering sources have been defined as an incandescent lamp for warm-light sources and natural daylight for cool-light sources. Both of these sources are considered to have a CRI of 100. For other light sources, the closer they come to this reference level, the better they are considered to render color [Energy Outlet (undated)]. Colored objects seen under light sources with poor color-rendering accuracy appear grayish, with less vivid colors (Steigerwald et al. 2002). Normal cool-white fluorescent lamps have a CRI of 62, while fluorescents with rare-earth phosphors have CRIs of more than 80 (Mischler 2003).

Lighting experts consider accurate color rendering an extremely important determinant of lighting quality. "Once you have picked the lamp type and the 'right' color temperature, whatever that is," they say, "it is best to go with the highest CRI lamp available in that family" (Retrofit Design Lighting 2003). Developers of SSL agree, noting that accurate color rendering is essential if the new technology is to achieve widespread acceptance in the general illumination market (Wessner 2003).

While developers have been steadily improving the CRIs of white light LEDs, the color-rendering accuracy of the devices does not yet equal the level that consumers expect, based on their experience with conventional sources. Current inexpensive LEDs achieve CRIs between 60 and 70; more expensive ones rate in the low 70s (Morrison 2002). Companies continue to make advancements in LED lighting, opening up new opportunities for their use in everyday applications. Lumileds Lighting, for instance, has just released the Luxeon III light source, which uses LEDs to produce up to 80 lumens of white light while consuming about 3.9 watts of power (Lumileds Lighting 2003).

Researchers at the Lighting Research Center (LRC) at Rensselaer Polytechnic Institute (RPI) question the legitimacy of CRI as an indicator of consumer preferences for color illumination [Narendran and Deng (undated)]. They asked subjects to rate a scene illuminated by various types of light sources. Subjects also rated the illumination of human skin tone by holding their own hands under each light source. The resulting preferences for color rendering did not match the objectively measured CRIs for the light sources. The subjects gave their highest preference to an LED light source that produced white light by combining light from red, green, and blue emitters although this source had the lowest CRI of the lamps tested. As a result of their experiment, the researchers "do not recommend the use of CRI as a target metric in the development of solid-state light sources because it could negatively impact overall performance. A better metric is long overdue to quantify light source color rendering and preference properties." As a result, the International Commission on Illumination (see http://members.eunet.at/cie/) has formed a committee with broad participation that is actively studying this issue and has recently developed several other metrics for color rendering. In addition, the Light Right Consortium (see http://www.lightright.org/about/index.htm), a collaboration of government, private non-profit associations, and industry, is assessing lighting metrics as part of their initial studies on lighting and worker productivity.

At a recent DOE-sponsored SSL workshop, Dr. Doug Kirkpatrick from the Advanced Technology Office, Defense Advanced Research Projects Agency (DARPA), indicated that computational limitations for evaluating light are no longer relevant and that a percentage deviation from daylight would be a more appropriate measure. In addition, he suggested that lumens may not be a good measure of how we see as reflected by recent studies of lumens and brightness. He suggests the need for broadening population studies for further assessment of this metric (Kirkpatrick 2003).

Reasonable Cost. The market introduction of CFL has shown that consumers are generally unwilling to pay significantly higher prices for lamps even if they would eventually recover the extra cost through longer product life and a long-term reduction in energy use. This factor is considered one of the principal barriers that must be overcome before SSL can achieve significant market penetration (Craford 2003, Duclos 2003). One expert notes that "the perceived expense of LEDs is almost a psychological factor" limiting acceptance of the technology (Chipalkatti 2003). Other observers state that LEDs will be able to penetrate the general illumination market only when their light output is increased by an order of magnitude and their cost-per-quantity of light produced is reduced by two orders of magnitude (Steigerwald et al. 2002).

Other Product Attributes. Researchers and industrial partners involved in the development of SSL seem confident that the technology can be refined to meet consumer requirements regarding longevity, light color, color-rendering accuracy, and cost. They emphasize, however, that public adoption of LED lighting technology will be driven primarily by the new opportunities it offers [Dowling (undated), Holt 2003]. "Solid-state lighting technologies will suggest entirely new sets of materials and ways to deliver and use light that go far beyond . . . the current bulb culture of lighting" (Kennedy 2003).

One principal way in which SSL will offer new capabilities is control. As evidenced by the demand for light dimmers, consumers have long demonstrated a desire to vary and control the intensity of interior lighting. With SSL, they will be able to control both the intensity and the color of the light with no loss in energy efficiency or lamp longevity. As digital devices, LEDs are inherently suited for automated manipulation using computer controllers. This type of control would not only allow the programmed activation of lighting devices at specific times, but the quality of the light provided could be automatically varied according to parameters entered into the control device. Light intensity and color, for example, could be varied on a daily, weekly, or annual schedule (Chipalkatti 2003, Feder 2003).

Color Kinetics has an actively used office that has both LED overhead illumination as well as fluorescent. The system allows the variation and control of the color temperature of the lighting and adds significant benefit to such lighting. The company has also been investigating the variation and control of lighting over the period of a day. Not only can outside lighting be mimicked, but cloud passage or the light of a particular location and time can be replicated as well. Color Kinetics has created a system that acts as a virtual window in which light sources, direction of light, etc., can be replicated and changed.

Solid-state technology could also allow the source of the energy to be separated from the device that radiates visible light. LEDs are being developed that emit invisible, ultraviolet light that excites phosphors, which respond by emitting white light. It may be possible to use a single ultraviolet source as a remote source to produce white light from several phosphor devices spread throughout a room (Bergh 2003). Only the ultraviolet source would have to be connected to the electrical system; the devices that emit visible light would be freestanding (wireless).

Perhaps the most exciting possibilities offered by SSL involve the integration of lighting with architecture and furnishings. Thanks to their ruggedness and long life, LEDs could be embedded into semi-permanent structural elements such as tiles and wall partitions. It may also be possible to weave

LEDs into rugs and curtains that then produce light (Kennedy 2003). The thinness and flexibility of OLEDs makes it possible to bend them around non-flat surfaces. They could also be applied to ceilings or walls—almost like wallpaper—to produce soft diffuse light from a large surface area (Thompson 2003).

The thinness of OLEDs may even offer possible improvements in the efficiency of building design. Fluorescent lighting requires a clear space of eight to12 inches above the ceiling surface to house the light fixture and to dissipate heat. OLEDs would essentially be part of the ceiling surface and would require no clearance above the ceiling. The elimination of the requirement for a clear space could allow an extra story for a tall, multi-story building (Chipalkatti 2003).

Finally, because of the low voltage required for output and minimum UV and IR radiation output, LED systems can be designed to be intrinsically safe. In addition, SSL does not contribute to mercury pollution of landfills as fluorescent sources do (Goldstein 2002).

SSL Attributes—Summary

Knowledge about what consumers now value about lighting can provide a point of departure in developing strategies for general market adoption of SSL. Table 1 provides a comparison of various lighting attributes and the perceived ability of conventional sources and SSL to satisfy consumers' expectations. Nevertheless, focusing alone on what is known about lighting preferences will not anticipate all the new and creative approaches offered by SSL that may lead to turning points in the market. Gaining more understanding about consumers' values for SSL early in the technology development process can support more effective market transformation. It is important to recognize that the majority of customers will not buy the SSL technology just to own the latest innovation. Rather the critical issue is how they will use it and what they can do with it. Focusing alone on matching cost per lumen or color-rendering index may be misguided. There are so many benefits and additional values for applications that support better integration and control with other residential uses. These approaches may prove the means to drive adoption of this technology.

Table 1. The ability of different lighting technologies to satisfy consumer expectations for lighting

Product Attribute	Ability to satisfy consumers' expectations			
	Solid-state		Incandescent	Fluorescent
	Current	Potential		
Long life	high	high	low	high
Light color	high	high	high	medium
Color-rendering accuracy*	low	high	high	low
Low initial cost	low	low	high	medium
Controllability	medium	high	medium	low
Flexible lighting design	medium	high	low	low
Ruggedness	high	high	low	low
Safety	high	high	low	low
Energy efficiency	medium	high	low	high
Environmentally friendly	high	high	medium	low

*While the color-rendering accuracy of SSL is considered fair when measured in terms of CRI, some tests indicate that consumers prefer the color-rendering attributes of SSL over those of incandescent lamps.

2.4 CURRENT AVAILABLE APPLICATIONS

LEDs are now primarily available in the commercial and industrial sectors. Though still used foremost as indicator lights, LEDs are now used in applications that require high light output. They are commonly used in traffic signals, automobile brake lights, and exit signs. They are gradually taking over the traffic signal market because they use much less electricity than incandescent bulbs and have to be replaced much less frequently (Craford 2003, Wilson 2003). They are also often used for retail signs and lighting and for large video display screens, such as the 8-story NASDAQ screen in New York City's Times Square.

LEDs are beginning to be marketed for general illumination uses, but only in specialty applications where their unique attributes make up for their higher costs. Subsequently, most consumers have low awareness of the potential of SSL as a generic light source, regarding it mostly as a novelty application. LEDs are being used increasingly in flashlights because of their long life and ruggedness and because their low-power demand results in longer battery life. LEDs are also offered in solar-powered landscape lights where their low-power requirement mates well with the output of a small solar cell. There are now cabin lights for sail boats that use LEDs to provide a moderate level of illumination for extended periods without draining the ship's batteries. One can also purchase small book lights that take advantage of the LED's low power draw and low level of glare. Finally, LED desk lamps are offered from on-line distributors touting the devices' long life, low power consumption, low heat, and absence of glare. This last example represents SSL's deepest penetration so far into the general illumination marketplace.

One market analyst (Maccagno 2002) reports that the LED market generated $1.2 billion in revenue in 2001. Table 2 indicates how the sales were distributed.

Table 2. LED Sales by Category in 2001

LED Application	Percent of Sales
Backlighting (handsets, digital cameras, PDAs)	30
Automotive (dashboard, interior, brake lights, tail lights)	26
Signs and displays (outdoor advertising, exit signs, full color displays)	26
Electronic equipment	10
Signals	4
Illumination	4

Source: Maccagno 2002.

OLEDs are in an earlier stage of development and are used to provide displays and backlights for electronic devices such as cellular phones, digital video cameras, DVD players, personal digital assistants, and car stereos (Dang 2003).

2.5 PROSPECTS FOR MARKET GROWTH

High-brightness light-emitting diodes (HB LEDs) have been a growth area, compared with an otherwise stagnant market for semiconductors and optical components of all types. The market for HB LEDs has grown nearly 50% per year since 1995, reaching $1.2 billion in 2001 and jumping to $1.8 billion in 2002, revitalizing the 30-year-old LED business. Based on continuing positive trends in this dynamic industry, the market for HB LEDs is forecast to grow to $4.7 billion by 2007. The HB LED market is worldwide, and is supported by manufacturers in several regions, including North America, Europe, Japan, Taiwan, and Korea (Bizwire 2003).

In spite of slow economic growth worldwide, LEDs continue to penetrate new and existing markets. In 2002, there was a ramp-up in the use of HB LEDs in mobile phones, including both backlighting for full-color liquid crystal display (LCD) screens and keypad backlighting. The automotive sector uses HB LEDs extensively, both for instrument panel lighting and external signaling. HB LEDs are the enabling components for full-color outdoor video screens used in sports stadiums, outdoor advertising, and large-venue concerts. Moreover, they have been widely adopted in red, green, and yellow traffic signals, primarily in North America, as well as in highway signs and moving message panels. LEDs claim 20% of the traffic signal industry in North America, up from just 8% a year or two ago. Their current success lies in their longevity (they outlast incandescent lamps by a factor of 10), energy efficiency, durability, low maintenance cost, and compact size. Replacing conventional lamps with LEDs in the United States alone will bring energy benefits of up to $100 billion by 2025, including reductions in consumption and new market growth potential (Maccagno 2002).

Research and development in the use of compound semiconductor materials (such as InGaAlP and InGaN) has led to increased efficiency and lower cost of LEDs. They are now being investigated, tested, and used in a number of lighting applications, such as architectural lighting; machine vision; illumination for signage; decorative, accent and marker lights; and flashlights.

Most of SSL applications to date have involved colored light. However, white-light illumination is the “Holy Grail” of the LED industry, in that LEDs must attain this level of illumination to correspond with consumer preferences for conventional white light. White LEDs, introduced in the late 1990s, have made tremendous progress in efficiency and lumen output, with efficiencies now exceeding those of incandescent lamps. As a result, white LEDs are now poised to enter the $12 billion market for general illumination (PennWell Corp. 2003).

Both LEDs and OLEDs have commercial entry points in special niche applications within the general illumination market. Neither technology is presently aimed at the residential market (displacement of incandescent bulbs) where the major economic and environmental impacts will be realized.

2.6 POTENTIAL TECHNICAL AND MARKET BARRIERS

Most current perceptions of market barriers correlate directly with the technology constraints that must be overcome to achieve product attributes like conventional light sources. These assumptions are based on what is known about consumers’ values and expectations for conventional lighting. Major players in the lighting industry recognize that successful adoption of SSL sources will require a paradigm shift in thinking about uses of and values for lighting. In addition, they believe that the innovative capabilities of SSL will likely drive market acceptance of SSL for general illumination. However, publicly available information on market characterization of SSL for general illumination acceptance is almost nonexistent. Discussions with key market players (see Sect. 5) indicates that they have been involved extensively in defining commercial niche markets, and are only exploring initial approaches to general illumination applications. They indicate that this information is proprietary. Market characterization for SSL is speculative and mostly based on understanding consumers’ values preferences for conventional lighting technologies.

Accordingly, most observers define the principal obstacles to the adoption of SSL for general illumination purposes as their high cost and the limited amount of light they produce (Wessner 2003, Chipalkatti 2003, Craford 2003, Duclos 2003, Steigerwald et al. 2002) compared with conventional lighting. These factors combine to make the price-per-lumen of light from an LED device much higher than that obtained from incandescent or fluorescent sources. Those involved in the development of SSL seem confident that these barriers can be overcome, citing the steady progress that has been made in improving the output and reducing the costs of LEDs in the four decades since they were invented. Current efforts are aimed at increasing light output by reducing defects in the manufacture of LEDs and by improving the packaging for more efficient light emission. More cost-effective production methods are also being pursued. When accounting for overall life-cycle cost today (energy costs, replacement costs, maintenance, etc) of LED-based illumination versus incandescent and halogen technology, the case can be made that LEDs are now economically viable. Given the development and pricing trends, LEDs could compete with fluorescent sources by 2007 (Dowling 2003).

Lighting experts also point out that improvements are needed in the color-rendering accuracy of LEDs as well as in other color qualities, including color temperature, color uniformity, and the stability of light color over the lifetime of the device (Wessner 2003, Duclos 2003, Morrison 2002). Color-rendering accuracy (as measured by CRI) has been a particular problem for SSL. To produce white light, LED devices either combine diodes of several different colors or use a blue or UV LED to excite a phosphor. For the most part, these techniques have not succeeded in producing a full-spectrum white light that renders all colors accurately. However, Lumileds introduced at the U.S. LightFair in October 2003 (and at the European LightFair in spring 2003) the Luxeon Warm White (3200 K, 90 CRI) light. According to Lumileds, all who saw the performance of the product gave its light quality high marks in comparison with incandescent and halogen sources. Furthermore, Lumileds is now selling this product as fast as it can be made. The price remains higher than incandescent and halogen, but the quality of light is comparable (Lumileds 2004). It is worth repeating, though, that high CRI does not necessarily translate into higher consumer acceptance of the lighting source.

Many industry experts are optimistic that solid-state technology will revolutionize the architectural lighting industry, though some problems remain to be solved. One of these problems is low system efficiency, caused by heat production that reduces LED performance. Another challenge is packaging the LEDs into lighting fixtures that are acceptable for architectural lighting (DOE 2003a). LEDs offer the opportunity to improve fixture efficiency. For example, fluorescent tubes emit light from a 360-degree cylinder. Most of this light is then reflected or refracted, resulting in the loss of about 50% of the light. LED packages are directional and light can be placed where desired, minimizing light loss and increasing illumination potential.

A final obstacle that must be overcome before SSL can compete effectively in the consumer market is system standardization. Uniformity of sockets, electrical supplies, and control interfaces will be required to reduce costs and make LEDs sufficiently easy to use to attract consumers (Wessner 2003). Standardization of interfaces—and possibly compatibility with current plugs and electrical supplies—seems particularly crucial for LEDs' penetration of the retrofit market.

2.7 SSL IN COMPARISON TO OTHER EFFICIENT LIGHTING TECHNOLOGIES

Since standards for SSL are focused on conventional lighting, comparison with these sources is appropriate.

Fluorescent Lighting. High-efficiency fluorescent lighting sets the current standard for energy-efficiency. Any replacement technology, such as solid-state, will have to displace this incumbent. White light LEDs are not even close to the fluorescent standard at the present time, emitting 20–30 lumens per watt (LPW) at a cost of 250–500 dollars per kilolumen, compared to 70–100 LPW at 50 cents per kilolumen for high-efficiency fluorescents. LED R&D is currently driven to make SSL competitive with conventional lighting output and cost: more than 150 LPW at a cost of less than $10 per kilolumen (Maccagno 2002). OLEDs are expected to achieve competitiveness with an output of 120 LPW at a cost of $6 per kilolumen (Duclos 2003). Moreover, the advantages that LEDs and OLEDs offer in variability and control will make them more attractive than fluorescents for many applications. In addition, the use of SSL avoids mercury pollution of landfills that occurs when fluorescent tubes are discarded (Goldston 2003).

CFL Technology. Several key players in the SSL market have mentioned compact fluorescent lighting (CFL) as a major competitor for the general illumination market (see Sect. 5), as well as a potential solution to attaining the U.S. energy-savings goals for lighting. However, there are also strong indicators from many of these individuals that inconsistent performance as well as lack of effective integration with the lighting fixture market have created consumer resistance to this technology. Understanding the lessons learned from the slow market adoption of CFLs is important in successful market penetration and adoption of solid-state technologies (see Appendix B for a more detailed discussion of market penetration issues for CFLs).

A CFL system has two components: the bulb and the ballast. The ballast starts the bulb and maintains its operation. The bulb is—just as it sounds—a small-diameter fluorescent, folded for compactness. The compact size of these bulbs allows them to screw into common electrical sockets, making them an ideal replacement for incandescent bulbs. CFLs provide the same amount of light (lumens) as standard incandescent bulbs, but have lower wattage ratings. CFLs use 66% less energy than a standard incandescent bulb and last up to 10 times longer. Replacing a 100-watt incandescent with a 32-watt CFL can save at least $30 in energy costs over the life of the bulb. CFLs operate at less than 100ºF; they are also safer than typical halogen bulbs, which are frequently used in floor lamps or torchieres and burn at 1000ºF. Due to their high heat output, halogens can cause burns and fires. CFLs are cool to the touch.

A standard incandescent light is very inefficient because much of the energy it uses becomes heat instead of light; a typical incandescent lamp wastes 90% of the energy it uses. A compact fluorescent bulb turns more of its energy into light and less into heat, using 75% less energy than standard incandescent bulbs. A 15-watt CFL system can supply the same amount of light as a 60-watt incandescent bulb (Pennsylvania State DEP 2003).

CFLs have either magnetic or electronic ballasts. Magnetic core and coil ballasts are the least expensive options, but they have some disadvantages. There will be a slight delay before the bulb strikes, especially in lower-than-normal room temperatures. Magnetic ballasts also are heavier, so they could be inappropriate for floor lamps because they would make the lamp top-heavy. Electronic ballasts represent the latest in lighting technology. They are lightweight and allow the bulbs to light almost instantaneously. They may cost more, but since they use less energy, the higher cost is more than recovered during their lifetime (Pennsylvania State DEP 2003).

High Intensity Discharge (HID) Lighting. Energy-efficient metal halide HID lighting is being used increasingly as point source replacements for incandescent and halogen bulbs. HID lights are named from the intense white light produced by the electrical discharge resulting from igniting an arc between two electrodes. Traditionally this type of lighting has been used for years in sports arena and stadium lighting. It is now being used extensively for vehicle headlights because of high brightness and efficiency. Dr. Doug Kilpatrick in his recent presentation (Kilpatrick 2003) at a DOE SSL workshop noted that compact HIDs now exceed the brightness and efficiency of CFLs.

Hybrid Solar Lighting. Hybrid solar lighting, another emerging energy-efficient technology, could also be seen as a competitor to SSL. However, one researcher involved in hybrid solar lighting development at ORNL sees the two technologies as complementary rather than competitive. Hybrid solar lighting systems require artificial lighting for periods when sunlight is not intense enough to provide sufficient illumination. Current hybrid solar lighting prototypes use adjustable-ballast, high-efficiency fluorescent lamps for this purpose. White-light LEDs might be even better suited for this purpose due to the facility with which both the intensity and color of their output can be varied and automatically controlled to match the characteristics of the solar lighting component (Cates 2003).

2.8 IMPACT OF LIGHTING DESIGN ON THE MARKET

Lighting design is considered one of the most promising and innovative vehicles for penetration of SSL into the general illumination market. It provides the foundation for using the unique capabilities of SSL. Yet discussions with major market players (see Sect. 5) revealed their concerns about market adoption.

- U.S. consumers lack sophisticated value for innovative lighting, since their major interest is with high brightness, white lighting.
- Most design fixture manufacturers are not well integrated into the SSL network.
- Fixture designers are not keeping up with development of SSL technology. Some of the resistance in this industry is based on lack of consumer responsiveness to design.

Nevertheless, lighting design will continue to provide the opportunity for exploring innovative general commercial and residential uses for SSL.

Architectural Design. According to Robert Steele (OE Magazine 2002), "Optical design is a key in enabling solid-state lighting. Almost everything you're going to do with an LED is going to require some optical thing to shape the light and direct the light and spread it out." Typical incandescent lighting fixture designs must accommodate certain factors: dealing with heat and avoiding a fire hazard, protecting people from burns from contact with hot light bulbs, and protecting the glass bulb from damage. These are the governing design constraints that define all conventional lighting assemblies. With LED lighting fixture design, none of these limitations exist.

Lighting Fixtures and Design. Demand for lighting fixtures is projected to advance nearly 5% per annum through 2006 to more than $21 billion, outpacing the gains posted during the 1996–2001 period. Growth will be stimulated by continued strength in the replacement market, which will in turn be supported by both residential remodeling activities and nonresidential retrofit projects aimed at increasing the energy-efficiency of existing lighting systems. Advances in lighting fixture demand will also be driven by a shift toward more expensive products that offer superior energy efficiency and performance, including electronic ballasts, high intensity discharge (HID) lighting and advanced technologies such as LED and fiber optic systems. Both the residential remodeling market and the increasing demand for expensive lighting fixture products provide further opportunities for introducing LED-based lighting applications.

Further trends in the design and fixture market include:

- Demand for portable light fixtures is increasing. Shipments of fluorescent and other non-incandescent portable fixtures, such as fixtures using LED light sources, are expected to show double-digit gains through 2006. Growth in portable fluorescent fixtures will stem from increasing consumer interest in the energy-efficiency advantages offered by fluorescent lighting, as well as from product developments that improve the quality of the light produced by such fixtures.
- Technological advances in LED and related fixture technology will spur increased sales of flashlights and other portable fixtures utilizing LED light sources. HID and other advanced types of nonportable indoor fixtures, as well as specialty industrial-type fixtures, will also post above-average gains through 2006.
- Construction applications dominate the fixture market. Construction-related applications are now the principal end use for lighting fixtures, accounting for two-thirds of total lighting fixture sales in 2001. Several construction markets will show above-average gains through 2006, including industrial buildings and nonbuilding applications (e.g., roadway and airport lighting). Both of these markets will benefit from above-average spending on new construction, as well as from continuing retrofit projects aimed at increasing the energy efficiency of existing lighting systems (The Freedonia Group 2002).
- Major challenges for the lighting fixture and design market in adopting LED lighting approaches include:

- LEDs require a systems approach. Because LEDs are so different from incandescents and fluorescents, they cannot be viewed simply on a lamp-versus-lamp basis. When transitioning to SSL, as stated by Makarand Chipalkatti, director of lamp module development at Osram OptoSemiconductors, "You're not replacing the lamp, you're replacing the lighting system." For example, before viewing different light sources in terms of an illumination specification, designers must consider how much light generated by the bulb (incandescent or fluorescent) is actually blocked by the fixture.
- Issues can arise when using an array of lights. LED light fixtures often use resistive/capacitive supplies, which are not expensive to make, but due to technical reasons, are not electrically efficient and may develop problems when a large number of them are driven from a transformer. Generally, a capacitive supply is used with an array of 5-mm LEDs in series, which means that when a single LED fails, the whole lamp will fail.

- LEDs can result in major building space savings. The low profile of tile-shaped LED light sources could call into question the need for drop ceilings that currently hide fluorescent lighting fixtures. Although not the only elements overhead, lighting fixtures may be the critical ones. Consider that in a multistory building, replacing overhead fixtures and their associated drop ceilings could add up to space savings, possibly equivalent to an additional story (Electronic Design 2002).

New Lighting Designs. LEDs are typically much smaller than conventional light sources, allowing for dramatically different lighting designs capitalizing on the unobtrusiveness of the source. This technology gives the lighting designer additional options and choices when compared with conventional lighting. With LEDs, the light source can be divided into multiple points of light, distributed across a surface or placed in multiple planes.

LEDs lend themselves well to shaped and three-dimensional structures. Many designs today use planar boards to accommodate the typical form of a printed circuit board, but any shape is possible with flexible circuit materials or through the use of interconnected forms. LEDs are enabling the development of lighting designs that were previously impractical. A striking example of such LED lighting illuminates the text frieze that encircles the interior of the Jefferson Memorial in Washington, D.C. (image at http://www.elecdesign.com/Files/29/2254/Figure_01.jpg). In this application, a series of 17,000 surface-mounted LEDs are assembled on 17-in. linear strips on a high ledge just below the frieze. The entire 250-ft-long fixture mixes white and yellow LED strips to produce a hue of light that nicely matches the marble wall. Before the LED lighting was installed, the frieze remained unlit because the ledge holding the LED strips was too shallow for a conventional light fixture (Electronic Design 2002).

As mentioned earlier, LEDs also offer the potential for color-controlled illumination. Consumers can take a red, green, and blue source and control the color temperature for "mood lighting," something that other sources cannot offer.

2.9 PROMOTIONAL STRATEGIES FOR MARKET ACCEPTANCE

Participants at a workshop held in March 2001 to discuss SSL (Wessner 2003) strongly emphasized the need for a government/industry partnership to develop and promote the technology. The goal of the partnership would be to "reduce costs, share information, and help accelerate technological innovation by coordinating pre-competitive research and collaboration on the development of common standards." Government's role would be to determine strategic directions, promote information exchange, and develop common standards (Bergh 2003). Safety standards are needed. For example, Underwriter's Laboratory has no specific testing for LED luminaries. Also seen as important were educating lighting designers and the public about the benefits of SSL and developing a common terminology for the new technology (Chipalkatti 2003).

Subsequently, DOE and OIDA produced a technology roadmap for the development of SSL, which concluded that "it will take a major government-sponsored, industry-driven initiative, involving academia and national laboratories, to accelerate the penetration of solid-state lighting into general illumination" (DOE and OIDA 2001). They caution that, in the absence of such a cooperative initiative, SSL technology and the market will go to other countries where government/industry cooperation is already underway. Assuming this cooperation is achieved, DOE and OIDA put forth the targets in Table 3 for assimilation of SSL into consumer markets.

Table 3. Targets for Penetration of LEDs into Consumer Markets

Year	LED Applications	OLED Applications
1	Monochrome signaling, traffic lights, automobile tail lights, large outdoor displays, decorative lighting	Small displays, decorative lighting
3	Low-flux white light applications, shelf lighting, stair/exit ramp lighting	Low flux white light applications, accent lights
5	High-demand general illumination, e.g., mechanical stress, high replacement cost, etc. Low-level outdoor illumination (parking lot)	Decorative illumination, glowing wallpaper, ceiling lights, etc.
10	Significant penetration into general indoor/outdoor illumination	

Source: DOE and OIDA 2001.

As an update to the original market targets for 2001, Arpad Bergh, one of the original authors of the roadmap, offers that signaling and lighting applications in mobile platforms (land, sea, and air vehicles) need to be the major focus for LED development in the next 10-20 years (Bergh 2003). The low-voltage, direct current attributes of SSL match the requirements of these applications. Furthermore, mobile applications have shorter life cycles than buildings (2–20 years versus 30–60 years) and offer opportunities to more easily integrate the technology into the vehicle infrastructure.

Because SSL offers potential for significant energy savings, various national governments have targeted LED technology for accelerated research and development funding. A national SSL effort is now underway in Japan, and proposals for a U.S. program have received broad-based support in Congress (Global Information Inc. 2003). For more information about current government programs and legislation see Appendix A.

2.11 RESEARCH AND DEVELOPMENT

The United States has strong industrial R&D, major expertise at national laboratories (Sandia National Laboratories, Lawrence Berkeley National Laboratory), and relevant fundamental research at more than 20 universities. Perhaps the subject of white lighting will depend most heavily on future technological breakthroughs. Presently, white LEDs are more akin to the fluorescent lamp than might be realized, since they operate with a fluorescent phosphor converting the light of a blue chip into white. Color rendering is adequate, but color temperature remains high. However, as with fluorescent technology, breakthroughs are expected that will realize much better color properties. Currently Lumileds and Japan's Nichia Chemical Corporation are unveiling high flux 3000-k white LEDS (Lamp & Gear Magazine 2003). Cree has also made some recent achievements in the warm white lighting arena at the recent LEDs 2003 conference. Appendix A presents more detailed information on R&D efforts.

3. OVERVIEW OF THE COMMERCIAL AND RESIDENTIAL LIGHTING MARKETS

An overview of the current U.S. lighting market is available in *US Lighting Market Characterization: Volume 1: National Lighting Inventory and Energy Consumption Estimate* (DOE 2002). It reflects both the energy use for lighting as well as use by lighting technology. General indications are:

- About 22% of all electricity generated in the United States is for lighting applications. Commercial users are the largest consumers with 51%, followed by 27% for residential, 14% for industrial, and 8% for outdoor stationary lighting. Lighting accounts for 8.2 quads (out of 37 quads generated for electricity in 2002) of energy use of which 6.4 supports the commercial and residential market.
- Approximately 17.6% per year of the total energy consumption for commercial and residential buildings is for lighting. This rate translates into 30.3% of overall buildings electricity use.

Data on the actual use of types of light by source and sector indicate that:

- About 60-70% of the lighting energy consumption in commercial and industrial sectors is by fluorescent sources, while more than 90% is by incandescent sources in the residential sector.
- Fluorescent is the most important light source in the United States, producing 62% of the lamp lumens. In comparison, HID sources produce 26%; incandescent, 12%.
- Incandescent accounts for 42% of the nation's electricity use for lighting. It consumes more energy than fluorescent (41%) and HID (17%) yet provides the least amount of light.

Replacing both fluorescent lighting sources in the commercial sector and incandescent sources in the residential sector are targets for SSL market penetration. Incandescent lighting is also the major target for efficiency measures. Because the commercial sector is the largest user of lighting energy, it is the principal target for SSL, although market adoption by the residential and industrial sectors will also be needed. Table 4 is an overview of the national lighting energy use by sector and light source. The table shows that SSL has barely entered the commercial sector at this point (Navigant 2002). Obviously, SSL has a long way to go to penetrate the major illumination markets and displace fluorescent and incandescent sources. Nevertheless, the SSL technology roadmaps (OIDA 2001, 2002) project that by 2025, SSL could compete effectively and displace the other lighting markets (see Fig. 1).

Table 4. National Lighting Energy Use by Sector and Source

Sector	Incandescent		Fluorescent		HID		Solid-state		Total	
	TWh/yr	Quads	TWh/yr	Quads	TWh/yr	Quads	TWh/yr	Quads	TWh/yr	Quads
Residential	187.6	2.02	19.9	0.21	0.7	0.01	0.0	0.000	208.2	2.2
Commercial	124.5	1.34	220.1	2.37	46.2	0.50	0.1	0.001	390.9	4.2
Industrial	2.6	0.03	72.3	0.78	33.0	0.36	0.0	0.000	107.9	1.2
Outdoor stationary	6.5	0.07	1.1	0.01	50.2	0.54	0.0	0.000	57.8	0.6
Total	**321.2**	**3.5**	**313.4**	**3.4**	**130.0**	**1.4**	**0.1**	**0.0**	**764.7**	**8.2**

From discussions with key market players (see Sect. 5) opinions vary about how to achieve general illumination market penetration for SSL. Most agree that the strategy proposed by the roadmaps (see

Table 5) reflecting the technical and cost parameters to be attained is crucial. They all agree that success in commercial niche markets is important. A critical success factor in moving into the general illumination market is effective support of customer expectations for product delivery. Several opinion leaders expressed concern about overselling product attributes that cannot be delivered (lifetime, color quality) across all applications. Even with lighting products that are moving into the commercial niche markets (transportation, entertainment, display, and outdoor lighting), the products must be credible with regard to consumer expectations. The mistakes made in the introduction of CFL are frequently cited as an example of disregarding consumer values and expectations, resulting in continued general consumer resistance to CFLs.

Table 5. Roadmap Scenario for SSL-LED Technology, along with Comparisons to Traditional Lighting Technologies

	SSL-LED 2002	SSL-LED 2007	SSL-LED 2012	SSL-LED 2020	Incan-descent	Fluor-escent	HID
Lamp Targets							
Luminous Efficacy (lm/W)	20	75	150	200	16	85	90
Lifetime (hr)	20,000	20,000	100,000	100,000	1,000	10,000	20,000
Flux (lm/lamp)	25	200	1,000	1,500	1,200	3,400	36,000
Input Power (W/lamp)	1.3	2.7	6.7	7.5	75.0	40.0	400.0
Lamp Cost (in $/klm)	200.0	20.0	5.0	2.0	0.4	1.5	1.0
Lamp Cost (in $/lamp)	5.0	4.0	5.0	3.0	0.5	5.0	35.0
Color Rendering Index (CRI)	70	80	80	80	100	75	80
Derived Lamp Costs							
Capital Cost [$/Mlmh]	12.00	1.25	0.30	0.13	1.25	0.18	0.05
Operating Cost [$/Mlmh]	3.50	0.93	0.47	0.35	4.38	0.82	0.78
Ownership Cost [$/Mlmh]	15.50	2.18	0.77	0.48	5.63	1.00	0.83

Other opinions about how SSL will move into the general illumination market include:

- There is an overriding belief that SSL lighting will be embraced by the marketplace and that the roadmap approach still works. Funding R&D will affect how rapidly SSL penetrates the general illumination market (anywhere from 10–25 years). General concerns about market penetration, besides continuing with technological improvement of LEDs, include the need to:
    - develop concurrent approaches for effective infrastructure support for LEDs,
    - clarify general consumer values about SSL and how these will affect product acceptance and use,
    - develop a better interface between source developers and fixture manufacturers (a carryover from the current lighting industry), and
    - create major visibility for LEDs through demonstration projects.
- Some believe that general (especially U.S.) consumers do not value the capabilities of lighting and will not easily embrace SSL as a replacement for the Edison, screw-in-the-bulb system. They also perceive that business is entrenched with current lighting systems and retrofitting fluorescent lamps with SSL systems may be difficult. Subsequently, a better approach is to move market strategy toward aggressive penetration of niche markets where SSL capabilities provide a market advantage because of various attributes discussed previously. At the recent review of the SSL roadmapping strategy, a recommendation was made to focus market development efforts on mobile platforms (land, sea, and air vehicles)(Bergh 2003). In addition, even though CFLs have experienced performance

problems earlier, they now seem poised to provide better quality, more reliable, and energy-efficient lighting. Retrofitting much of the general illumination market with CFLs in addition to focusing SSL use in niche commercial and industrial applications could still attain the 50% energy consumption savings supported by roadmap goals. However, this approach would require some adjustment to the current roadmap.

- As stated earlier, standards for measuring attributes of conventional lighting sources, CRI and output in lumens, may not be relevant for SSL applications. Subsequently, current comparisons with conventional lighting sources may not make sense. This supports the fact that SSL is not the same as conventional technology and needs a fresh and creative approach. One example given is that though incandescent lights, by definition, have a CRI of 100 and are the unbeatable standard for other lighting, SSL—with a lower CRI—was considered to provide more favorable light in a study with consumers.
- The latest version of the roadmap (OIDA 2002) devotes some discussion to the need for better understanding and clarification of all the elements necessary to ensure SSL penetration of the general illumination market, including:
  - developing lighting system components for SSL: light engine chips, lamps, and luminaires;
  - integrating SSL into building architectures;
  - acquiring understanding of the physiological impact of SSL on the human visual system; and
  - balancing the goals of energy conservation with the reality of how people will actually use the technology.

Among these the roadmap acknowledges that "lighting systems are the ultimate vehicle for implementing solid-state lighting." In other words, effective lighting fixtures and support systems preclude market adoption.

The more primary success factor for general market adoption is consumer acceptance. Many market leaders realize that recognizing and responding to customer expectations is critical. What seems to be missing in all the discussion is an acknowledgement that understanding consumer values regarding the technology, as well as factoring these values into the design of lighting system products, will be required for market success.

In addition to understanding consumer values for SSL, it is also important to recognize where opportunities for general illumination market adoption might be. The *Buildings Energy Data Book* (DOE 2003) outlines current energy end-uses for commercial and residential buildings. In commercial buildings, the highest percentage of total annual lighting energy is for retail and service (24.8%), office (24.5%), and education (10.1%) applications. In addition, the annual lighting end-use intensity per total floor space (kWh/ft2) is highest for healthcare and food service applications. All of these applications are people-intensive sectors. Having a better understanding of end-user values for lighting in these situations is important.

In the residential market, for a $240,000 new single-family house, only 1% (or $2400) of the current cost is spent for lighting fixtures. Another 2% ($4800) goes into wiring. Acceptance for SSL in this market will require understanding more about consumer values and how to translate this into lighting awareness and demand. Most home renovations (for pre-1999 homes) include remodeling kitchens, bathrooms, and adding rooms. Finishing a basement and adding an interior bathroom are key renovations for homes built after 1999. Determining how consumers might value SSL regarding these types of renovations might support greater general market acceptance.

4. SUPPLY-CHAIN ANALYSIS

Market adoption of SSL for general illumination requires an understanding of the supply chain. Recent developments in the SSL industry and what these developments suggest for the emergence of product supply chains in support of an energy-efficient *residential lighting* sector are discussed, including.

- industrial processes,
- key supply-chain members ,
- supply chains and supply-chain management strategies, and
- DOE's role in advancing this transition-to-market process.

4.1 PRINCIPAL SUPPLY-CHAIN PROCESSES

Supplying these complex lighting products to the residential market will involve numerous players (Appendix C lists most of the key players) and steps in product development, manufacturing, and distribution. Delivering SSL lighting for general illumination to residences will involve a wide variety of technologies and the industries that develop them. The product of interest here is not just a device or fixture but a lighting environment (OIDA 2001, 2002). The major processes and products required for successful, market-supported SSL technology are:

- Fabrication of basic materials from which SSL devices are constructed, including construction of
  - the light-emitting components of LEDs and OLEDs—the semiconducting dies (chips) and light-emitting phosphors and polymers;
  - the electrically insulating substrates on which these are placed; and
  - the encapsulants required to connect the two.
- Packaging of these devices to produce "lamps" of one form or another, including fabricating the
  - power connections and drivers to control current flow;
  - illumination-grade and heat-sinking mounting materials;
  - reflectors, diffusers, and lenses;
  - luminaires or housings for these lamp assemblies; and
  - dimmers and other, notably digital, lighting controls.
- Any other, principally aesthetic, additions of lighting fixtures used in residential illumination.
- Storage and transportation of goods between these basic materials suppliers, SSL packagers such as lighting fixture original-equipment manufacturers (OEMs), and their retail and wholesale distributors.
- Delivery of SSL products to residences, either through wholesaler delivery to building sites, pickup of lighting products by residents and builders/developers from local retail outlets, or through regional or local delivery of Internet-ordered products.

General purpose, white-light-based LED and OLED technology is still very much in the development stage. As suggested earlier, the biggest payoff for the SSL industry will come through the development of cost-effective white-light devices with sufficient brightness to compete on a cost basis with current incandescent and fluorescent general lighting technologies. SSL technology appears poised to enter the current $40 billion worldwide market for general-purpose lighting. Within the U.S. portion of this market (about one-third of the worldwide total), residential illumination represents about 27% of primary energy use, suggesting a $4 billion to $5 billion annual market for residential lighting products. Of the $40 billion worldwide lighting market, it is estimated that only about one-third is spent on producing the lamp (i.e., that portion of the lighting device that contains the light emitters). The remaining two-thirds are spent on luminaires (the lamp housings), drive-electronics, and lighting-specific architectural features. As digital lighting controls become more popular and widespread, and as OLED-based lighting shapes and fixture options in particular evolve as replacements of current fluorescent lighting, the aesthetic components of SSL lighting technology are likely to play a significant role in both market adoption and, eventually, in the formation of new and increasingly customer-driven supply chains.

4.2 KEY SUPPLY-CHAIN MEMBERS

The supply chain for delivery of general purpose residential SSL is likely to be influenced by recent and anticipated market successes in the broader area of SSL innovation and adoption. The majority of SSL applications to date have involved colored light and what might be termed “niche markets” (mainly in the commercial sector) such as lighting displays for cell phones and cameras, larger colored-background lighting displays, indicator lighting for aircraft and automobiles, and message and warning lights.

Some of the “niche” lighting applications are now beginning to find their way into residences. For example, Color Kinetics, a Boston, Massachusetts-based company, holds a number of patents in the SSL field and markets a range of microprocessor-controlled “intelligent” LED products. On August 18, 2003, The Holmes Group, a $700-million-dollar, Milford, Massachusetts-based global manufacturer of room lighting and other consumer products announced an agreement to license Color Kinetics’ patented Chromacore® technology and expertise to develop a line of LED-based illumination products for residential use. With 57% of the U.S. lighting market associated with the commercial sector, both technical and business developments in the broader area of commercial, residential, and industrial building illumination are also likely to influence the how, when, and who in general residential lighting.

The current leaders in the lighting industry, notably General Electric, Osram Sylvania, and Philips, are likely to be key players in the use of SSL devices for general illumination. Among them, these multinational, multibillion dollar companies supply a large percentage of the U.S. residential lighting market with light bulbs, lighting installation components (e.g., ballasts) and industrial/commercial lighting fixtures. All three are among the many companies now developing and selling LED-based products, and all three have active semiconductor divisions that sell a variety of components as well as integrated semiconductor products. SSL technology represents one of the most successful new growth areas in the compound semiconductor industry. Because of their dominant influence on the general lighting market, these companies will be compelled to balance the consumer demand for SSL with their existing conventional market segments.

The biggest questions about SSL industry participation now are associated with the materials and component suppliers of these large lighting OEMs. Some of the world’s largest chemical companies, such as Dow and DuPont in the United States and Sumitomo in Japan, are now involved in SSL materials research and manufacture. The electronics industry should also be a major player by providing digital and other control devices for LED- and OLED-based lighting systems. While OLEDs are slightly behind LEDs in their development for the general lighting marketplace, considerable innovation as well as a wide variety of OLED-based products are expected. Currently DuPont, Samsung, Sony, IBM, Kodak, Lucent, and Philips are among the heavyweights already in this OLED manufacturing race. Dow is also involved in light-emitting polymer (LEP) development. Many smaller companies are also working on polymer technologies, including Cambridge Display Technology, Optronics, Opsys, and Universal Display.

Other key players will be the customers of these large lighting OEMs, notably the nation's large home appliance dealers and retailers, both large and small wholesale lighting fixture distributors, and retail lighting stores. These organizations are not currently well engaged with technology initiatives. (For a list of key players in the lighting industry, see Appendix C.)

4.3 SUPPLY-CHAIN MANAGEMENT AND INTEGRATION

Complex Supply Chains. Delivering SSL lighting systems for residential (as well as commercial and industrial) buildings is going to involve some very complex, multistep supply chains. As noted recently by Dallas, Texas-based i2 Technologies, working with Philips Semiconductors: "The semiconductor industry has one of the longest and most complex manufacturing processes in the entire business world." And semiconductors are, as described in Sect. 4.2 above, just one of a number of industries involved in the delivery of SSL lighting products.

Outsourcing, Horizontal, and Vertical Integration. Efficiently organized supply chains can save a great deal of money and help to reduce the cost of bringing complex products such as SSL lighting fixtures and systems to the marketplace. There is a good deal of vertical cooperation between the lighting industry's large OEMs and both their suppliers and downstream customers. A certain amount of horizontal integration may also be expected. For example, the Internet-based electronics business-to-business marketplace *lightxchange*, which started up in 2001, now boasts a membership consisting of 1621 lighting industry suppliers and 8 buyers, Philips, GE, and Osram Opto Semiconductors included. These large OEMs also offer their own Internet-based ordering and related support services to their customers.

What is not clear about these commercial SSL activities is just who will ultimately be responsible for each step in the basic manufacturing of LEDs, OLEDs, and the various supporting materials being offered by the large residential lighting OEMs (who themselves offer many different components and services to their own "OEM" clients).

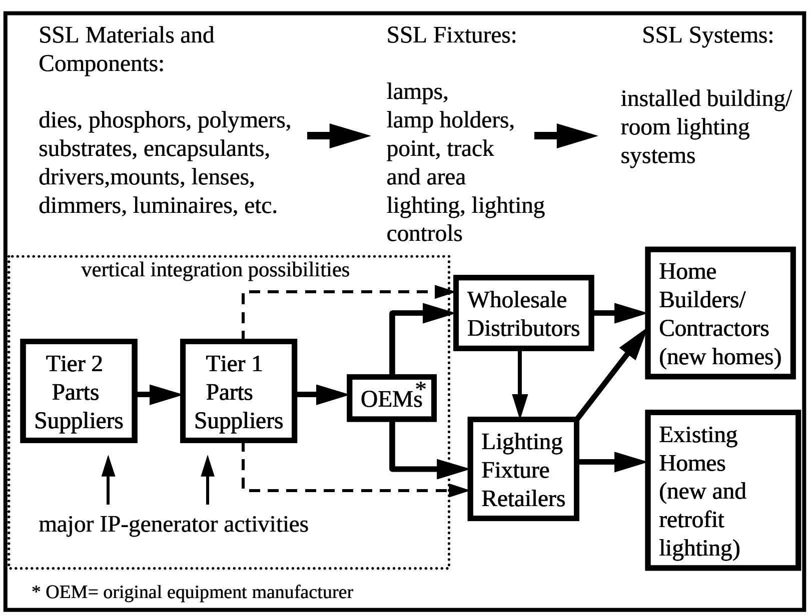

Fig. 2. High-level concept for an SSL supply chain.

Figure 2 shows a very high-level concept of an SSL supply chain. Production is represented here by SSL raw materials and parts developers, who supply large and small OEMs who in turn complete the integration of the light fixtures and distribute to wholesale and retail outlets around the country. The latter include the nation's major hardware, home appliance, and home furnishing chains, as well as more dedicated lighting stores and suppliers. It is unclear just how integrated the major lighting OEMs will become with their materials and parts suppliers, how much outsourcing will occur, and where each of the assembly tasks involved in creating complete LED- and OLED-based lighting fixtures will eventually take place. Philips, GE, and Osram Opto Semiconductors already have extensive and well-developed residential product storage and distribution channels in place. Alternatively, direct delivery of fully integrated SSL fixtures to retail outlets, from smaller and more specialized residential and/or commercial lighting product manufacturers, may also prove a viable commercial channel for many new SSL lighting products in the future.

How builders and homeowners might view these new lighting products is discussed elsewhere in this report. An important aspect of product supply will be the education and training process required for new lighting systems as well as fixture adoption, especially if SSL products become associated with concurrent advances in digital lighting control systems.

Recent technological advances in SSL appear to have initiated a good deal of inter-company activity. Within continued advances in light-emitting materials (e.g., improvements in LEPs and in epitaxial deposition), new companies, new collaborations, and new business units within existing companies are to be expected. The treatment of intellectual property associated with each advance is expected to play a part in how these alliances or mergers turn out for some of these recent business developments. The enormous promise of the SSL industry is creating multinational business alliances, with partnering between smaller companies with intellectual property in LED and OLED materials or control technologies, and larger chemical, electronic, and lighting OEMs. Example collaborations include the following:

- Cambridge Display Technology of the United Kingdom has sold manufacturing licenses for its LEP technology to Toshiba, Delta Optoelectronics, DuPont Displays, DNP, MicroEmissive Displays, Osram Opto Semiconductors, Philips, and Seiko-Epson. CDT has also crossed the Atlantic. Litrex Corporation is a wholly owned subsidiary of CDT located in Pleasanton, CA, with a focus on the development of ink jet deposition technology for LEP displays.
- In the United States, the semiconductor manufacturer Cree, Inc., of North Carolina recently received a large order for LEDs from Sumitomo Corp. of Japan.
- Among DuPont's partners are CDT and Universal Display Corp. for intellectual property; Covion and Dow for materials; Vitex for barrier films; and RiTdisplay for mass production.
- Dow has also developed working relationships with complementary companies such as CDT and with developers of electronic drivers and deposition technologies and material suppliers like H.C. Stark. Dow's direct customers are the display-cell fabricators and module manufacturers that use Dow LEDs in their OLED devices. The customers for these fabricators, in turn, are the OEMs that take advantage of OLED device technology to create complete lighting fixtures.

State agencies, utilities, and academia are also getting into the SSL act. For example, The Alliance for Solid-State Illumination Systems and Technologies (ASSIST) project is a collaboration of academic researchers, manufacturers, utilities, and government. Its goal is to facilitate broad adoption of LED technology by OEMs and product specifiers by helping to reduce major technical hurdles and identifying important applications for energy-efficient SSL technologies. Currently, ASSIST sponsors include GELcore (a joint venture of GE Lighting and Emcore Corporation); Lumileds Lighting; Osram Sylvania/Opto Semiconductors; Nichia America Corp.; Boeing; the California Energy Commission; and the New York State Energy Research and Development Authority.

In many industries today, including the electronics industry, OEMs are increasingly outsourcing core manufacturing operations and focusing on other strengths (such as brand marketing and R&D). The specialized suppliers of these OEMs in the electronics industry, for example, have seen exceptional annual growth in recent years, taking the opportunity to supply similar products to competing OEMs. A scan of the Internet suggests that this sort of specialization is also present in the general lighting industry, but with an as-yet-unclear relationship between a firm's size and a firm's role as a component supplier/OEM, and with some of the larger lighting companies acting as both.

More data are needed on the roles of each major company now involved in SSL development. Will the major lighting OEMs also become the major manufacturers of LEDs and OLEDs through expansion or acquisition? Or will they develop both intellectual property and materials supply agreements with independent suppliers of substrate materials, integrated semiconductors, and SSL equipment packagers? The supply chains linking the current lighting-industry OEMs, as well as the major electronics and residential appliance-supplying OEMs, to their major wholesale and retailer distributors are well established. Given this, the area warranting the most attention now is the link from these large OEMs back to their first- and second-tier suppliers. It should also be considered whether it is feasible that a number of medium- to large-sized companies currently focused on semiconductor development, chemicals, electronics, or optics could enter the market as major SSL OEMs.

4.4 POSSIBLE DOE ROLES IN MARKET DELIVERY

SSL R&D. One obvious role for DOE is as a facilitator for basic SSL R&D. The extent to which federal funding should be used to support this role is being discussed.

DOE–EERE has already initiated numerous ongoing collaborations in SSL R&D, notably through its Building Technologies Program. These collaborations involve various players from the private sector (including Cree Lighting, General Electric, Meadow River Enterprises, and Osram Sylvania); academia (including the University of California at Santa Barbara and San Diego, RPI, the New York State College of Ceramics at Alfred University, and Marshall University); and DOE's own national laboratories (including the National Renewable Energy Laboratory, Lawrence Berkeley Laboratory, Pacific Northwest National Laboratory, and Sandia National Laboratories). There have been a number of recent calls for a much larger national R&D program in SSL, including a call introduced to Congress in 2001 for a "Next-Generation Lighting Initiative" (NGLI) (see Appendix A). DOE–EERE collaboration with OIDA and NEMA on an SSL technology roadmap aims to bring LED- and OLED-based general illumination into the marketplace within a decade.

Intellectual Property in SSL Supply Chains. The role of intellectual property in the budding SSL industry is crucial to U.S. industrial success in this global market. We can expect a significant number of patents to be sought on breakthrough technologies employed at different stages in the SSL fixture construction process. In each case, the R&D roles played by federal government, universities, and privately operated laboratories is likely to remain of central importance for the next decade and beyond. Here, DOE's role in helping to foster private-public partnerships for the development of specific technological advances may be paramount. Possibly, transglobal alliances will be necessary to gain access to the latest in SSL technology. If so, what then are the most likely and profitable pathways for U.S.-based OEMs to gain access to the results of these R&D collaborations?

4.5 SUMMARY

Clearly, SSL's emerging entrance into the general illumination market is volatile and the future supply chain structure cannot be known at this time. The evolution of SSL might provide the catalyst to completely restructure the lighting industry. Though the top three lighting manufacturers will likely remain engaged, multiple opportunities exist for new players to enter the market to support needed innovation. Wholly new manufacturing technology associated with LEDs and OLEDs might enable mass customization approaches in local markets through integrated design-build-install operations. These operations could be franchised. This early development stage of the general SSL illumination market provides great opportunities for early engagement with end-use consumers to assess the most effective market sectors and approaches to product adoption. This consumer feedback could also influence future supply chain structure.

5. MARKETPLACE RELATIONSHIPS

Our review of the current technology roadmap, web-based and published literature, and presentations and papers from major conferences covering the SSL industry resulted in compilation of a list of key organizations and individuals affecting the future of SSL's market adoption (Appendix D). This list was used to conduct informal discussions with representatives from many of these companies and organizations (Appendix E), addressing their understanding of various market issues. Subjects discussed included consumer values and product attributes, market adoption, the role of government, and importance of branding for SSL. Many of these organizations maintain contact with one another through associations, such as IALD, NEMA, and OIDA; through developed partnerships, particularly between companies and specific laboratories or universities, or among companies and their various suppliers; and through mutual interest in the future of the SSL roadmap and the NGLI.

Many of these organizations, though not all, are aware of or participated recently in a NGLI Industry Alliance Technology Demonstration for members of Congress. In addition, many of them revisited the 2002 SSL Roadmap in November 2003. Most participants have no major expectations of changing the roadmap at this time. A few believe that the roadmap needs to be rewritten to reflect the diminished level of resources expected to be forthcoming from the government for this initiative. Many are concerned about technological competition from Asia (Japan, Taiwan, and Korea) and Europe and believe that the United States could lose its competitive edge in the SSL industry without committed government investment. Overall, participants define many areas outside the technology roadmap that need to be addressed to support market adoption of SSL in the general illumination market.

The perspectives of various players in the current supply chain are summarized below. Most of the discussion focused on LEDs, because these devices are more "market-ready." Only members of the R&D community had comments regarding OLEDs.

5.1 MANUFACTURING PERSPECTIVE

Representatives from most of the major LED manufacturers were included in these discussions. We also talked with two LED lighting fixture manufacturers.

Consumer Values. The primary focus for these manufacturers is on niche markets in the commercial and industrial arenas. These companies have conducted much analysis on viable market segments, but decline to discuss any findings other than generally. Most of this market information is not publicly available and is considered proprietary. There is general recognition that what is valued depends upon the actual market segment. Major segments include niche applications for outdoor, entertainment, industrial, retail, commercial (office and institutional), industrial, and residential. SSL is not yet able to provide sufficient lighting quality and efficacy for general residential and commercial illumination applications. The technological capabilities of LEDs as well as the infrastructure support needed to deploy LEDs through the current wiring, building, and lighting fixture design structures is not present. From the manufacturing perspective, the attributes consumers value for lighting include:

- Life cycle cost—overall cost, including purchase, longevity, maintenance, and efficiency. Most participants agreed that efficiency would not be a primary consumer benefit and would be more important to commercial than residential consumers. Cost elements may vary depending on the particular market segment. Residential consumers would be influenced more by first purchase cost than commercial or industrial consumers, whose first interest would be long life and efficient maintenance. Examples of applications with good payback for life-cycle cost include traffic signals, automotive instrument cluster lighting, and theatrical lighting.

- Quality (color consistency, low glare, and high illumination)—Some participants reported that general consumers are not very sophisticated in their appreciation of the benefits of light. Therefore their primary expectation is for lighting that has high quality (and is comparable to incandescent light sources). Special lighting effects will not be of interest to the general consumer.
- Durability (resilience to shock, temperature extremes, and vibration)—this is especially valuable for applications for mobile use (transportation) or in hazardous or remote environments. LEDs, because they emit less heat, will lend themselves to plastic over glass packaging. This will be valuable for automotive applications, resulting in safer parts and lower shipping costs.
- Color quality—LEDs provide better and brighter color appearance than other forms of lighting (colors appear purer and richer). This is especially valued in the entertainment industry and for outdoor lighting effects. For example, LED Christmas lights are starting to become popular.
- Programmability/Control—the ability to tune light, changing the color hue, temperature, etc., as well as being able to integrate lighting with other digital control devices and incorporate them with electronic circuits. LEDs can be controlled through the Internet or programmed to respond to a person entering a room and tailoring the light to that person's preference. A garage door opener could be set up to turn on lights. These capabilities show great promise. For example, Kevin Dowling, Color Kinetics, Inc., is already seeing demand for applications that mimic the passage of time to create light that varies in intensity and color temperature to correspond to human circadian rhythms. Other potential applications are suggested by Bill Kennedy, Toyoda Gosei, as follows: dialing in the right "white" light color to compensate for color blindness, preparing kindergarten children for their naps by changing the quality of the light, and producing an intrusion alarm whose sudden light doesn't rob the awakened homeowner of the ability to see in the dark. Though most participants believe that these potential applications will not be of interest to general users for a long time, they also indicate that these uses will drive general consumers into the SSL market.
- Safety—LEDs have low-heat emittance and require low voltage, thus are much safer than other lighting devices.
- Environmental friendliness—low UV transmission, energy efficiency, and no hazardous waste components. As a result, LEDs are good light sources for museums because they will not damage objects on display from UV or IR light.
- Compactness—small size allows devices to be integrated into building structures and surfaces and used in applications where conventional lighting sources will not fit.
- Ability to use off-grid sources of power, such as batteries, solar panels, or wind turbines—this is particularly useful for outdoor applications.
- Overall, when considering product attributes and consumer values, Keith Scott, Lumileds, summed up that the general illumination market would be driven by the convenience and "wow" factors of the new technology.

Market Adoption. All participants agreed that this technology would be adopted into the marketplace, first through industrial and commercial niche markets, and then gradually into the residential market for more specific lighting applications. The perceptions of general market penetration ranged from 10 to 25 years, depending on many factors. The market introduction of the CFL was cited as a "wake up call" for the industry to be more cognizant of consumer issues as well as the entire infrastructure needed for SSL to succeed. Although CFL was introduced more than 25 years ago, and market penetration, quality, and performance are all increasing (and cost is decreasing), consumers ***still*** express skepticism about its reliability. Therefore, it is important for the industry to effectively deliver SSL products that meet consumers' expectations for quality and reliability.

Other market adoption issues raised included:

The lack of sophisticated appreciation for lighting by U.S. consumers results in their tendency to over-light and value high brightness. Subsequently lighting is considered a commodity, rather than an aesthetic enhancement or art form. In contrast the European and Asian markets use lighting as part of the home décor and consider light fixtures as pieces of art. Because of the appreciation for more subtle and colored forms of lighting abroad, SSL is being adopted much more rapidly in overseas markets and can provide insight into how it could be adopted in the United States once consumers learn more about it. Nevertheless, the lack of U.S. consumer responsiveness does not encourage the lighting fixture industry to support development of fixtures for SSL applications.

- Forcing LEDs into current ways of thinking about lighting infrastructure and fixtures will sour consumers on the technology. SSL cannot compete within the system that has been designed around the Edison bulb. The industry needs to capitalize on the SSL's capabilities and design fresh, new infrastructure and applications that are appropriate for the technology.
- There needs to be standardization of the infrastructure so that consumers know how to use the technology. In addition, standardization of how products are connected and interchangeability of products from different companies needs to be explored. One company pointed out the difficulty of getting UL certification, resulting in a need to over-engineer the application to comply with incandescent light codes.
- A link between LED manufacturers and fixture manufacturers is needed to provide effective consumer solutions. Traditional lighting fixtures are not conducive to LEDs (the disconnect between CFLs and lighting fixtures has been pointed out here as well). Eric Kramer, Targetti, explains that in the LED market the fixture manufacturer becomes representative of both the fixture and the light. Product warranty becomes a big issue because LED manufacturers often only offer a 90-day warranty. Fixture manufacturers offer 1- to 5-year warranties on their fixtures. So there is a disconnect between the warranties of the various lamp components, resulting in lighting manufacturers taking on liability for possible LED failure. More lighting fixtures designed specifically for LEDs are now becoming available, particularly for commercial uses in indicator, step, decorative accent, and hospital night lighting, or other applications not easily accessible for regular maintenance. Lumileds has launched the Luxeon Lighting Network (http://www.lumileds.com/solutions/network.cfm), which certifies luminaire manufacturers who are demonstrating competence in design and manufacturing. The luminaires are then collectively promoted by the Lumileds and Network members to the specification and end-user community. It is a set of de-facto standards for the design and /building of high-power LED fixtures in the absence of any formal standards.
- Basic LED technology is developing faster than applications for it. More companies are still working on the diode dies than on the luminaires and other components needed to deliver a new lighting system. In addition, with the rapid changes in the technology, systems designers do not generally understand LEDs well enough to develop products that have quality and long life.
- Technical performance of base semiconductors needs to increase. LEDs need to produce more light. Consistent color and temperature are both factors, particularly with fixture manufacturers.

- Determining what electrical system is best for LEDs and how to get this into a home that needs higher voltage for appliances is an issue. Possibilities for systems might include supplying low-voltage power at the curb (via telephone lines), using autonomous power (solar, wind, batteries) for residential lighting, or having a 24-volt DC lighting circuit.
- Systems solutions need to be conceived that include the drive source, thermal management, and optics. The product will fail if the entire system is not correctly designed.
- Installation of SSL systems will require different skills than those of current lighting installers. These technicians do not react well to changes in technology. One manufacturer indicated that it took two years to understand how to put together circuits that produce good results in fixtures using LEDs.
- Demonstrations are needed to foster market penetration. Bill Ryan, Philips, offered that his company is building a small demonstration/experimental room to be lit by SSL. The room should be operational within a year. In addition to using the room to demonstrate SSL capabilities, Philips will have people come in and use the room for various purposes (such as work) for extended periods, then survey them to find out about their experience with light. Ryan emphasizes that Philips wants to know the effects that light will have on people before putting it on the market.
- LED manufacturers need to get input from fixture manufacturers early in the development process. Srinath Aanegolar, GELcore, explained that GE and GELcore are doing this using their 6Sigma process for identifying customer needs early in the design process.

Role of government. Most participants agree that both federal and state government needs to support research and development to improve materials and processes for SSL. Of particular emphasis is the need to invest in analysis and modeling to determine the infrastructure needed to make the transition to widespread use of LEDs. Another consistent issue is that investment is needed to ensure U.S. technological competitiveness with Asia and Europe, particularly since these countries are 1 to 2 years ahead of the U. S. in adopting and using new lighting. Most breakthroughs in semiconductors and optoelectronics have occurred in Japan, where the government invests heavily in technological development. One participant mentioned that U.S. companies making LEDs for traffic signals are being hurt by Taiwanese companies that are importing unpatented LEDs. California, for example, is buying these imports. On the other hand, California’s Title 24, mandating energy efficiency, is perceived as creating opportunities for SSL.

Other suggested roles for government include:

- Extending the current approach of furthering market adoption in specific applications (rebate programs for changing to LEDs in traffic lights) to more general illumination applications.
- Providing tax incentives (tax credits, accelerated depreciation, etc.) to companies that adopt SSL.
- Offering research grants and incentives to develop specific applications (such as creating warm, low-luminance task lighting). This will help get more attractive products on the market.
- Using SSL lighting in government facilities.
- Sponsoring and developing demonstration spaces and exhibits.
- Evaluating the attributes of SSL to find out what consumers want from the technology, with emphasis on specific segments (baby boomers, “20-somethings,” etc.).

- Taking a total system perspective beyond just the technical development, including ways to tailor light for use in spaces.
- Promoting education and awareness about capabilities and benefits of SSL.
- Developing a common vocabulary (with organizations like NEMA) and commonality of components (heat sink, power supply technology, etc.).
- Providing rebates to end users through their utility companies

Other specific suggestions are discussed below.

Bill Kennedy (Toyada Gosei) suggested that the government should help convene a committee to work out the infrastructure changes needed to support SSL. This committee should bring together all the major stakeholders, including DOE, DOT, OSHA, NIST, state organizations, utilities, and lighting and industrial associations to decide how best to adopt SSL technology. Mr. Kennedy's opinions of the key issues that need to be addressed include:

- standardizing some initial formats so that they could be designed and produced in high volume for cost-efficiency purposes;
- getting fixture manufacturers to design fixtures so they function as heat sinks;
- getting utilities to supply 12-volt or 24-volt power at the curb;
- getting support for wind and solar power supplies;
- establishing appropriate standards, codes, qualifications, and testing methodologies applicable to SSL; and
- studying the psychophysical merits/phenomena of LED monochromatic and white lighting technologies with an eye toward improving the quality of life.

As an example of what government can do to support development of SSL technology, Brent York (TIR) cited the $6.6 million (of an overall $22.7 million SSL Enabling Technology Research Program) from the Canadian Federal Government under its Technology Partnerships Program. The Canadian government's investment pays for approximately a third of the overall research spending for SSL.

It might be valuable to evaluate the theory that the eye's perception of color is dominated by colors at three specific wavelengths, and if possible, specify the wavelengths on which to concentrate. If this theory could be proven, the costs of producing LEDs with pleasing light quality could be cut dramatically

Branding. Most participants agreed that branding is important for the mainstream lighting community. For many people having a fixture available from a well-known company can overcome resistance to new technology. Srinath Aanegola (Gelcore) indicated that both the GE brand and Energy Star labeling have helped in adoption of LEDs for traffic signals. Bill Ryan (Philips) pointed out that some of the key players in the adoption of a new lighting technology (OEMs, designers, architects, etc.) are slow to incorporate new technologies into their projects and more likely to accept a technology based on brand recognition. One participant noted that the industry has mixed opinions about Energy Star labeling. He gave an example of some poorly performing CFLs imported from China that had Energy Star labels. Nevertheless, Kevin Dowling (Color Kinetics) thinks that certification-type branding such as Energy Star is useful because when an architect or lighting designer specifies a product, they are looking for an edge, which this labeling could provide.

5.2 Research and Development Perspective

Representatives from key national laboratories, universities, and industrial R&D were contacted to discuss their perspectives on marketplace adoption of SSL.

Key technology issues. Participants are involved in a range of research to improve LEDs and OLEDs. Work on LEDs includes efficiency improvement, phosphor development, chip design, packaging, light output, sizing, materials issues, and systems issues. The manufacturers suggested no mention of work with OLEDs. However, research on OLEDs includes efficiency, light output, and packaging (such as use in wall-to-wall sheets). OLEDs are bendable. Current applications are focused on display lighting (screens).

Consumer values. All participants were highly aware of the importance of consumer values in having an impact on product development and availability. Some suggested that though consumer values have been discussed at the SSL roadmapping session, there is little research going on in this area at this time. In addition to the attributes discussed previously by the manufacturers, R&D participants pointed out the following:

- LEDs are a much greener technology. They use no mercury or other hazardous materials that create problems for disposal. Their small size and long life result in a reduction in waste. Their energy efficiency translates into lower demand for fossil-fuel based electricity generation with its associated effects (CO_2, acid rain).
- LEDs could produce much “healthier light” than conventional sources (better spectral composition). Some research shows that spectral composition of light has influence on circadian rhythms and sense of well being. Other research suggests that inappropriate light can lead to breast cancer (G. Brainerd at Thomas Jefferson University, PA).
- Standards currently used for measuring light quality for conventional lighting may not be appropriate for SSL. Nadarajah Narendran, RPI, pointed out some technical issues involving use of the measures CRI and LPW. He suggests that the color-rendering index (CRI) may not be a good measure for evaluating light quality. For example, incandescents have a CRI of 100—a perfect CRI. However, tests asking human subjects to express their preferences actually resulted in their choosing LEDs for illuminating objects over other sources, including incandescents. People in the lighting industry are beginning to look at “color gamut” instead of CRI. In addition, he suggests that the lumens-per-watt output of a lamp, which is used to express efficiency, ignores the specific function or application for which the light is being used. For example, the Lighting Research Center discovered that the fluorescent lights commonly used in freezer display cases in super markets are inefficient because so much energy is used to overcome the cold temperature. LED fixtures, which are unaffected by cold, can illuminate the display case with one-third the lumens of fluorescents and produce a brighter, more uniform display at the same time.
- Advantages of LEDs may not be realized until the technology is in widespread use. For instance, Fred Schubert (RPI) pointed out that after LEDs were chosen for automotive brake lights because of their longevity, it was discovered that they might have slightly faster turn-on time that provides a marginal safety benefit. He adds, “With emerging technologies, we must be prepared for positive surprises.”

Market Adoption. Most of the research and development participants offered that LED technical performance needs to improve in several areas, including efficiency, advances in phosphors to get full-spectrum color conversion, materials to achieve longer life, and better packaging. From a systems perspective, some method of dissipating heat needs to be incorporated into the fixture.

Other ideas for market adoption include:

- There is a need to address the gap between makers of the light sources and luminaire manufacturers. While the light producers are highly technical, the luminaire people are interested in lighting values, operating conditions, and applications. At this point, the luminaire manufacturers are not as fully engaged because of the expense of the technology. The gap will close as it becomes apparent how they can make money.
- More studies are needed on the impact of light on human productivity and activity, including the variability and control offered by SSL. This involves human factors and psychology. There is a need to quantify the impact of specific light colors, intensity, etc., on productivity.
- The cost of LED lamps is the primary barrier to market success. U.S. consumers look at the cost of lighting, not at its value. If the public's mentality from concentration on cost to concentration on value can be changed, the SSL market may be able to succeed. The marketing focus must be on the things SSL can do that standard lighting technologies cannot.

Role of Government. All participants agree that funding to develop the technology and building commonality of standards (possibly by working through agencies such as NIST, OIDA, or IEEE) would help SSL succeed. Another important role is to support demonstration of potential general illumination applications of SSL within niche markets as a basis of educating consumers about the values and benefits provided by SSL.

Other specific roles include:

- Developing an energy-efficiency rating for lighting similar to that used on appliances.
- Providing more support for integrating SSL into the lighting industry. For example, the California Energy Commission is starting programs on how LEDs will work in fixtures.
- Encouraging the development of other supporting industries for LED development (such as those that create materials for thermoconductivity).
- Finding out what people want from light and how to meet those needs with available technology.
- Supporting a Sematech-like organization in LEDs/optoelectronics to keep optoelectronics manufacturing in the United States strong.

Branding. Many of the participants were concerned about the performance integrity of the Energy Star label (mixed results with CFLs and certification of inferior products). To be effective, it needs to correspond effectively with the evolution and improvement of the technology. The Energy Star certification should be made more stringent to provide incentive for the technology to improve. It could provide standardization in measurement of efficiency and ensure quality and consistency of the information manufacturers provide to consumers. Name brands can be effective in helping consumers accept new technology products. The Underwriters Laboratories (UL) label would also be valuable.

5.3 ASSOCIATIONS AND OTHER INTERMEDIARIES

Contact with members of this group was somewhat limited. Discussions were held with architects and trade association representatives.

Consumer values. All participants agreed that SSL was not currently appealing for general illumination. It was suggested that incandescents are better for general illumination and that development of SSL will take another 20–25 years. Comparing incandescent lamps and LEDs suggests that incandescents are compatible with the existing infrastructure (AC current), high CRI, and heat dissipation ability.

CFLs are also becoming more attractive, providing better color, long life, and energy efficiency. However, the appeal of SSL is with general illumination applications within the commercial and industrial market niches. Key market niches (based on the same attributes discussed previously by manufacturers) as viewed by these participants include:

- Entertainment sector—gaming, sports, retail, shopping centers and graphic signage (based on attributes described by manufacturers);
- Mobile platforms—illumination for cars, boats, airplanes, etc.; and
- High-end architectural applications, including integration into building materials.

Architect Sheila Kennedy suggested that SSL presents an opportunity to integrate lighting and information technology. LEDs can be programmed to transmit and react to information, providing an intelligent organization of light. One example is using LEDs essentially as pixels, such as in the NASDAQ display. One potential residential application would be to incorporate LEDs into kitchen cabinets and appliances to show heat levels and other information.

Market adoption. These participants focused primarily on the barriers to adoption of SSL for general illumination. These include:

- Fixture design will need to adopt to current existing wiring, since buildings won't be rewired to accommodate SSL.
- The lighting industry is an entrenched marketplace. There is a need to define what the process of market introduction for SSL will be (marketing and sales infrastructure, shipping issues, consumer complaints).
- Cost for lighting designers, although a barrier, will not be insurmountable. Consumers will be attracted to more expensive lighting if life-cycle cost is good and if lighting meets a specific need.
- Consumers will not benefit from the attributes of LEDs for a long time.

Role of government. All participants agreed that the government should provide various forms of funding, such as providing a "kick start" to companies with market interest in SSL. This would help to develop more consumer awareness through public demonstrations of the technology, support R&D to sustain technological competition in the United States, and give tax incentives for sustainable buildings that include SSL solutions. Other suggested roles include:

- Serving as a catalyst to smaller firms that are making progress with SSL. This is in response to the dominance of a few lighting firms that have a market interest in sustaining incandescent and fluorescent technology market share.
- Encouraging the big companies to commit to a percentage of SSL products by a certain date.
- Encouraging people and companies to pursue off-grid power, such as solar and wind, which are well suited for LED applications.
- Providing training sessions for building designers.

Branding. Consumers value corporate branding. A manufacturer with name recognition supports greater public trust in adopting new technology. Al Borden, IALD, suggests that "Energy Star is hardly seen at all, except on some consumer products, but LEED is huge." LEED certification is awarded by the Green Buildings Council, an organization with established goals, methodologies, and standards for promoting sustainable architecture. They provide training and certification for all types of designers and engineers involved in the building industry.

5.4 Implications for Moving SSL into the General Illumination Marketplace

As indicated earlier, most key marketplace players are focused on niche applications in the commercial and industrial markets rather than applications that would support general illumination in both commercial and residential sectors. Many are exploring potential general illumination applications tangentially to other business pursuits. Information about this market analysis is not available publicly and is considered proprietary by these players.

Consumer Values. Most of the key players mention life-cycle cost and color quality as the major variables for general market adoption of SSL. Nevertheless, SSL has several unique attributes, particularly programmability, compactness, durability, and safety that can support commercial and residential applications now for both indoor and outdoor lighting. Based on current commercial lighting use, developing appropriate applications for retail, office, education, healthcare and food services would offer opportunity for greater SSL market penetration. For residential applications, focusing on applications for kitchens, bathrooms, and basement refinishing would offer an entrée into using SSL. Outdoor lighting applications are another important venue. Overall, advantages of LEDs may not be realized until their use becomes more widespread.

Market Adoption. A general concern expressed for market adoption of SSL is the perceived lack of consumer value for lighting capabilities, particularly in the United States. Because most consumers consider lighting a commodity, the sophisticated capabilities of SSL may not be fully appreciated. This perception also correlates with the major gaps between the makers of light sources and those making light fixtures. The lighting fixture companies need to become more engaged with supporting solutions to market SSL applications.

Role of Government. Most of the key players equate the role of government with technology development, the major thrust of the current roadmap, as well as leveraging the relationships among the players to ensure that the technology gains wider use. Some other suggestions for accelerating general market adoption included:

- providing incentives for developing specific applications geared to the generic market,
- finding out what consumers really want from the technology,
- encouraging the development of supporting industries for SSL,
- supporting the integration of SSL into the lighting fixture industry, and
- serving as a catalyst to small firms making progress with SSL.

An overview of the suggested roles of government compared with the perceived technical and market barriers are listed in Table 6.

Table 6. Roles Of Government (as Indicated by Major Market Players) In Overcoming Barriers to SSL Market Adoption	
Barrier	**Possible Role of Government**
LEDs—Technical Issues	
Heat management within the lighting fixture may limit LED applications (e.g., replacement of incandescent bulbs)	Fund research into (1) materials that can most effectively absorb/dissipate heat generated by LEDs (2) ways to increase light output of LEDs so fewer are needed to produce a given luminance level
Light output needs to improve to at least 40-50 l/w, preferably to 100 l/w	Fund research into ways to increase light output of LEDs
Purchase price needs to be much lower (a function of light output)	Fund research into ways to increase light output of LEDs. Provide rebates and other incentives to reduce purchase price
Variations in LED dies as they come off production line results in inconsistency in color of white light and reduces light output ratings	Fund materials science research to reduce defects in dies
Better semiconductor designs needed to achieve non-traditional applications	Research funding for semiconductors and optics
Need for higher quality white light from LEDs; may involve developing better phosphors	Support research in improved phosphors. Research grants to develop specific applications (e.g., warm, low-luminance lighting)
Advances are needed in optics and packaging to get more light out of the LED package	Research funding for semiconductors and optics
General Lighting Industry—Market Issues	
Traditional fixture manufacturers lack the knowledge and skills to design fixtures for LEDs; they are uninterested in learning until demand for LEDs increases.	
Need for solid design and engineering of SSL applications to avoid reputation for failure	
Need for some standardization of components (e.g., drive sources, thermal packaging, optics)	Put together a committee to work out needed infrastructure changes. Developing a common vocabulary and commonality of components
Need for some standardization in how products are connected together and interchangeability between products of different manufacturers.	Put together a committee to work out needed infrastructure changes. Developing a common vocabulary and commonality of components
Installers don't react well to changes in technology	
To succeed in retrofit market, need LED device that screws in to replace incandescent bulb. This involves solving significant heat absorption problems	Fund research into materials that can most effectively absorb/dissipate heat generated by LEDs
Issues Involving Electrical Infrastructure	
Lack of standardized infrastructure for SSL will be confusing to consumers	Sponsor a committee to work out needed infrastructure changes
Appropriate power supply infrastructure for LEDs needs to be determined and a plan developed for getting this infrastructure into place	Sponsor a committee to work out needed infrastructure changes
Need for lighting/electrical codes that make sense for SSL	

Issues Involving Consumer Knowledge and Expectations	
Avoid exaggerated claims regarding the capabilities of SSL	
Need to change U.S. consumers' concentration on cost of lighting to concentration on value of lighting	Expand Sandia's excellent website to include OLEDs and make it widely available Develop an energy rating system for lighting similar to that for appliances Demonstrations that educate consumers about SSL benefits in light quality and life-cycle cost Fund development of demonstration projects targeting high-visibility cultural and commercial locations Research funding for how light impacts human productivity and activity Education and awareness about energy Research into specifics of how the eye perceives color (3 specific wavelengths) Research to find out what consumers want from the technology
Need for interesting products—showcase LED attributes	
Other Recommendations for Government Actions to Accelerate Market Penetration of SSL	
	Establish standards for lighting quality
	Give tax incentives to companies that adopt SSL
	Use SSL in government facilities

Branding. Most players agree that brand recognition will accelerate adoption of SSL applications, particularly when associated with a well-known company. The use of Energy Star labeling is seen as mostly positive, though issues with labeling potentially unreliable CFL products with Energy Star has created some doubt about this factor. One suggestion was to integrate SSL with LEED certification.

6. CONCLUSIONS

As the first truly new lighting technology in at least 50 years, SSL offers tremendous potential to reduce energy consumption, but more importantly represents great opportunity to use light to enhance the quality of human life though innovation in general illumination. As has been suggested throughout this study, SSL is here to stay. What is unclear is how rapidly the technology will be able to penetrate the general illumination market where its greatest benefits may be realized. The success of market adoption will depend largely on how consumers' values and expectations about lighting compel them to use this new technology. In addition, the potential capabilities of SSL must drive consumers to shift from Edison-based lighting systems to electronic ones. The future of SSL will evolve not by replacing conventional lights in their sockets, but by creating a new lighting paradigm.

EERE has produced an SSL roadmap that inspires the endeavors of and provides a uniform strategy for many of the key market players in the lighting industry. Most of the participants believe that SSL's penetration into the general illumination market will happen initially through niche applications [transportation (all mobile platforms, including land, sea, and air vehicles), entertainment and display lighting, outdoor lighting], with significant further adoption through general applications within 10 to 25 years. They believe a crucial factor influencing timing for general market adoption is to be able to make a significant investment in U.S. technology development to improve LEDs and OLEDs so they can successfully compete in cost and lighting output with conventional incandescent and fluorescent sources. Subsequently, the push for the NGLI near-term technology funding investment is tremendous. Major market players have been exploring approaches to enter the general illumination market tangentially to their primary focus on niches. This information is considered proprietary and is not publicly available. With the focus on technology development at this stage, there is very limited discussion about the consumer's role in making SSL happen. Important conclusions include:

- Significant market penetration will be required if SSL is to achieve its potential for reducing national energy consumption through general illumination applications. This penetration will depend largely on how consumers' expectations and values about lighting compel them the adopt it. SSL has many of the capabilities valued by consumers for conventional lighting. Most importantly, SSL has unique attributes that will create new consumer values and expectations. Gaining greater understanding of consumers' values for SSL and translating these into available products will provide more effective market adoption.
- Key market players have conducted extensive characterization for SSL within niche lighting markets, but limited market analysis for general illumination purposes. Public availability of these types of analyses is almost nonexistent, since most of this information is considered proprietary. Most market assessment for general illumination purposes is speculative. More studies of consumers' reactions to general illumination applications are needed.
- The ineffective adoption of CFL technology is cited as a "lessons learned" for the SSL market. Continued resistance to CFL products results from product attributes not meeting consumer values and expectations. It behooves market players to continue to assess consumers' values for lighting, understand their needs, and then translate these into products consumers will buy.
- Lighting design is considered one of the most promising vehicles for using SSL capabilities. Nevertheless the combination of U.S. consumers' lack of value for sophisticated lighting applications and the resistance of lighting fixture manufacturers to provide appealing consumer products needs to be considered.

- The general illumination market is volatile and emerging. It provides great opportunities for early engagement with end consumers to assess market sectors and approaches to product adoption. Though the top three lighting manufacturers must be engaged, opportunities need to be available for new players to enter the market.
- There is no consensus on how SSL will be adopted into the general illumination market. Some believe that once consumers better understand the benefits of SSL in terms of flexibility, quality, and performance, they will be eager to use this source of lighting. These observers believe that market penetration will be extensive and fairly rapid. Others believe that consumers do not really value lighting, wanting only a system that can be switched on with a minimum of thought to provide lighting adequate for general uses. In this scenario, consumers will not respond well to having to retrofit the existing simple, screw-in-the-bulb system. If this scenario is reality, the best approach to market adoption for SSL will be to concentrate on the niches within the lighting industry where the technology attributes provide the most cost benefit. These niches include mobile applications (transportation), retail display and entertainment, and outdoor lighting. The wide range of opinion around consumer acceptance of this technology points out a need to fully understand what consumers will value about this technology and how they will use it. Carefully designed studies are needed to clarify the many assumptions being made about how consumers will respond to SSL technology.
- The SSL roadmap provides a uniform strategy among key partners for technology development. Many other factors need to be addressed concurrently for effective market adoption. Infrastructure changes needed to support transition to LED/OLED lighting have not been systematically examined. In addition, the application of lighting to human well-being is perceived to be a key benefit of SSL. The Light Right Consortium has initiated studies on lighting and human productivity. More work in these areas is needed.

As implied in the above discussion about the technology road map, other critical success factors for general market adoption include:

- Understanding the expectations of consumers for this technology. This includes ensuring that products will perform as explained (which may require that companies undersell their products as the technology evolves) and helping consumers understand how the technology can benefit them. Greater understanding is needed of consumers' values for specific lighting applications and how consumers will use SSL products. In addition, consumers need to be informed about the impact of the new lighting paradigm that will be required to use SSL. Several aspects of SSL will be very different from traditional lighting, including:
    - fixtures and powering,
    - heat management at the lighting source,
    - color standards including ideal colors for various applications,
    - definition of light source end of life (tolerable degradation in brightness), and
    - energy savings.
- Offering a viable lighting source that can compare favorably in lighting output, price, lifetime, and lighting color and quality with a 100-watt incandescent lamp. [Currently, this translates into the following parameters: a 1600-lumen light output attainable under 16 watts, price under $3.00, a lifetime (with 20% loss of original light output) of over 10,000 hours, and a CRI greater than 80 over the lifetime of the source (Bergh, 2004).]
- Ensuring that all members of the supply chain are fully engaged in the process of moving to a new lighting technology. As the study of the supply chain indicates, this is a semiconductor

process (already one of the most complex of all manufacturing processes) added to the lighting industry. To add to the complexity, this is only one of numerous other industries involved in the delivery of SSL products. Currently, though there are still primary companies engaged, the market entertains the involvement of new players.

- Engaging the lighting fixture manufacturers and lighting distributors with SSL through the roadmapping process.
- Focusing on development of the infrastructure (electrical system, drive sources, thermal management, optics, etc.) needed to support SSL sources. This includes developing new approaches to transitioning away from the conventional lighting infrastructure and developing flexible standards that can adapt to an evolving technology.
- Understanding how the various attributes of SSL can be used to improve human performance or enhance human well being. Several studies have indicated that lighting has profound effect on human behavior and health. The capabilities of this technology may enhance the ways in which lighting can be used for human welfare.
- Supporting widespread and public demonstrations of how the technology can be used as the most effective way to inform the general consumer of SSL attributes.

To support SSL for general illumination, EERE has an important and strategic role to:

- Assemble and create strategic alliances of key partners to support national solutions in market adoption. It is also important to consider effective ways to create global alliances in the deployment of SSL.
- Invest in technology development to support the U.S. competitive edge with Europe and Asia.
- Sponsor research and development in understanding SSL infrastructure and human factors issues, as well as studies supporting consumer values and effective product development.
- Promote education and awareness about SSL, particularly through demonstrations and the development of an integrating information website.
- Support an industry-wide effort to identify and develop an appropriate level of standardization for SSL products and infrastructure and to prepare model electrical codes pertinent to SSL applications.
- Develop a more appropriate evaluation system for comparing SSL with conventional lighting. CRI and luminous efficacy is not always appropriate for SSL applications.
- Be a catalyst to support smaller firms with the potential to achieve technological breakthroughs that will support the marketability of SSL.

Corporate brand recognition is perceived as a positive influence for general consumer market adoption because of the association with public trust. The use of Energy Star labeling received mixed reactions, with comments about lack of performance for “Energy Star-labeled CFLs.” Others perceived Energy Star labeling as giving a product “an edge” in the marketplace. The UL rating was also considered important. In the buildings industry, association with LEED certification is considered a positive factor. Linking SSL with LEED might be helpful.

Overall, there is a tremendous amount of enthusiasm and excitement about moving forward with this technology. As one discussion participant suggested, “We need to capitalize on the high level of enthusiasm for moving ahead with this technology.” This will provide the impetus for the creative breakthroughs required for successful adoption of SSL.

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APPENDIX A. FURTHER INFORMATION ABOUT SOLID-STATE LIGHTING

A1. OVERVIEW OF SSL TECHNOLOGY

LEDs consist of semiconductor chips impregnated with impurities that create a positive/negative junction. When voltage is applied to the device, the flow of current across the junction results in the release of photons, producing light. LEDs were invented in the early 1960s. Because of the low level of light they initially produced, LEDs were used primarily for indicator lights, watches, and calculators. Interestingly, the watch displays required a button-push to be activated, and the calculators had a shroud so the display could be seen. Later, lower-power LCDs displaced LEDs in those applications. Recently, however, great advances have been made in the quantity of light LEDs can produce, and LEDs are being used for more diverse purposes. Because of their small size and the intensity of the light they produce, LEDs are functionally similar to incandescent bulbs (DOE and OIDA 2001). They are best suited for point-source light applications such as spotlights, traffic lights, light filaments, and projection lamps (Duclos 2003).

An OLED consists of a semiconducting, carbon-based film sandwiched between two electrodes, one of which is transparent. When voltage is applied to the electrodes, current flows through the film causing it to release light emitted from the device through the transparent electrode. OLEDs can be extremely thin, with a total thickness comparable to wallpaper. OLEDs were discovered much later than LEDs and their development is much less advanced. Since they are much larger than LEDs and the light they produce is less intense, OLEDs are suitable for diffuse lighting applications similar to those currently filled by fluorescent lamps [Duclos 2003, DOE and OIDA 2001, Johnson (undated)].

The production of light through these processes is extremely energy efficient because, theoretically, all the energy goes toward generating light with little heat production. SSL devices produce some heat because of impurities in the materials used. In reality, present LED arrays have to be carefully cooled, sometimes by blowers combined with heat sinks, to keep them operating. As LED efficiency increases, the heat released is expected to decrease. This is a great hope for the future development of LED capabilities, when LED arrays might be thought of as “cool.” (Cates 2003)

The actual materials used in LEDs are not pure semiconductors but are instead compound semiconductors made up of elements such as aluminum, indium, gallium, and others. Such compounds include AlGaInP (aluminum, indium, gallium phosphide) and AlGaInN (gallium nitride), which are the primary materials for red and blue/green LEDs, respectively.

Several technological issues need to be addressed in the process of introducing SSL for general illumination applications:

- An improved understanding of the physics of AlGaInP and AlGaInN compound semiconductor materials and nanostructures
- Improved optoelectronic devices for high-photon generation and extraction efficiency
- Improved wavelength-conversion color-mixing technologies for generation of white light
- Improved packaging technologies for high power
- New lighting fixtures and systems based on the unique ways in which people can interact with SSL

- Development of the science and technology foundation for high-volume, low-cost manufacturing (Sandia 2003)

Most of these are integrated into the technology roadmap strategy.

A2. Government Funding and Legislation for SSL

The U.S. government already has several scattered R&D initiatives that benefit HB LEDs, either directly or indirectly. The most notable is at Sandia National Laboratories, which spent $2.3 million in 2002 on several projects, according to Jerry Simmons, manager of Sandia's semiconductor physics department. There are also modest R&D programs covering various aspects relevant to SSL at the Defense Advanced Research Projects Agency, the Office of Naval Research, and at Lawrence Berkeley National Laboratory.

Although the U.S. government has invested the most so far in SSL R&D, there are also government-funded efforts in Japan, Korea, Taiwan and Europe. All these initiatives are aimed at LEDs since OLED as a lighting source has not yet been demonstrated. The Japan Research and Development Center of Metals and the New Energy and Industrial Technology Development Organization are the two agencies administering Japan's government effort, "Light for the 21st Century." It concentrates on bright UV LEDs. Europe's activities include scattered projects in industry and academia, some with funding from the European Union, and many focusing on substrates suitable for use with gallium nitride (GaN) LEDs (IEEE Spectrum 2002).

Next Generation Lighting Initiative Act. Introduced in January 2003, the Next Generation Lighting Initiative Act (Bill # S.167) was sponsored by Senator Jeff Bingaman (D-NM). His state includes Sandia National Laboratories, which has an SSL program and would directly benefit from the legislation. The bill directs the Secretary of Energy to implement

- the Next Generation Lighting Initiative to support research, development, demonstration, and commercial application activities related to advanced SSL technologies based on white-light-emitting diodes;
- fundamental research activities of the Initiative through a private consortium (which may include private firms, trade associations and institutions of higher education) selected through a competitive process; and
- development, demonstration, and commercial application activities of the Initiative through awards to private firms, trade associations, and institutions of higher education.

The bill, cosponsored by Senator Mike DeWine (R-OH), has been referred to the Committee on Energy and Natural Resources (Congress.org 2003).

Overall, the Act authorizes $50,000,000 annually for FY 2008 through FY 2012 to support research, development, demonstration, and commercial-application activities related to advanced SSL technologies based on white-light-emitting diodes to:

- develop (by 2012) advanced SSL technologies based on white-light-emitting diodes that, compared to incandescent and fluorescent lighting technologies, are longer lasting, more energy-efficient, and cost-competitive;
- develop an inorganic, white-light-emitting diode with an efficiency of 160 LPW and a 10-year lifetime; and
- develop an organic, white-light-emitting diode with an efficiency of 100 LPW with a 5-year lifetime.

The Act states that, "The Next Generation Lighting Initiative shall engender an annual operating plan which shall include research priorities, technical milestones, and plans for technology transfer, and shall be carried out through a private consortium (which may include private firms, trade associations, and institutions of higher education). National laboratories may participate in the research and may receive funds from the consortium."

Energy Bill and SSL. House Science Committee Chairman Sherwood Boehlert (R-NY) and Ranking Member Ralph Hall (D-TX) introduced H.R.238, a comprehensive energy R&D package. The bill includes all the R&D language agreed to by the House and Senate conferees in last year's comprehensive energy bill, H.R.4. The legislation includes several new energy sections, including a Next Generation Lighting Initiative to help industry develop energy-saving and more flexible SSL. All told, the bill authorizes more than $30 billion in R&D programs, including those run by DOE's Office of Science. The Energy Bill passed the Senate on July 31, 2003.

A3. REASSESSMENT OF SLL ROADMAP

The SSL roadmaps (OIDA 2001, OIDA 2002) are based on the assumption that a $1 billion cooperative R&D program between industry and government will exist over 10 years, commencing in 2002 and leading to several scientific breakthroughs in SSL. Expectations for government funding were based on the authorization bill introduced into the Senate (S.1166) on July 11, 2001, and later passed in both the Senate and the House (HR4 Sec.1213) in 2002. The outcome of this legislation, however, is still uncertain and the available R&D funds to support SSL are only a small fraction of the anticipated $50 million/year.

Based on continuing funding uncertainties, as well as greater understanding of the issues facing introduction of SLL for general lighting applications, Arpad Bergh, President of OIDA, indicates that several assumptions in the current roadmap need updating as follows (Bergh 2004):

- The efficiency figures cited in this roadmap ignore losses from converting the 110 Volt ac to 3.5 Volt dc required for the SSL sources (estimated loss ~20%). Similar losses for fluorescent lamps are included in the published LPW performance.

- The goal of achieving 200 LPW performance (without losses for voltage-down conversion) was based on high-efficiency RGB light sources with over 50% external quantum efficiency. The efficiency in the green is still too low, and the aging characteristics and temperature dependence of the RGB LEDs are different. It is impractical to assume high-efficiency, low-cost RGB light sources without major technological breakthroughs, such as those anticipated from accelerated R&D funding. This is consistent with the LED-performance goals of national programs in Japan, Korea, Taiwan, and China, which are based on blue or UV LEDs with phosphor wavelength converters and future efficiency targets of 80–130 LPW, as opposed to the original U.S. target of 200 LPW.

- The emergence of CFLs to replace incandescent lamps was not considered in the roadmap for projecting future energy savings and market penetration. CFLs can replace incandescent lamps in conventional sockets and cut 75% of the energy consumption of incandescent bulbs. LEDs, however, need heat sinks because they dissipate heat by conduction (not through radiation like incandescent lamps).

- Progress is measured by scientific terms, like lumens per Watt, and not by commercially meaningful parameters such as a 1600-lumen light output attainable under 16 watts, price under $3.00, a lifetime (with 20% loss of original light output) of over 10,000 hours, and a CRI greater than 80 over the lifetime of the source)

- The lack of performance or end-of-life standards for solid-state lights needs to be addressed.
- Currently, there is no government funding to maintain U.S. leadership in source technology.

A3. Research and Development Trends

Quantum Dot Technology. Researchers at DOE's Sandia National Laboratories have developed the first solid-state white-light-emitting device using quantum dots. In the future, the use of quantum dots as light-emitting phosphors may represent a major application of nanotechnology. The approach is based on encapsulating semiconductor quantum dots—nanoparticles approximately one billionth of a meter in size—and engineering their surfaces so they efficiently emit visible light when excited by near- UV LEDs. The quantum dots strongly absorb light in the near-UV range and re-emit visible light that has its color determined by both their size and surface chemistry.

This nanophosphor-based device is quite different from an alternative approach based upon growth of blue-, green-, and red-emitting semiconductor materials that requires careful mixing of those primary colors to produce white illumination. Efficiently extracting all three colors in such a device requires costly chip designs, which likely cannot compete with conventional fluorescent lighting but can be attractive for more specialized lighting applications. For the quantum dots to be used for lighting, they must be encapsulated, usually in epoxy or silicone.

To date, Sandia's quantum-dot devices have largely been composed of the semiconductor material cadmium sulfide. Because cadmium is a toxic heavy metal similar to lead, alternative nanophosphor materials are desired. Fortunately, other types of materials can be used, including nontoxic nanosize silicon or germanium semiconductors with light-emitting ions like manganese on the quantum-dot surface.

Besides investigating the use of quantum dots as phosphors as part of an internally funded research project, researchers are also using a grant from the DOE Office of Building Technologies for a collaborative project with Lumileds Lighting, a joint venture between Agilent Technologies and Philips Lighting. In this project, researchers are helping Lumileds measure quantum efficiency of light emission from various types of dots (Europe Intelligence Wire 2003).

Blue LED Plus Phosphor Technology. One problem common in white-light LED devices is the "halo effect" where an observer from the side sees multi-colored, not white, light. Typically this is caused by a drop of phosphor "globbed" onto the top of the blue chip. Because the thickness of the phosphor varies, we see rings of blue, yellow, and white. Another problem is that a limited amount of blue light is absorbed by the phosphor. Long-term research is necessary to identify new phosphors with strong absorption of the blue spectrum. In 2002, Lumileds implemented a new phosphor-coating process, similar to electroplating, in which the chip is coated very evenly with yellow phosphor. The result is a uniform emission of white light.

A Method to Predict Life of Phosphor-Converted White-Light LEDs. Presently when a white LED lighting system is created it is hard to say how long the system will last. One way is to measure the system's light output over time and determine the point at which the light level drops below the specified value—a time-consuming process. Alternatively, if the system life can be estimated by measuring certain optical properties, it would shorten the time. LRC researchers are developing a methodology that can be used for rapidly estimating the useful life of white LED systems (Lighting Research Center 2003).

Increasing the Size of LEDs. LED chip size factors into the amount of light delivered—the bigger the chip, the more light. Pursuit of a bigger LED has been a focus of the work at Durham, North Carolina-based Cree, which makes some of the brightest blue LEDs on the market. Last year Cree introduced an LED chip measuring 900 by 900 micrometers. It provides nine times the light-emitting surface area of the 300- by 300-micrometer chips that had been the industry standard. This expansion yields a simpler and less costly device. Lumileds is also developing larger chips and was able to deliver one of the world's brightest white-light LEDs: a five-watt device that puts out as much light as a 10-watt incandescent bulb. The Lumileds Luxeon was developed several years ago and continues to use a standard chip size of 1-mm square (1000 micrometer × 1000 micrometer) (MIT Technology Review 2003). A larger die does not necessarily guarantee higher efficacies or lower costs. The manufacturers have jumped from fractional-watt to 1-watt packages and above, but the jump in price of the electronics required to drive such devices is not proportional. There is a "sweet spot" at around 150-mA drive currents that actually makes equivalent light output less, not more, expensive. In addition, larger dies exacerbate thermal issues. There needs to be more examination of these issues from a system perspective.

Recent DOE Developments. Efforts to develop building and lighting architectures that could, at a system level, exploit the unique characteristics of SSL, while still appealing at a consumer level to human ergonomics, are already underway (e.g., RPI's LRC, Lawrence Berkeley's Lighting Systems Research Group, and other efforts connected to DOE's Office of Building Technologies, State and Community Programs). These efforts need to be expanded.

The RPI LRC is working in conjunction with the University of California at Santa Barbara to develop a highly efficient SSL system for general illumination. Dr. Shuji Nakamura, who developed the world's first GaN LED, is leading the University's team in working on a semiconducting laser-light source that is more efficient than traditional LEDs. The LRC team, led by Dr. N. Narendran, director of research, will focus on three main areas: human factors studies to define specifications for the new light source, development of suitable epoxy materials to encapsulate the semiconductor element, and integration of the device with optics and electronic controls to develop energy-efficient lighting systems for general illumination applications.

APPENDIX B. CFL: COMPARISON WITH OTHER CONVENTIONAL LIGHTING TECHNOLOGIES AND CONSUMER ACCEPTANCE

B.1 COMPARING CFL WITH OTHER CONVENTIONAL LIGHTING TECHNOLOGIES

CFLs have long dominated the consumer market in both Europe and Asia. Because of consumer resistance, market conversion has been much slower in the United States, where incandescent lamps have dominated the residential lighting market for years and still do today (International Rectifier 2001.) Incandescent lamps dominate the unit sales of lamps with more than three-fourths of the U.S. market. Other lamp types with significant market shares of unit sales include specialty (14%), fluorescent (5%), and halogen (3%) lamps. The market shares of CFLs in California more than tripled from the fourth quarter of 2000 to the first quarter of 2001 (1.2% to 3.8%). This continued in the second quarter 2001 when the market shares of CFLs rose to 8.4%. This increase coincides with California's 2001 "energy crisis," in which rolling blackouts occurred (California Lamp Trends 2001.) Growth in unit sales of CFLs has not been uniform across all types of CFLs, but has been strongly concentrated in 14- to 18-watt bulbs (equivalent to 60-watt incandescent).

Halogen bulb sales have also grown due to heavy promotion by manufacturers. These products are likely competing with CFLs for the attention of consumers willing to try alternatives to standard incandescent light bulbs (California Lamp Trends 2001).

B.2 CONSUMER ACCEPTANCE OF CFLS

Understanding the reasons behind U.S. consumers' resistance towards CFL technology is beneficial when assessing the market adoption of SSL. Primary reasons consumers resist CFLs include:

- Higher price than incandescent sources—the lower operating costs of CFLs have so far failed to overcome consumer resistance to higher purchase prices. The major cost of lighting is the electricity that powers the light bulb. Lighting cost as a percentage of the electric bill averages about 9.5%–15.4% for consumer residential end users and 12.7%–17.6% for commercial end users. Measured in terms of efficacy or LPW, incandescent light bulbs produce 14–18 LPW and CFLs produce 60–105 LPW. Incandescent bulbs last between 750–1000 hours depending on wattage. CFLs average 10,000 hours of life. The bottom line is that CFLs use approximately 75% less electricity and last 10–14 times longer than their incandescent counterparts do. The first CFLs in the marketplace retailed at well over $20, even in high kilowatt-per-hour markets. The payback point for CFL bulbs versus incandescent was often several years. Now that the cost of CFLs is decreasing through volume production and utility-funded rebates and subsidies, the payback is shorter and more attractive to consumers. In addition, DOE's interest and participation is helping to increase consumer awareness about the benefits of using CFLs instead of incandescent bulbs. The price for a CFL bulb averages $13.00 with an expected life of 10,000 hours. On the other hand, an incandescent bulb is $.50 with an expected life of 750 hours. Electricity charge is equal to $.06/kWh. If you operated the CFL in the above scenario for 4 hours per day, the expected life of that lamp is 7 years, with a payback of 2.5 years when compared to an incandescent lamp.

- Low capability for dimming control—The CFLs available today cannot be safely operated on standard dimming circuits. The dimmer must be replaced by a standard switch before compact fluorescents can be installed. Dimmable compact fluorescent bulbs were recently introduced on the market, but require special controls.

- Incompatibility with existing fixtures—Some compact fluorescent bulbs may be longer than traditional incandescents are because they need a ballast and because of the unusual lamp shape (long, folded tubes).
- Limitations in outdoor lighting applications—While compact fluorescents function efficiently in an enclosed heated space, most are not designed to operate outdoors or in cold indoor temperatures. Typically, electronically ballasted compact fluorescents work better in colder temperatures.
- Delayed startup—Even under ideal operating conditions, bulbs with magnetic ballasts may take a second or two to turn on, and may flicker initially. Electronically ballasted units will come on instantly, with no flicker. Also, compact fluorescent bulbs may require two to three minutes to achieve full light output.
- Lower color rendition—An improvement over earlier CFLs, the latest compact fluorescent lamps have improved color rendition. The light is a warm tone that is almost identical to that of an incandescent lamp. Most people cannot tell the difference.

B.3 RESIDENTIAL CFL MARKET

According to DOE's Energy Information Administration (EIA) report, "87% of the 523 million lights used in residential households are incandescent, and only 9% of households use CFLs." The EIA report goes on to say "By replacing most incandescent light bulbs with compact fluorescents, American homes would save 31.7 billion kilowatt hours of electricity annually, which is enough to light about 1/3 of all U.S. households for an entire year." It has been suggested that achieving lighting-energy conservation goals can be a certainty *today*, not just a possibility in the future, if the government subsidized the lease program for CFLs rather than the SSL program, which has more formidable technological barriers to overcome, not to mention marketplace penetration (*Physics Today* 2003).

All major bulb manufacturers have a line of compact fluorescents. Their availability has greatly improved over the last few years. Compact fluorescents are available at home improvement, grocery, and department stores as well as at commercial light bulb supply outlets. Home improvement stores play a dominant role in efficient lighting sales, especially in California. This is not surprising given the heavy focus on these stores by that state's lighting programs. However, grocery stores still sell a substantial percentage of incandescent bulbs and might be a useful channel in which to explore additional CFL sales opportunities.

After successfully introducing 16 new subcompact fluorescent lamps (sub-CFLs) into the market, and facilitating the sale of more than 3 million sub-CFLs, DOE's Subcompact Fluorescent Lamp Program has been discontinued. Elements of the program, however, have been assumed by the Northwest Energy Efficiency Alliance, a nonprofit organization that seeks to bring about significant and lasting changes in markets for energy-efficient technologies and practices, improve the region's efficient use of energy, and reduce long-term costs to consumers and the electric system. The Northwest Energy Efficiency Alliance has launched a new program to promote sales of sub-CFLs to retailers. BetterBulbsDirect.com, part of the Northwest Energy Efficiency Alliance's Northwest Energy Star Residential Lighting Program, is the retailer's resource for buying and promoting energy-saving, high-performance sub-CFLs.

B.4 IMPACT OF ENERGY STAR LABELING ON CFLS

The Energy Star label identifies products where large gains in energy efficiency and potential pollution reduction can be realized cost-effectively and where the label can play an influential role to expand the market for these products. Energy Star would like to take the CFL program to the next level. Beyond the foundational standard of producing and offering high-quality, efficient CFLs, it is essential to streamline the program to make accessing qualified products easier for the utilities, lighting distributors, retailers, and consumers. DOE has begun the revision process of the current Energy Star specification for CFLs with input from stakeholders. On April 29, 2003, DOE held an Energy Star CFL Criteria Meeting at DOE Headquarters in Washington, D.C., to discuss the second revision of the CFL criteria specification. This meeting was an opportunity for Energy Star CFL partners and industry stakeholders to discuss the suggested revisions and additions to the current criteria for CFLs and discuss other potential additions to the specification.

Energy Star CFL partners and stakeholders include:

- CE Lighting of North America
- Conglom, Inc.
- Consortium for Energy Efficiency
- Dash Lighting
- Feit Electric
- Greenlite Lighting Corporation
- Idaho Power
- Intertek Testing Services
- Lighting Research Center (LRC)
- MAXLITE
- National Electrical Manufacturers Association
- Natural Resources Defense Council
- Osram Foshan Lighting Co. Ltd.
- Roberts Research and Consulting
- Technical Consumer Products, Inc.
- Westinghouse Lighting Corporation

B.5 LESSONS FOR SSL ADOPTION

Though CFLs have proven far more efficient and long lasting than incandescent bulbs, continued consumer resistance indicates the challenges and opportunities that may be faced in the general illumination market adoption of solid-state technology. General consumers have resisted CFL technology primarily because they do not perceive that benefits outweigh costs. What consumers value about incandescent lighting has not been translated yet into attributes of CFLs. Disadvantages of CFLs include inconsistent performance (dimming, delayed startup, color rendition) and poor adaptation to lighting fixtures (bulb and ballast issues). CFLs do not perform well outdoors. General market adoption of SSL will encounter these same issues. Therefore, it behooves market players to continue to assess consumer values for lighting technologies, understand consumer needs for using this technology, and introduce the technology into the market in ways that support these factors. Cost and benefit continue to be drivers for consumer decisions. Consumers must perceive the advantages of solid-state technology attributes as meeting their specific market needs.

CFL market adoption has benefited from government development and incentives. Energy Star labeling appears to have enabled support for the product (although some of our key participants expressed skepticism about the credibility of Energy Star labeling for some CFL products). SSL could also benefit from some of these approaches.

APPENDIX C. KEY MARKET PLAYERS IN SOLID-STATE LIGHTING

A review of the business literature provides the following list of key players in the marketplace.

C1. MANUFACTURERS

Advance Transformer Company
Division of Penac
10275 W. Higgins Rd.
Rosemont, IL 60018-5603
(847) 390-5000
http://www.advancetransformer.com

Agilent Technologies
395 Page Mill Rd.
PO Box 10395
Palo Alto, CA 94303
(650) 752-5000
(877) 424-4536
Fax: (650) 752 5300
http://www.semiconductor.agilent.com/

Product developments: Agilent has developed an intelligent light sensor for use in adjusting the brightness of LEDs used in display backlighting. A leading manufacturer of scientific instruments and analysis equipment, Agilent is the primary supplier of electronic test and measurement products, including data generators, multimeters, and oscilloscopes. The company also makes an array of semiconductor products, such as LEDs, optoelectronic components, and RF chipsets. Agilent's test and measurement unit accounts for more than half of the company's revenue.

Agilent has made serious job cuts and reduced salaries to control costs, and in 2001, the company sold its health care business (patient monitoring and other clinical measurement and diagnostic equipment) to Philips Electronics. The company is also outsourcing more of its production, and moving manufacturing operations to Asia in an effort to further lower costs. Agilent is depending on its strength in R&D of new products to drive its business and maintain its market leadership.

AXT, Inc.
4281 Technology Dr.
Fremont, CA 94538
510-683-5900
Fax: 510-683-5901
http://www.axt.com

AXT LED TECHNOLOGIES (AXT-LED TECHNOLOGY IS A DIVISION OF AXT, INC.)
2019 Saturn Street
Monterey Park, CA 91754.
(323) 278-0820
Fax: (323) 838-0653
http://www.axt.com/

AXT makes semiconductor substrates from compounds such as gallium arsenide (GaAs) and indium phosphide (InP), and from single elements such as germanium. Manufacturers use AXT's substrates to make high-performance chips for products—including cell phones, fiber-optic devices, and satellite solar cells—for which standard silicon chips are not adequate. AXTI manufactures and distributes high-performance compound semiconductor substrates, as well as optoelectronic semiconductor devices, such as high-brightness LEDs, and vertical cavity surface-emitting lasers (VCSELs). The company has announced plans to discontinue its unprofitable optoelectronics product lines. AXT said it could not estimate the gain or loss for discontinuing the optoelectronics operations, as it is still reviewing its options. That includes spinning off the division, possibly in a joint venture, the sale of some or all of the division's assets, or liquidation. Optoelectronics accounted for 29% of the company's 2002 sales and 18.3 million in 2002 sales. (Hoovers 2003)

AXT claims that Cree Inc.'s lawsuit alleging infringement of a patent regarding LEDs is without merit and plans to defend itself vigorously (Dow Jones Business News 2003).

Citizen Electronics
Headquarters/Main Plant
1-23-1, Kamikurechi Fujiyoshida-shi Yamanashi-ken 403-0001, Japan
(81)555-23-4121
Fax(81)555-24-2426
http://www.c-e.co.jp/e/home.html

Citizen Electronics was founded in 1970 as a joint venture between the Japanese firm Citizen Watch Co., Ltd. and the United States' Bulova Watch Company, Inc. Twenty years ago, Citizen launched its CITILED chip LED; 14 years later, it developed the CL-280 series chip, then the world smallest; and 2 years later, the multi-color LED chip. Since 2000, Citizen has developed an LED backlight unit for color liquid crystal displays (LCDs); the world's first pastel-color LEDs; 18 types of white LEDs for color LCD backlights; and the CITILIGHT Series, white LED lamps for cellular phones with a camera.

Color Kinetics, Inc.
10 Milk St., Ste. 1100
Boston, MA 02108
(888) 385-5742
http://www.colorkinetics.com

Color Kinetics is the pioneer in intelligent LED illumination. Color Kinetics designs, manufactures, and markets an award-winning line of products that apply the practical and aesthetic benefits of LEDs for use in professional lighting, OEM and licensing, and consumer applications. Its flagship line of technologies take advantage of a patented layer of digital intelligence, called Chromacore®, to generate and control millions of colors and dynamic lighting effects. Products include architectural lighting fixtures, lighting systems, lamp replacements, controllers, user interfaces, playback units, authoring software and more.

Color Kinetics pioneered the systems-based approach to integrating and controlling LEDs as a highly efficient, long lasting, environmentally friendly, and inherently intelligent source of illumination. The company's proven technology is used worldwide in thousands of sophisticated commercial lighting systems, residential and consumer products, and third-party lighting solutions that exhibit both the cost efficiency and visual impact of LEDs as a fast-growing alternative to conventional illumination methods. Customers include Brookstone, Disney, Ernst & Young, Hairspray on Broadway, Harrah's, Marriott, New York State Bridge Authority, NBA Entertainment, Northwest Airlines, Saks Fifth Avenue, and Wheel of Fortune.

Color Kinetics' investment in research and development is reflected by its far-reaching intellectual property portfolio, which today includes 20 issued U.S. and international patents and well over 100 patents pending covering a range of solid-state lighting technologies and applications. Founded in 1997 by George Mueller and Dr. Ihor Lys, Color Kinetics is headquartered in Boston, MA with worldwide distribution, offices in the Netherlands and China, and a joint venture in Japan.

Corning Incorporated
Display Technologies
HP-AB-03-4
Corning, NY 14831 United States
Tel: +1 607-974-5439
Fax: +1 607-974-7097
http://www.corning.com

Cree Lighting Company
Subsidiary of Cree, Inc.
340 Storke Rd.
Goleta, CA 93117
(805) 968-9460
http://www.cree.com/

Cree develops and manufactures semiconductor materials and devices based on silicon carbide (SiC), gallium nitride (GaN), silicon (Si) and related compounds. The company's products include blue-, green-, and ultraviolet- (UV-) LEDs, near-UV lasers, radio frequency (RF) and microwave devices, power-switching devices and SiC wafers sold for production and use in R&D. Targeted applications for these products include SSL, optical storage, wireless infrastructure, and power switching.

Dialight Corporation
1501 Route 34 South
Farmingdale, NJ 07727
(732) 919-3119
http://www.dialight.com

Eastman Kodak
Dr. James C. Stoffel
CTO, Director of Worldwide R&D and
Senior Vice-President, Eastman Kodak Company
Kodak Research Laboratories
1999 Lake Avenue
Rochester, New York 14650
http://www.kodak.com/US/en/corp/researchDevelopment/worldwide/rochester.shtml

GE
http://www.gelighting.com

One of the General Electric Company's major businesses, GE Lighting is headquartered in Cleveland, Ohio. A leader in lamp technology, manufacturing and marketing in the global lighting industry, GE Lighting has operations in North America, South America, Europe and Asia. Today, the company manufactures approximately 7,000 various lamp products for commercial, industrial and consumer markets.

GELcore
http://www.gelcore.com
GELcore LLC
6180 Halle Dr.
Valley View, OH 44125
216-606-6555
http://www.gelcore.com

GELcore—a joint venture of **GE Lighting** and **EMCORE** Corporation—is dedicated to advancing the world of LED technology through superior engineering and customer service. By combining the lighting industry knowledge, brand recognition and global reach of GE with the compound semiconductor expertise of EMCORE, GELcore has set the stage to change the world of lighting as we know it.

Traffic signals, signs, automotive and specialty applications will never be the same. GELcore advances the application of LED technology and creates world-class LED systems by combining superior engineering in electronics, optics, mechanicals and thermal management. And the unique GELcore customer management system is designed to build strong long-term relationships with LED specifiers and product application engineers --- through truly attentive customer service. GELcore is also pushing forward in the White Light Power package LED category with its advanced near-UV-based power package technology and the launch of a new higher-quality white LED.

Hess America
PO Box 430
Shelby, NC 28151
(704) 471 - 2211
Fax: (704) 471–2255
http://www.hessamerica.com

Hess America, a stateside affiliate of Hess from Germany, introduced the Millenio, the first pole light using LEDs as the source. This product, along with many in the Hess line, is ideal for use in theme parks as well as malls, walkways, etc. The housing is comprised of two parallel, slender aluminum sections reminiscent of a tuning fork. Each section houses 450 LEDs and a specially designed teardrop lens.

Honeywell, Inc.
Honeywell Plaza
PO Box 52
Minneapolis, MN 55408
Phone: 800-328-5111
http://www.honeywell.com

Lumileds Lighting, LLC
370 W. Trimble Rd.
San Jose, CA 95131
Phone: (408) 435-6855
http://www.lumileds.com
CEO: Mike Holt
Contact: George Craford
www.lumileds.com

Lumileds makes HB LEDs and LED dice. The company's products are designed for automotive, display, and general lighting applications. Lumileds recently released a warm white version of its HB Luxeon LED that features a correlated color temperature in the 3200-K range, a typical color-rendering index of 85+, and an average light output of 22 lumens (see p. 11).

Lumileds, a joint venture between Agilent Technologies and Philips Lighting, is the world's leading manufacturer of high-power LEDs and a pioneer in the use of SSL solutions for everyday purposes including general lighting, automotive lighting, traffic signaling, signage, and LCD backlighting. The company's patented Luxeon Power Light Sources are the first to combine the brightness of conventional lighting with the small footprint, long life and other advantages of LEDs. Lumileds also supplies core LED material and LED packaging, manufacturing billions of LEDs annually.

Lumileds is in the forefront of SSL technology with its Luxeon family of LED light sources. The Luxeon 5-watt is the world's brightest LED, providing 120 lumens of light output per LED or a brightness equivalent to that of a 10-watt incandescent bulb. This output is up to 60 times greater than that of competitive devices, greatly expanding the kinds of light fixtures that can use LED lamps and making LED light sources a practical illumination alternative for the first time.

MoonCell, Inc.
PO Box 3068
Stafford, Virginia 22555-3068
(877) 396-3142
Fax Number: (413) 403-6100
http://www.mooncellusa.com/

MoonCell Inc. is a manufacturer of energy efficient SSL products and integrated wind and solar renewable energy products.

Nichia
491 Oka, Kaminaka-Cho, Anan-Shi, Tokushima 774-8601, Japan
(81) 884-22-2311
Fax: (81) 884-21-0148
American Subsidiary Locations: Lancaster, Detroit
President: Eiji Ogawa
http://www.nichia.co.jp

Products: Phosphors for CRT, Lamp and X-ray, LEDs, laser diodes, optical semiconductor devices, fine chemicals (electronics materials, pharmaceutical materials, food additives), evaporation materials, battery materials, magnetic materials. Nichia was established in Japan in 1956 to manufacture calcium phosphate used in the production of fluorescent lamp phosphors. Since that time, Nichia has grown in the field of manufacturing and sales of fine chemicals, particularly inorganic luminescent materials (phosphors), high brightness InGaN LEDs, and InGaN laser diodes. Nichia is headquartered in Anan, Tokushima, Japan and has operations throughout the world, including Nichia America Corporation, a U.S. subsidiary based in Mountville, Pennsylvania.

Nichia is the world's largest LED manufacturer and the first to commercialize HB indium gallium nitride (InGaN) LEDs, including blue InGaN LEDs that remain critical to the overall development of SSL. The company also pioneered white LEDs in 1996 by covering a blue light-emitting InGaN die with a thin coat of YAG (yttrium, aluminum, and garnet) yellow phosphor, which is still considered the simplest and most practical method. Nichia has patent cross-licensing agreements for LED technology with Cree, Lumileds, and Osram.

NorLux Corporation
A Subsidiary of Uniroyal Technology Corporation
575 Randy Road
Carol Stream, IL 60188
877.894.2697
http://www.norluxcorp.com/

Products: LEDs
NorLux Corp. specializes in the design and manufacture of custom LED lighting solutions and applications. As a solutions company, NorLux partners with OEMs, distributors, architects, engineers and designers to design and build LED applications.

OSRAM Opto Semiconductors Inc.
3870 North First St.
San Jose, CA 95134
Phone: 408-456-4040
http://www.osram-os.com

OSRAM Opto Semiconductors Inc. is one of the world's largest makers of lighting products. It makes lamps (including Sylvania- and Osram-branded products) for consumer and commercial use. The company also makes lamp-related products (ballasts, fixtures) as well as LEDs. In addition to lighting products, the U.S.-based Osram Sylvania also makes consumer electronics such as televisions.

Among the new products at Osram Opto Semiconductors are the Metalarc Powerball Ceramic 150-W 3000-K lamp that combines energy efficiency with high color rendering (CRI 89); Linex mercury-free linear lamp systems for entertainment, studio, and architectural lighting, especially in extreme temperature situations or when rapid lamp switching and critical color are needed; the Linearlight Colormix LED dimmable system, used in conjunction with the Optotronic LED power supply to provide dynamic control of color-changing LED modules with 30 surface-mounted LEDs; the patent-pending HPR 575/115 high-performance reflector tungsten halogen lamp, the newest member of the family of lamps for theatrical, concert, and architectural applications. Osram Opto Semiconductors' new Octron 28W T8 Supersaver Ecologic won the fluorescent category in Lightfair's New Product Showcase.

Philips Lighting Company
P. O. Box 6800
200 Franklin Square Drive
Somerset, NJ 08875-6800
Phone: 732-563-3039
http://www.lighting.philips.com/nam

Philips Lighting, a division of the Netherlands-based Koninklijke Philips Electronics, the primary household light bulb maker in the world, makes lights for nearly every application. The division has four primary segments: automotive lighting, lamps (fluorescent and incandescent lights, mercury vapor and sodium lamps, and other types of light bulbs), lighting electronics, and gear (ballasts and other fixtures) and luminaires (lighting devices). Philips Lighting has also begun to focus on lighting digital data projection, infrared lighting, theatre lighting, and ultraviolet lights (to disinfect air and water).

Toyoda Gosei
1, Nagahata, Ochiai
Haruhi-machi
Nishi-Kasugai gun, Aichi 452-8564, Japan
(81) 52 400 5131
Fax: (81) 52 409 7491
http://www.toyoda-gosei.com/

Uniroyal Technology Corporation
575 Randy Rd.
Carol Stream, IL 60188
Phone: 630-784-7500
http://www.norluxcorp.com

Uniroyal Technology, now in Chapter 11 bankruptcy protection, spent the last several years selling off assets to focus on HB LEDs used in traffic signals, signs, and autos. The LED market, however, has not shined as brightly as Uniroyal Technology expected, and, cash-strapped, it filed for bankruptcy protection in 2002. Most of the company's sales actually come from producing Naugahyde, a vinyl-coated fabric used as an alternative to leather, and that business might be sold. A $200 million company in the late 1990s, Uniroyal Technology now banks less than $10 million a year.

In 1999 the company predicted that high-brightness LEDs would grow to $150 million in company sales by about 2004, so it sold off slow-growth business such as plastics and acrylic windows to focus on LEDs. In addition, Uniroyal Technology has long planned to sell its "cash-cow" Naugahyde business, though that sale might be stalled as the company reorganizes. The company sold its Sterling Semiconductor unit to Dow Corning for roughly $11 million.

Complicating its cash and debt woes, Uniroyal Technology has to contend with EPA liabilities and shareholder lawsuits.

Universal Display Corporation
Contact: Mike Hack
375 Phillips Boulevard
Ewing, N.J. 087618
www.universaldisplay.com

Universal Lighting Technologies
26 Century Blvd., Ste. 6000
Nashville, TN 37229-0159
Phone: 615-316-5100
http://www.universalballast.com

Sales Range: $50 million to $75 million
President: Pat Sullivan

C2. LIGHTING FIXTURE DESIGNERS AND MANUFACTURERS

OptiLED
16662 Hale Avenue
Irvine, California 92606
http://www.optiled.biz/

OptiLED is a manufacturer, designer and direct supplier of high-intensity, super-bright LED lamps for general lighting purposes. Their range of products include residential, landscape, designer, commercial, and architectural lighting.

Color Kinetics Incorporated
10 Milk Street, Suite 1100
Boston, MA 02108 USA
http://colorkinetics.com

Color Kinetics has received its fifth U.S. patent (#6,292,901), "Smartjuice" intelligent power technology. This patented technology encompasses methods and systems for multiplexing power and data over conventional wiring, allowing for control of intelligent digital light fixtures. The technology can be found in the company's Juice Box product, which is used to enable advanced control of the company's iColor MR lamps. Smartjuice is described as a "groundbreaking technology that adds a whole new level of lighting control and design options in many environments, such as retail, architectural, and residential. Smartjuice technology multiplexes power and data on one wire so that data can be delivered over existing wiring, eliminating the need for separate wires."

Color Kinetics Incorporated offers the ColorBlast® Intelligent Lighting Indoor or Outdoor. ColorBlast is Color Kinetics' original indoor/outdoor wall-washing fixture that generates rich, uniform colored light and effects to bathe walls with beautiful colors and eye-catching effects. ColorBlast fixtures offer a variety of mounting and aiming options—the versatile base allows the fixture to be mounted on a wall or ceiling or placed as a stand on a floor.

Another product of Color Kinetics is the iColor Accent, which marries Color Kinetics' intelligent digital control with the latest LED advancements in an affordable, low-voltage indoor/outdoor direct-view linear light, offering designers and architects a cutting-edge, low-maintenance option for incorporating colored light and color-changing effects in direct-view applications.

The iColor MR from Color Kinetics is the world's first digital color-changing lamp that fits into standard MR16 fixtures. Since it is the same size and shape as standard MR16s, it fits right into the thousands of fixtures already designed for these lamps.

Tokistar Lighting Inc.
1561 Gemini Place
Anaheim, CA 92801
714-772-7005
www.tokistar.com

FL Series Lightstrings: Tokistar's FL Series is a system of sockets permanently attached to flexible wiring. Lightsources include incandescent lamps or LED's. All-weather construction make Lightstrings ideal for use in landscape lighting design, and their unique fastening system can easily transform signs into attractive lighting displays. Since all sockets are wired in parallel, single lamp failures do not affect the operation of others. Lightstrings may be ordered in rolls, and cut to exact size on the job.

Vista Lighting
A Subsidiary of JJI Lighting Group
1805 Pittsburgh Ave.
Erie, PA 16502
814-454-2266
Fax: 814-454-3319
www.vistalighting.com

LED Step Lighting: Vista's new LED Step Lights provide crisp, glare-free illumination to demarcate steps, stairwells, and corridors for both interior and exterior applications in hospitals, nursing homes, limited healthcare facilities, schools, hospitality venues, offices, and public and private buildings of all kinds.

Lucifer Lighting Company
www.luciferlighting.com

SL1-LED Stealth Series LED is powered by an LED and separate driver to illuminate up to 12 individual Stealth fixtures on a 350 or 233-milliamp circuit, up to 30 feet in overall length. The solid-state design has a low current draw and uses a fraction of the power required by conventional light bulbs. With indicated useful LED life of 50,000+ hours, the fixture ensures minimal maintenance cost and is highly energy efficient.

Ardee Lighting Inc.
Ardee Lighting
639 Washburn Switch Road
P.O. Box 1769
Shelby NC 28151
www.ardeelighting.com

Ardee has introduced LED LightTiles—surface-mounted luminaires that provide highly energy-efficient, long-life illumination from compact, versatile wall tiles. LED LightTiles can serve as illuminated door markers and room identifiers in corporate, educational, and institutional environments. They can also be grouped to form decorative designs and patterned lighted wall accents.

Lamina Ceramics, Inc.
120 Hancock Lane
Westampton, New Jersey 08060
www.laminaceramics.com

Lamina Ceramics, Inc., has introduced a low-temperature, co-fired, ceramic-on-metal package designed for LED arrays used as replacements for incandescent bulbs. Lamina Ceramics is a leading manufacturer of multi-layer ceramic-integrated circuits (MCIC), electronic packages, and components. The HB LED package based on its low-temperature co-fired ceramic on metal (LTCC-M) technology addresses the price and heat dissipation concerns of HB LED arrays.

C3. INVESTMENT ORGANIZATIONS

Koch Genesis LLC
Timothy J. Cesarek, President
4111 East 37th Street
Wichita, Kansas 67220
www.kochgenesis.com

C4. LIGHTING INFRASTRUCTURE AND ASSOCIATIONS

Alliance for Solid-State Illumination Systems and Technologies (ASSIST)
The Alliance for Solid-State Illumination Systems and Technologies (ASSIST) is a collaborative effort by researchers, manufacturers, utilities, and government. Its goal is to facilitate broad adoption of LED technology by original equipment manufacturers (OEMs) and specifiers by helping to reduce major technical hurdles and identifying key applications for energy-efficient SSL technologies.

Currently, ASSIST sponsors include GELcore, Lumileds Lighting, NYSERDA, OSRAM Sylvania/OSRAM Opto Semiconductors, Boeing, California Energy Commission, and Nichia America Corporation.

Optoelectronics Industry Development Association (OIDA)
Contact: Arpad Bergh
email: bergh@oida.org
(202) 785-4426
www.oida.org

In March 2001, the DOE's Office of Building Technologies, State and Community Programs, and OIDA published the results of an 18-month cosponsored SSL technology roadmapping effort.

OIDA is a North American industry association representing 50 members, including both large and small companies. Because of their importance as industry R&D resources, our membership is extended to national laboratories and universities. OIDA members represent the leading providers of optoelectronic components and systems enabled by optoelectronics, supporting much of the information age. OIDA's members lead in the research and development of new enabling optoelectronics technology in diverse areas such as fiber optic communications, digital imaging, and storage.

OIDA's mission is to promote optoelectronics worldwide and advance the competitiveness of its members. OIDA serves as the voice of industry to government and academia, acts as liaison with other industry associations worldwide, and provides a network for the exchange of ideas and information within the industry. It also facilitates the sharing of resources and the formation of joint ventures and partnerships.

OIDA conducts industry workshops to assess international market trends and technology roadmaps, develops worldwide trade statistics, and works with the Federal Government to identify issues of concern to its members. OIDA develops a shared industry-government consensus on the gaps in optoelectronics, and works to implement solutions to these problems.
OIDA seeks to engage all levels of the optoelectronics supply chain. Our goal is to assure a broad perspective on issues related to technology and markets and to facilitate the timely introduction of new products. Current emphasis is on strengthening the infrastructure and metrology for high-volume, low-cost manufacturing and facilitating R&D in critical areas of the technology.

National Electrical Manufacturers Association (NEMA)
NEMA has an SSL section, which is part of their Lighting Systems Division. The division provides the organizational framework for manufacturers of lighting equipment to work together on projects that impact their industry and their businesses. A major cooperative effort is the establishment of technical standards and codes. Related issues, such as product compatibility, conformity assessment, and safety, are also addressed. Legislative and regulatory matters also are dealt with on an industry-wide basis.

NEMA's members are in the energy-efficiency business. As such, NEMA has exercised influence and played a key role in the legislative and regulatory arenas for many years. The division advises DOE and executive agencies on lighting research and market transformation needs.

NEMA advises DOE's Federal Energy Management Program (FEMP) on energy-efficient lighting recommendations and coordinates with the DOE and the Environmental Protection Agency on Energy Star Buildings and Energy Star voluntary product labeling programs. NEMA advocates market-based approaches to enhance the use and penetration of energy-efficient technologies.

NEMA succeeded in getting several provisions written into this year's Energy legislation. These include:

1. Requirements that efficiency ratings for transformers conform to NEMA standards TP 1, TP 2, and TP 3.
2. Lighted exit signs and traffic signs must be certified as Energy Star products.
3. A federal procurement standard for motors based on the NEMA Premium standard.
4. Higher energy-efficiency goals for federal retrofits and new construction.
5. "The establishment of a consortium to develop solid-state lighting technology." (Energy Efficiency/Power Quality News 2002)

Lighting Research Center
(518) 687-7100
Fax: (518) 687-7101
http://www.lrc.rpi.edu/

Part of Rensselaer Polytechnic Institute, the Lighting Research Center is the leading university-based research center devoted to lighting.

National Lighting Bureau
Contact: NLB Chairman Cary S. Mendelsohn, Vice President, Imperial Lighting Maintenance Company, representing International Association of Lighting Management Companies (NALMCO)
http://www.nlb.org/

The NLB is an educational, nontechnical organization that promotes "High-Benefit Lighting" through magazine articles, awards programs, news releases, and other publications. The NLB is sponsored by professional societies, trade associations, manufacturers, and agencies of the federal government. NEMA's Lighting Fixtures Section, including 17 member companies, is a primary sponsor of the NLB.

C5. DOE NATIONAL LABORATORIES

Sandia National Laboratory
DOE's Lighting Research and Development (LR&D) Program's goal is to develop viable technologies having the technical potential to conserve 50% of lighting consumption by 2010. The Program partners with industry, utilities, universities, and research institutions to create energy-efficient lighting technologies in pursuit of this goal.

Sandia National Labs has initiated a Grand Challenge Laboratory-Directed Research and Development project called "A Revolution in Lighting: Building the Science and Technology Base for Ultra-Efficient Solid-State Lighting" in October 2002. This interdisciplinary project draws together more than 20 researchers from various organizations at Sandia.
http://lighting.sandia.gov/Xsslatsnl.htm

Lawrence Berkeley National Laboratory
LBNL is active in SSL technology, with an emphasis on OLEDs and light distribution systems. LBNL also has a research project dedicated to reducing energy use in hotels by using occupancy sensors and an LED nightlight.

C6. DOD INITIATIVES

Defense Advanced Research Projects Agency
The Defense Advanced Research Projects Agency's SUVOS program aims to develop semiconductor UV optical sources for bioagent detection. These UV sources may also be useful, after phosphor down-conversion, for SSL.
Contact: LTC John C. Carrano, Jcarrano@Darpa.Mil
(703) 696-2252
Fax: (703) 696-2206 (Fax)
http://www.darpa.mil/mto/suvos/index.html

Office of Naval Research
The Office of Naval Research has been a long-standing champion and supporter of wide-bandgap semiconductor materials research, including the GaN-based materials on which most commercial blue-and green-light emitters are based. Thanks to some impressive technical breakthroughs over the past decade or so, SSL technology has emerged as a viable means of significantly reducing the energy demands for lighting. SSL here refers to the use of LEDs and OLEDs as light sources. The greatest impact of these technologies on both lighting costs and associated energy savings will come through the replacement of the conventional incandescent and fluorescent lamp technologies used in the general illumination of residential, commercial, and industrial buildings.
http://www.onr.navy.mil

APPENDIX D. LIGHTING FIXTURE MANUFACTURERS AND DISTRIBUTORS AND KEY LIGHTING CONSUMER GROUPS

D1. Lighting Fixture Industry

The U.S. lighting fixtures and equipment industry is worth $16.5 billion. The demand for lighting fixtures in this country will grow 4.8 percent yearly through 2006, driven by continued strength in replacement markets where efficiency concerns generate remodeling and retrofit projects. High-efficiency products will lead gains, including electronic ballasts, high-intensity discharge lighting, light-emitting diodes and fiber optic systems (Fredonia Group 2002).

"The lighting business is resilient. When the United States was hit with the double whammy of an economic downturn and a national tragedy, some industries were decimated. But not the residential lighting business, which showed slight growth, to $4.59 billion in retail sales last year, up from $4.57 billion. Of that figure, lighting fixture sales took a small hit, down 2.2 percent, but portable lamps grew by 4.6 percent." [Source: Lights Shine in Dark Economy, Lamps and lighting fixtures market size data, HFN , Volume: 76 , Number: 22 , Page: 25+ , June 03, 2002]

The retail market for residential lighting fixtures declined slightly last year to $2.72 billion. While the business is largely tied to home building and remodeling, which seemed to withstand the economic downturn, a number of factors took their toll. A repositioning at Home Depot, a general price erosion and to a lesser degree, the failure of House2Home and Dekor, cut into the overall sales of the category. Marginal improvement is estimated for 2003 as the U.S. lighting fixtures market stabilizes. Domestic manufacturers will continue to lose market share to imported products but can expect growth of 3.1% annually from 2003 to 2008.

Exports rebounded 7.1% in 2002 primarily due to a 41% surge in shipments to Mexico. Fast-growing markets in 2002 also included France, the Dominican Republic, Israel, and Korea. Imports regained momentum in 2002, as unit and dollar volume climbed 12.0% and 9.8%, respectively, expanding its share of the U.S. market to 37%. China boosted its stake in the U.S. lighting fixture market to 21% as sales soared by 23% (Source: The U.S. Lighting Fixtures Market , 2003 Edition).

Clearly dominated by lighting specialty stores, discount department stores, and home improvement centers, this $4.4 billion category is expected to grow an additional $200 million in 2003. The greatest growth in the category, which includes ceiling fans with lights, is in home improvement centers, which have the space and equipment to effectively display and sell this category. Sales there are projected to break the billion-dollar mark in 2003, nearly catching the $1.2 billion projected for discount department stores. Furniture stores, traditionally timid here, home accent specialty stores, and gift stores appear to be developing more interest in the category (Home Accents Today 2002).

Lighting Fixtures Distribution Channels			
	2002 sales (in millions)	**% change '02 to '03**	**2003 sales projected**
Furniture stores/chains	132	4	137
Home accent specialty stores/chains	44	5	46
Gift specialty stores/chains	44	5	46
Lamp/lighting stores	1,676	3	1,729
Discount department stores	1,191	-1	1,183
Interior designers	132	-31	91

Lighting Fixtures Distribution Channels			
	2002 sales (in millions)	**% change '02 to '03**	**2003 sales projected**
Mail order/Internet/TV	176	3	182
Home improvement centers/warehouse clubs	970	13	1,092
Other	44	5	46

D2. PORTABLE LAMPS

Comfortably in third place in the home accent universe are portable lamps, with sales of $8.2 billion this year and a 13% market share. Dominating the category are discount department stores with $1.8 billion in sales this year, projected to grow to $1.9 billion in 2003. Close behind are furniture stores with $1.47 billion in sales this year, projected to grow to $1.52 billion in 2003, with the new mix stores contributing to the growth. Lamp/lighting stores complete the big three in this category with healthy sales of $1.2 billion this year, projected to increase to $1.3 billion in 2003. Home accent specialty stores remain strong in this category with projected 2003 sales of $845 million. With department stores and home textile specialty stores continuing to back away from portable lamps, home improvement stores have embraced the category. They are positioned to take up the slack with sales of $901 million this year projected to grow another 13% to just over $1 billion in 2003. Also projected to grow in this category is mail order/Internet/TV with sales this year of $655 million and projected 2003 sales of $761 million (Home Accents Today 2002).

Portable Lamps			
	2002 sales (in millions)	**% change '02 to '03**	**2003 sales projected**
Furniture stores/chains	$1,474	3%	$1,521
Home accent specialty stores/chains	$819	3%	$845
Gift specialty stores/chains	$246	3%	$254
Home textile specialty stores/chains	$246	31%	$169
Lamp/lighting stores	$1,229	3%	$1,268
Department stores	$328	-23%	$254
Discount department stores	$1,802	3%	$1,859
Interior designers	$246	3%	$254
Mail order/Internet/TV	$655	16%	$761
Home improvement centers/warehouse clubs	$901	13%	$1,014
Other	$246	3%	$254

Lamps are sold through a wide range of distribution channels that vary widely based upon the end-use market. For distribution purposes, the lamp market is divided into three distinct segments: consumer, OEM and other. The consumer segment includes lamps for residential applications, as well as lamps purchased for aftermarket vehicular use. The OEM segment comprises lamps used for OEM applications in motor vehicles, consumer products and other types of equipment. The other segment encompasses lamps used in such nonresidential buildings as commercial, institutional, industrial, government, and other buildings. Because the needs of each of these end-use categories vary, producers and distributors generally alter their strategies accordingly.

Lamp producers utilize a variety of internal distribution activities, including regional sales offices and direct sales forces. Regional sales offices are primarily used to meet the needs of regionally based end users. Specific regions and markets are also commonly served by independent manufacturers' representatives. Direct sales forces are principally used by large producers with extensive sales teams, but are also employed by some smaller producers. This technique is particularly helpful to a lamp producer when selling to high-volume retailers or end users. Although lamp producers often use these internal distribution methods, the majority of lamp sales are made through distributors and retail outlets.

Industry Structure: Lamp Demand by Distribution Sector (Million Units) 1990-2010					
	1990	**1995**	**2000**	**2005**	**2010**
Total lamp demand	4620	5241	6066	6810	7665
Consumer	2626	2951	3303	3640	4050
OEM	1221	1468	1843	2155	2490
Other	773	822	920	1015	1125

D3. PROJECTED MARKET GROWTH IN LIGHTING

Manufacturers and electrical distributors of lamps and lighting fixtures can expect steady growth through 2006, according to a new market study. According to a study published by The Fredonia Group Inc., a Cleveland-based industrial market research firm, revenues in world lighting equipment (lamps and lighting fixtures) totaled $78.7 billion in 2001 and are projected to jump 5.3 percent per annum through 2006 to $102 billion (Electrical Wholesaling 2003).

D4. LIGHTING DISTRIBUTORS

Distribution continues to shift away from the department stores and, to a certain degree, furniture stores--two channels that took major hits with the demise of Wards, the closing of Rich's lamp department and the liquidation of major furniture chains. The big winners are home decor specialists such as Kirkland's, Garden Ridge, the linens chains, Pottery Barn, Crate & Barrel, Pier I Imports and others, that HFN classifies as specialty stores and includes with independent lamp and lighting showrooms in our distribution pie chart.

These retailers have become destinations for home decor, because they are easy and fun to shop, and have the right looks at the right time. While independent lighting showrooms have, on balance, added more portable lighting and accessories to their mix, their ranks continue to thin. Additionally, a number of them have struggled financially and have poor credit, further reducing suppliers' willingness to do business with them. Retail consolidation throughout the industry is far from over, observers predict.

The mass merchants showed market share growth due to sheer store numbers, despite Kmart's problems, Ames' massive store closings and the failure of Bradlees Hardware and home centers showed a slight clip, which can be attributed to changes at Home Depot and Lowe's, the demise of House2Home and Dekor, and, to a small degree, Expo Design Centers' shift to more promotional goods. Home Depot, which had only sporadically carried lamps, consolidated nine regional buying offices into one at its Atlanta headquarters and stalled buying until its strategic rollout of portable lighting in 2002. They may be a factor in next year's industry figures. But Lowe's continued to command a dominant share of the market in lamps. Lowe's made several merchandising changes, including the installation of the Design Trends' mix-and-match display system, and the addition of higher-end lamps, which affected sales (HFN 2002).

Lowe's Home Improvement Warehouse
1605 Curtis Bridge Rd., PO Box 1111
North Wilkesboro, NC 28656

Tel: 800-891-8035
Fax: 336-658-5168
http://www.lowes.com/

Supplier of commercial products including hardware, lumber, building materials, doors, windows, paints, janitorial supplies. Lowe's is the second largest home improvement retailer and the 14th largest retailer in the United States.

The Home Depot
2455 Paces Ferry Rd. N.W.
Atlanta, GA 30339
Tel: 800-430-3376
Fax: 877-496-9470
http://www.homedepot.com

Building, maintenance and electrical products including building materials, lumber, hardware, cleaning supplies, etc.

Advance Lighting Technologies
www.adlt.com

Wholesale supplier of all lighting and fixture manufacturers, as well as a full line of ballasts, emergency lighting batteries and replacement lenses and diffusers.

Atlas Specialty Lighting
1111 W. 22nd St.
Hialeah, FL 33010
Tel: 800-227-6745
Fax: 305-888-2973
Or Call: 305-885-8941
http://www.asltg.com

Distributes a full line of standard and special lamps and light bulbs for industrial, commercial, and residential applications.

Capitol Light
http://www.capitollight.com/
National lighting distributor for retail stores. The largest national lighting supplier in the United States.

Crossman
2226 Castle Harbor Place S.
Ontario, CA 91761
Tel: 800-523-8674
Fax: 909-930-5540
http://www.crossmanmanufacturing.com

Supplies acrylic and polycarbonate components to the lighting industry.

Miller Lighting & Energy, Inc.
http://www.millerlight.com/

Wholesale lighting distributor specializing in energy-efficient technologies, dedicated to working with businesses to help substantially reduce utility bills and maintenance costs.

National Specialty Lighting
Colorado Tech Center, 1753 Boxelder St.
Louisville, CO 80027
Tel: 303-926-1100
Fax: 303-926-0011
http://www.nslusa.com

Manufactures and distributes architectural and decorative lighting including xenon task lighting, Brite Strip, Light-Rope, and Tube-Lite.

Philips Lighting Co.
200 Franklin Square Dr.
Somerset, NJ 08873-4186
Phone: 732-563-3000
Fax: 732-563-3740
http://www.lighting.philips.com

Lamp/light bulb supplier for all industrial, commercial/specialty applications. Offers compact fluorescents, halogen optics, HID, etc.

Professional lighting
http://www.professionallighting.com/

North Carolina specialty lighting distributor and resource for state-of-the-art lighting products for commercial, industrial and residential use. Lighting Products and Design Services for commercial, residential and industrial markets. Professional lighting maintains a large inventory of quality lighting products and strong vendor relationships.

Progress Lighting
http://www.progresslighting.com

A source for residential and commercial lighting, featuring online shopping for outdoor and indoor lighting fixtures with database of products and searchable local dealers nationwide.

Spectrum Lighting
http://www.spectrum-lighting.com/

Wholesale distributor of commercial lighting products and provider of energy-saving solutions.

Tristar Lighting Co.
1349 Ford Rd.
Bensalem, PA 19020-4501
Tel: 800-544-1525
Fax: 800-544-1517
Tel.: 215-638-8180
http://www.tristarlighting.com

Manufactures and supplies energy-efficient lighting products based exclusively on ballast, lamp, and optic technologies.

WESCO International, Inc.
Commerce Ct., Ste. 700, 4 Station Sq.
Pittsburgh, PA 15219
Tel: 412-454-2200

Fax: 412-454-2505
http://www.wescodist.com

The company distributes electrical products (fuses, terminals, connectors, enclosures, fittings, circuit breakers, transformers, switchboards); industrial supplies (tools, abrasives, filters, safety equipment); lighting wares (lamps, fixtures, ballasts); wire and conduit materials; automation equipment (motors, drives, logic controllers); and data communication apparatus (patch panels, terminals, connectors). WESCO offers more than a million products from some 24,000 suppliers. Directors James Singleton and James Stern own about 44% of WESCO.

D5. CONSUMER GROUPS

Efficient Lighting Initiative (ELI)
The IFC/GEF Efficient Lighting Initiative (ELI) is a three-year, US$15 million program designed by the International Finance Corporation (IFC) and funded by the Global Environment Facility (GEF) to promote the growth of markets for energy-efficient lighting technologies in seven countries. ELI works directly with the lighting industry to address the barriers to the adoption of cost-effective, environmentally beneficial lighting products in Argentina, the Czech Republic, Hungary, Latvia, Peru, the Philippines and South Africa. In addition to supporting consumer education and product labeling and certification initiatives, ELI works through retailers and consumer groups to build demand for efficient lighting products. ELI also works with manufacturers to lower prices and increase product availability. Finally, ELI complements these activities by working through local electric utilities and financial institutions to provide capital for investment in energy efficient lighting technology. The program seeks to aggregate the power of the seven country markets in order to influence the lighting industry globally, while using distinct country strategies to leverage an additional US$30-80 million in direct private sector investment in the seven ELI country markets.
http://www.efficientlighting.net

American Council for an Energy-Efficient Economy
The ACEEE provides information on energy-efficient lighting and other home energy-conservation opportunities. The ACEEE has a commitment to making energy efficiency the center-piece of our nation's energy policy. They develop specific energy efficiency policy initiatives; analyze- their impacts; advise national, regional, and state policymakers; and work with coalitions of environmental, consumer, business, and progressive energy organizations in order to influence energy legislation.
http://www.aceee.org/consumerguide/index.htm

Alliance to Save Energy
The Alliance to Save Energy promotes energy efficiency worldwide to achieve a healthier economy, a cleaner environment and energy security. Founded in 1977, the Alliance to Save Energy is a non-profit coalition of business, government, environmental and consumer leaders. The Alliance to Save Energy supports energy efficiency as a cost-effective energy resource under existing market conditions and advocates energy-efficiency policies that minimize costs to society and individual consumers, and that lessen greenhouse gas emissions and their impact on the global climate. To carry out its mission, the Alliance to Save Energy undertakes research, educational programs, and policy advocacy, designs and implements energy-efficiency projects, promotes technology development and deployment, and builds public-private partnerships, in the United States and other countries.
http://www.ase.org/consumer/index.htm

Better Way To Save
This site includes energy efficiency tips, online energy savings calculators, dealer locators, and rebate information for Energy Star appliances and lighting. **http://www.betterwaytosave.com/**

Buy Energy Efficient
This organization provides information about the economic, environmental and health benefits of buying energy-efficient products for the home. **http://www.buyenergyefficient.org/index.html**

Consortium for Energy Efficiency
CEE provides information on energy-saving opportunities for appliances, lighting, air conditioning systems and gas heating. CEE's High-Efficiency Residential Lighting Initiative has the objective to increase the availability and acceptance of energy-efficient lighting (including fixtures), and create a self-sustaining market for this technology. **http://www.ceeformt.org/resid/rs-lt/rs-lt-main.php3**

Consumer Energy Center - California Energy Commission
CED gives advice for saving energy in a variety of home systems, both indoors and outdoors, and in home construction. **http://www.consumerenergycenter.org/homeandwork/homes/**

Consumer Energy Information
This comprehensive U.S. Department of Energy site (from EERE), includes a glossary, fact sheets, and tips for several home systems and appliances.
http://www.eere.energy.gov/consumerinfo/saveenergy/save_light.html

Energy Outlet
Energy Outlet is a resource center promoting electrical energy conservation.
http://www.energyoutlet.com/

ESP Energy
The ESP Energy site provides energy-saving information on all areas of the home. Including air conditioning, heating, insulation, windows, appliances, and lighting.
http://www.espenergy.com/energy_tips.htm

Green Building Concepts
Green Building Concepts supplies information exchange on a more resource and energy efficient lifestyle. The site includes information exchange on resource- and energy-efficient home building. Product tips, building hints, and newsletter archive. **http://www.greenconcepts.com/**

Lighting Research Center
Part of Rensselaer Polytechnic Institute, the Lighting Research Center is the leading university-based research center devoted to lighting. Since they began in 1988, the institute has built an international reputation as a reliable source for objective information about lighting technologies, applications, and products. They provide training programs for government agencies, utilities, contractors, lighting designers, and other lighting professionals. **http://www.lrc.rpi.edu/index.asp**

New York Energy $mart Web Site
This site's Energy Smart University teaches about energy use, energy industry deregulation, and energy efficiency; it also provides tools to conduct a home energy analysis.
http://www.getenergysmart.org/index.jsp

Northeast Energy Efficiency Partnerships (NEEP)
The Energy Efficient Residential Lighting Initiative was organized by NEEP to achieve significant energy savings by establishing quality, energy-efficient luminaires as a standard product in residential lighting markets. The initiative builds on the recommendations of research sponsored by the Boston Edison DSM Settlement Board in 1996.

Northwest Energy Efficiency Alliance
The Northwest Energy Efficiency Alliance is a non-profit group that supports regional programs to make affordable, energy-efficient products and services available in the marketplace. The alliance works to help Northwest consumers and businesses use energy more efficiently.**http://www.nwalliance.org/index.asp**

Partnership for Advanced Technologies in Housing
PATH is a voluntary initiative that seeks to accelerate the creation and widespread use of advanced technologies to improve the quality, durability, environmental performance, energy efficiency, and affordability of housing. **http://www.pathnet.org/**

D6. MAJOR U.S. MANUFACTURERS OF LIGHTING FIXTURES

Catalina Lighting
8191 NW 68th Ave.
Miami, FL 33015
Phone: 305-558-4777
Fax: 305-558-3024
Toll Free: 800-966-7074
http://www.catalinaltg.com

The firm sells and distributes residential and office lighting fixtures and lamps under the Catalina, Dana, Illuminada, Ring, and Westinghouse brands. he company markets its goods primarily through large retailers in the United States and through wholesale distributors in Europe and Asia. Catalina manufactures most of its products inexpensively in China through its Go-Gro Industries subsidiary.

Cooper Lighting
600 Travis, Ste. 5800
Houston, TX 77002
Phone: 713-209-8400
Fax: 713-209-8995
http://www.cooperindustries.com

Cooper makes electrical products, tools, hardware, and metal support products. The company's electrical products include electrical and circuit protection devices, residential and industrial lighting, and electrical power and distribution products for use by utility companies. They manufacturer incandescent, fluorescent, exit and emergency, vandal resistant, and other styles, under the Halo, Portfolio, Lumark, and Lumière brands.

GE Consumer Products
Appliance Park
Louisville, KY 40225
Phone: 502-452-4311
Fax: 502-452-0352
http://www.geconsumerproducts.com

The company is the second largest U.S. manufacturer of major household appliances (behind Whirlpool), including refrigerators, air conditioners, washers, and dryers. GECP sells its appliances (with brand names including GE, Monogram, and Profile) to retailers and building contractors. Its lighting unit makes 6,000 types of lights and lighting systems, ranging from residential lights to systems that illuminate entire sporting complexes. The firm creates a wide variety of light bulbs and operates globally. GECP was formed in 2002 when parent company GE combined its appliances and lighting divisions.

The Genlyte Group Incorporated
10350 Ormsby Park Place, Ste. 601
Louisville, KY 40223 (Map)
Phone: 502-420-9500
Fax: 502-420-9540
http://www.genlyte.com

The Genlyte Group makes commercial, industrial, and residential lighting products through its Genlyte Thomas Group LLC joint venture with Thomas Industries . A leading lighting manufacturer in North America, the company produces all of its lighting fixtures and controls through the 68%-owned joint venture. Genlyte Thomas' indoor and outdoor lighting products include incandescent, fluorescent, and high-intensity discharge fixtures sold under such brand names as Bronzelite, Capri, Lightolier, Starlight, and ZED.

Genlyte Thomas Group LLC
10350 Ormsby Park Place, Ste. 601
Louisville, KY 40223 (Map)
Phone: 502-420-9500
Fax: 502-420-9540
http://www.genlytethomas.com

The joint venture—of which Genlyte owns 68%, Thomas 32%—plays a leading role in the North American lighting market. Genlyte Thomas' lighting fixtures and controls are used both indoors and outdoors, for decoration, landscaping, and tracking. Brand names include Bronzelite, Capri, Lightolier, and ZED. The company markets to distributors, who resell the products for use in the construction and remodeling of residential, commercial, and industrial facilities. Genlyte Thomas' flagship Lightolier division is teaming up with Steelcase to develop workplace lighting.

Hubbell, Inc.
584 Derby Milford Rd.
Orange, CT 06477-4024
Phone: 203-799-4100
Fax: 203-799-4205
http://www.hubbell.com

The company's three operating segments -- electrical, power, and industrial technology -- make electrical and electronic products for commercial, industrial, and telecommunications applications. Its products include lighting fixtures, outlet boxes, enclosures and fittings, wire and cable, insulators and surge arresters, voice and digital signal processing components, and test and measurement equipment. The company has manufacturing divisions and subsidiaries in North America, Puerto Rico, Singapore, and the UK, plus a joint venture in Taiwan. The United States accounts for about 90% of sales.

Juno Lighting, Inc
1300 S. Wolf Rd.
Des Plaines, IL 60017
Phone: 847-827-9880
Fax: 847-296-4056
Toll Free: 800-323-5068
http://www.junolighting.com

Juno Lighting makes light fixtures for commercial, institutional, and residential buildings. It also makes showcase lighting fixtures under the Danalite name, fiber optic lighting products, and emergency and exit lighting signs based on LED technology. Juno's other products include recessed lighting and track-lighting systems. The company counts contractors and remodelers as its chief customers. Its Isis Light (formerly Advanced Fiberoptic Technologies) subsidiary makes fiberoptic wire, cable, and lighting products. The United States accounts for more than 90% of sales.

Luminex Lighting, Inc.
13710 Ramona Ave.
Chino, CA 91710 (Map)
Phone: 909-591-5653
Fax: 909-591-0643
Toll Free: 800-586-4693
http://www.luminexlighting.com

The company primarily manufacturers energy-saving lighting alternatives, such as fluorescent lighting fixtures and undercabinet lighting. Luminex also makes ceiling mount, decorative vanity, and compact ceiling mount fixtures for the residential and commercial markets. The company offers a five-year warranty on all their products. While Luminex sells the majority of its products in the United States and Canada, it has expanded its market area to include Asia and the Middle East.

Philips Lighting B.V.
Bldg. EDW-113
5600 JM Eindhoven, The Netherlands
Phone: +31-40-27-56476
Fax: +31-40-27-57052
Primary US Office:
200 Franklin Square Dr.
Somerset, NJ 08873-4186
Phone: 732-563-3000
Fax: 732-563-3740
http://www.lighting.philips.com

Philips Lighting, a division of the Netherlands-based Koninklijke Philips Electronics , is the #1 household light bulb maker in the world, it makes lights for nearly every application. The division has four primary segments: automotive lighting, lamps (fluorescent and incandescent lights, mercury vapor and sodium lamps, and other types of light bulbs), lighting electronics and gear (ballasts and other fixtures), and luminaires (lighting devices). Philips Lighting has also begun to focus on digital data projection, infrared lighting, theatre lighting, and ultraviolet lights (to disinfect air and water).

Progress Lighting Inc.
Physical Address
101 Corporate Dr Ste L
Spartanburg, SC 29303-5043
Phone: 864-599-6000
www.progresslighting.com

Manufactures lighting fixtures for residential and commercial use.

APPENDIX E: KEY CONTACTS FOR MANUFACTURING AND MARKETING OF SOLID-STATE LIGHTING

The following organizations and individuals were identified as potential contacts for further exploration of the relationship between consumer values and the development and marketing of solid-state lighting.

Key Contacts for Manufacturing and Marketing of Solid-State Lighting		
Contact	**Telephone**	**E-mail address**
Research and Development		
Sandia National Laboratory		
James Gee Sandia National Laboratory Senior Scientist Energy Efficiency & Renewable Energy PO Box 5800 MS 0752 Albuquerque, NM 87185	(505) 844-7812	**jmgee@sandia.gov**
Jeffrey Y. Tsao Sandia National Laboratory P.O. Box 5800 MS 0601 Albuquerque, NM 87185-0601	(505) 844-7092	**jytsao@sandia.gov**
Jerry Simmons Sandia National Laboratory Manager Semiconductor Materials and Device Sciences MS 0601 P.O. Box 5800 Albuquerque, NM 87185-0601	(505) 844-8402	**Jsimmon@sandia.gov**
Lawrence Berkeley National Laboratory		
David Attwood Lawrence Berkeley National Laboratory Director, Center for X-Ray Optics Materials Sciences Division Ernest Orlando 1 Cyclotron Rd Berkeley, CA 94720 MS 2R0400	(510) 486-4463	**DTAttwood@lbl.gov**
Steve Johnson Ernest Orlando Lawrence Berkeley National Laboratory University of California Building Technologies Department Environmental Energy Technologies Department Mail Stop 90R3111 1 Cyclotron Road Berkeley, CA 94720	(510) 486-4274	**SGJohnson@lbl.gov**

Rensselaer Polytechnic Institute		
Nadarajah Narendran Lighting Research Center Rensselaer Polytechnic Institute Troy, NY 12180	(518) 687-7100	narenn2@rpi.edu
E. Fred Schubert Senior Constellation Professor Rensselaer Polytechnic Institute Dept. of Electrical, Computer and Systems Engineering 110 Eighth Street Troy, NY 12180	(518) 276-8775	efschubert@rpi.edu
University of Arizona		
Ghassan E. Jabbour Associate Research Professor University of Arizona Optical Sciences Center 1630 East University Blvd. Tucson, AZ 85721	(520) 626-8324	gej@optics.arizona.edu
Needham & Co., Inc.		
Pierre Maccagno Analyst (specializing in semiconductor sector) Needham & Co., Inc. 445 Park Avenue No. 2C New York, NY 10022	(212) 705-0383	pmaccagno@needhamco.com
Kennedy & Violich Architecture Sheila Kennedy, AIA Director of Applied Design & Research Kennedy & Violich Architecture, Ltd. (Application design and integration strategies for semiconductors) 160 N. Washington St. 8th Floor Boston, MA 02114	(617) 367-3784	skennedy@kvarch.net
Manufacturing		
Optoelectronics Industry Development Association (OIDA)		
Arpad Bergh, President Optoelectronics Industry Development Association 2010 Massachusetts Ave, NW Suite 200 Washington, DC 20036-1023	(202) 785-4426	bergh@oida.org aboida@osa.org
Hess America 38 Washburn Switch Shelby, NC 28151	704-471-2211	totoole@jjishelby.com www.hessamerica.com
Ardee Lighting, Inc. PO Box 1769 637 Washburn Switch Rd. Shelby, NC 28151	704-482-2811	ardee@jjishelby.com www.ardeelighting.com

MoonCell, Inc. PO Box 3068 Stafford, VA 22555-30068	877-396-3142	http://www.mooncellusa.com/
National Electrical Manufacturers Association (NEMA)		
Kyle Pitsor Industry Director, Lighting Design NEMA 1300 N. 17th St. Suite 1847 Rosslyn, VA 22209	(703) 841-3274	Kyl_Pitsor@nema.org
Ron Runkles Technical contacts		Ron_Runkles@nema.org
Douglas Troutman Government contacts		Dou_Troutman@nema.org
International Association of Lighting Designers		
Marsha L. Turner, CAE Executive Vice President IALD Headquarters Office Merchandise Mart, Suite 9-104 200 World Trade Center Chicago, IL 60654	312-527-3677, fax 312-527-3680	Marsha@iald.org
Robert Prouse, IALD Director of Education IALD Headquarters Office	312-527-3677, fax 312-527-3680	Prouse@brandson.com
Al Borden, IALD Director of Marketing and Communications IALD Headquarters Office	312-527-3677, fax 312-527-3680	Aborden@thelightingpractice.com
Illuminating Engineering Society of North America		
William Hanley Executive Vice President Illuminating Engineering Society of North America 120 Wall Street, Floor 17 New York, NY 10005	212-248-5000, ext. 114	Whanley@iesna.org
Rita Harrold Director, Educational and Technical Development	212-248-5000, ext. 115	Rharrold@iesna.org
International Commission on Illumination (CIE) U.S. Committee		
United States National Committee of the CIE c/o Thomas M. Lemons, TLA-Lighting Consultants, Inc. 7 Pond Street Salem, MA 01970	(978) 745-6870	tmlattla@aol.com
Color Kinetics		
Kevin Dowling Vice-president for Strategy and Technology 10 Milk St, Suite 1100 Boston, MA 02108	(617) 423-9999	kevin@colorkinetics.com

Lumileds (joint venture between Philips Lighting and Agilent Technologies)		
Lumileds Uwe Thomas, PhD. Applications Engineering Manager 370 W. Trimble Rd 91-UK San Jose, CA 95131	(408) 435-6650	uwe.thomas@lumileds.com
Menko de Roos Vice-President, New Business Development	(408) 435-6661	menko.de.roos@lumileds.com
Jason Posselt Director of Product Marketing Lumileds Lighting, LLC	(408) 435-6642	jason.posselt@lumileds.com
George Craford Chief Technology Officer	(408) 435-6561	george.craford@lumileds.com
Targetti North America		
Eric Kramer, CEO Targetti North America 1513 E. Saint Gertrude Place Santa Anna, CA 92735	(714) 957-4919	ekramer@targettiusa.com
TIR Systems Ltd.		
A. Brent York Chief Technology Officer TIR Systems Ltd 7700 Riverfront Gate Burnaby, BC, Canada V5J 5M4	(604) 473-2313	brent_york@tirsys.com
GE Global Research Center		
Anil R. Duggal GE Global Research Center		Duggal@crd.ge.com
Cree Inc. (largest U.S. supplier of high-brightness LEDs)		
Cree Inc. J. Shiang C. M. Heller D. Foust	(919) 313-5300	www.cree.com
Toyoda Gosei Optoelectronics		
Bill Kennedy General Manager, LED Sales Toyoda Gosei Optoelectronics 301 Zorro Vista San Clemente, CA 92672	(949) 218-8996	bill.kennedy@tggroupna.com
AXT LED Technologies		
Heng Liu Chief Technology Officer AXT LED Technologies 9650 Telstar Avenue El Monte, CA 91731 (626) 277-4188	(510) 226-4300	
Gelcore (joint venture between General Electric Co. and Emcore Corp.)		
Gelcore Carl Will VP Sales GELcore 6180 Halle Drive Valley View, OH -44125	(216) 606-6597	www.gelcore.com

OSRAM Opto Semiconductors, Inc.		
Makarand H. Chipalkatti Director, Lamp Modules North America OSRAM Opto Semiconductors Inc. c/o Osram Sylvania 100 Endicott St. Danvers, MA 01923	(978) 750-2307	**makarand.chipalkatti@sylvania.com**
Marketing/Retailing		
Technical Consumer Products, Inc.		
Joe Colant, Vice President Technical Consumer Products, Inc. Commercial/Industrial Sales 300 Lena Dr. Aurora, OH 44202	(330) 995-6111	
The LED Light.com		
Brookstone		

APPENDIX F: KEY CONTACTS FOR SOLID-STATE LIGHTING DISCUSSIONS

(Discussions conducted in September and October 2003)

Manufacturers		
Contact	**Telephone**	**E-mail address**
Srinath Aanegola, GELcore	216-606-6579	srinath.aanegola@gelcore.com
Chuck Becker, GE Global Research Center	518-387-7712	
Makarand (Chips) Chipalkatti, OSRAM Opto Semiconductors, c/o Osram Sylvania	978-750-2307	makarand.chipalkatti@sylvania.com
Kevin Dowling, Color Kinetics, Inc.	617-423-9999	kevin@colorkinetics.com
Anil Duggal, GE Global Research Center	518-387-7712	duggal@crd.ge.com
Mike Dunn, Cree	919-313-5508	mike_dunn@cree.com
Bill Kennedy, Toyoda Gosei Optoelectronics	949-218-8996	bill.kennedy@tggroupna.com
Eric Kramer, Targetti North America	714-957-4913	ekramer@targettiusa.com
John Palembas, Ardee Lighting	704-471-2211	
Bill Ryan, Philips Lighting	732-563-3039	bill.ryan@philips.com
Keith Scott, Lumileds	408-435-6643	keith.scott@lumileds.com
Brent York, TIR Systems Ltd	604-473-2313	brent_york@tirsys.com
Research and Development		
Steve Johnson, Lawrence Berkeley National Laboratory	510-486-4274	SGJohnson@lbl.gov
Shelia Kennedy, Harvard University; Kennedy & Violich Architecture	617-367-3784	skennedy@kvarch.net
Nadarajah Narendran, Rensselaer Polytechnic Institute, Lighting Research Center (RPI LRC)	518-687-7100	narenn2@rpi.edu
Fred Schubert, RPI	518-276-8775	efschubert@rpi.edu
Jeff Tsao, Sandia National Laboratory	505-844-7092	jytsao@sandia.gov
Associations and Other Intermediaries		
Arpad Bergh, Optoelectronic Industry Development Association (OIDA)	202-785-4426	bergh@oida.org
Al Borden, International Association of Lighting Designers	215-238-1644	aborden@thelightingpractice.com
Nadarajah Narendran, Alliance for Solid State Illumination Systems and Technologies	518-687-7100	narenn2@rpi.edu

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21. J. R. Brodrick, PhD., 1J-018, EE-2J, 1000 Independence Ave. SW ,Washington, DC 20585
22. R.L. Orrison, U. S. Department of Energy, EE-2J, Forrestal Bldg., 1000 Independence Ave. SW Washington, DC 20585