How large are the potential energy savings?

The impact of replacing all lighting in the United States with solid-state lighting would be enormous. Studies have projected the following benefits to the United States alone (with global benefits that are proportionately larger) by the year 2025:

- Reduction by 50 percent of electricity used for lighting
- Reduction by 10 percent of total electricity consumption
- Reduction by 75,000 megawatts of the demand for electrical generating capacity (roughly equivalent to 75 large generating plants or the residential demand from all the homes in California, Oregon, and Washington)
- Reduction in carbon emissions by the equivalent of 28 million tons per year

These large reductions in the nation's energy demands would help decrease our dependence on foreign energy sources, lessen the impact on the environment, and increase the reliability and responsiveness of the nation's electrical grid.

National Security benefits

Much of the fundamental technology being developed for solid-state lighting will provide ancillary benefits to a host of other national security interests. For instance, high-power electronics can use gallium nitride (GaN), which may make it possible to manufacture much lighter, high-power electronic devices. The new unmanned aerial vehicles now being used to great advantage by the military would benefit from lighter radars and other electronics, allowing the vehicles to fly longer and further. GaN can be used to make ultraviolet LEDs and lasers that can be used to detect chemical and biological warfare agents. When illuminated with UV light, many biological agents fluoresce (re-emit light at a slightly longer wavelength). We are exploring the feasibility of this technique for rapidly identifying pathogens such as anthrax. And solid-state lighting itself is long lived and highly shock resistant, critical for military vehicles and ships operating in harsh environments under hostile conditions.

Ultra-violet LEDs can be used to detect hazardous agents, important for homeland security. Gallium nitride-based materials, used for solid-state lighting, can be used in light-weight high-power radars flown in unmanned aerial vehicles.

For more information:

For specific information about Sandia's R&D program in this area, see **http://lighting.sandia.gov,** or contact **Jerry Simmons, jsimmon@sandia.gov, 505-844-8402.**

National Nuclear Security Administration

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000. CA. 1.20.04 MV

Sandia National Laboratories

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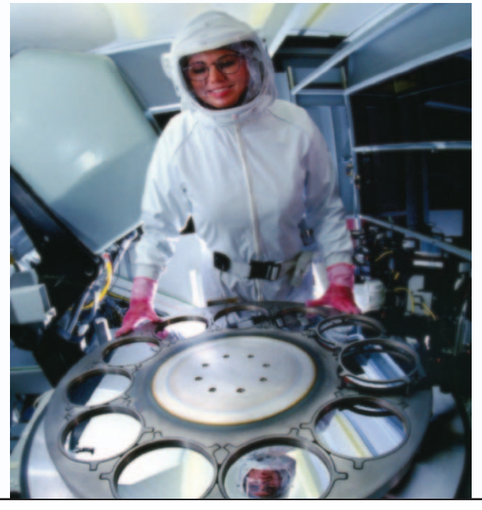
Solid-State Lighting R&D at Sandia

Energy Efficient Lighting Using Semiconductor Technology

Sandia's research program in solid-state lighting

Sandia National Laboratories has a long history of research in semiconductor optoelectronic devices. We were pioneers in the technology of the vertical cavity surface emitting laser, or VCSEL, which is now a mainstay of the telecommunications industry.

A few years ago we began to realize the tremendous possibilities presented by harnessing semiconductor technology for lighting. Sandia, working with leading industrial scientists from Agilent, wrote some of the first papers on solid-state lighting. In 2000, we helped the Department of Energy and the Optoelectronics Industry Development Association (OIDA) organize a national Solid-State Lighting Technology Roadmapping Workshop. That workshop identified the major scientific and technological challenges to be overcome and established technology milestones for future years. A follow-up workshop on light-emitting diodes or "LEDs" updated the challenges and milestones.

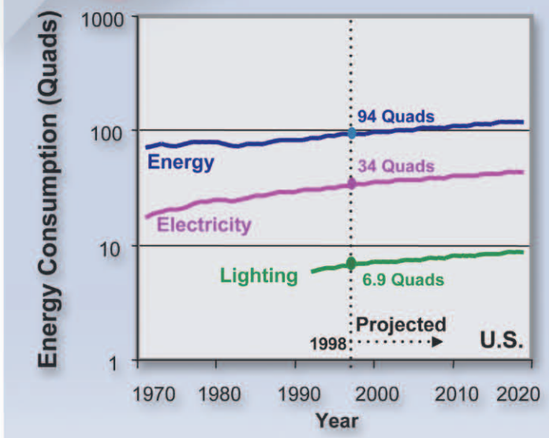


Sandia is now conducting a major R&D project devoted entirely to solid-state lighting, involving about 30 researchers and seeking to overcome the challenges identified in the OIDA technology roadmaps. It focuses on the physics of defects and impurities in gallium nitride-based semiconductors; the growth of high-quality, low-cost, gallium nitride semiconductor material; the design of high-efficiency LEDs; the development of phosphors for white light; and new encapsulant materials and packaging to give LEDs long lifetimes and improved performance. We are collaborating in these research areas with several universities and industrial partners, such as Lumileds Lighting of San Jose, California.

The problem and history

Energy consumed by conventional lighting

About 20 percent of the United States' electricity consumption now goes for lighting. The vast majority of that lighting is provided by incandescent and fluorescent



Efficiencies of energy technologies in buildings:

Heating:	70 - 80%
Elect. motors:	85 - 95%
Fluorescents:	25%
Incandescents:	5%

Electricity use is responsible for 1/3 of the nation's energy consumption, and lighting uses about 20% of total electricity. However, conventional lighting technologies are only 5 to 25 percent efficient.

bulbs. Incandescents are quite inefficient, with only about five percent of their electricity consumption being converted to visible light. The remainder is converted to waste heat, which contributes significantly to building cooling loads. Fluorescent lighting is much better, but still converts only about 25 percent of the electrical energy into visible light.

Solid-state lighting: a new lighting technology

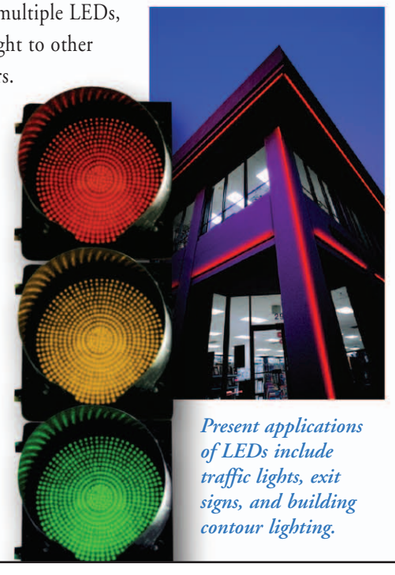
Solid-state lighting has the potential to far exceed the energy efficiencies of incandescent and fluorescent lighting. Solid-state lighting uses LEDs for illumination, the same kind of practical and inexpensive devices that provide the letters on a clock radio. The term "solid-state" refers to the fact that the light in an LED is emitted from a solid object—a block of semiconductor.

Growth of LED technology: addition of blue and green

LEDs have been following a kind of "Moore's law" of growth in performance since their invention in the early 1960s. The brightness of commercially available red LEDs has increased by a factor of 20 every 10 years, while simultaneously the cost has decreased by a factor of 10 every 10 years. About 10 years ago, an innovative new semiconductor material was developed—gallium nitride (GaN)—which enabled development of the first LEDs with bright emission in the blue and green spectral range. (Previously, bright LEDs were available only in red and orange.) This was a crucial development, since now white light could be realized by mixing different wavelength light from multiple LEDs, or alternatively by down-converting blue light to other colors of longer wavelength using phosphors.

Traffic lights and other monochrome applications

In the past few years, technology has progressed sufficiently that inexpensive and energy efficient LEDs are now the only logical choice for single color applications such as traffic signals. Conventional 12-inch-diameter red traffic signals use a long-life, white, 140-watt incandescent bulb. The red filter over this white light bulb discards 90 percent of the light, allowing only the red light to pass through. A commercially available LED, however, uses 18 red LEDs to provide the same amount of red light, but consumes only 14 watts—one tenth as much. While LED traffic lights cost more, the reduced electricity consumption allows them to pay for themselves in a year or less. They then save about $1,000 per intersection per year in electricity charges. LED traffic lights last as much as 10 times longer—10 years—reducing maintenance costs. As a result, LED-based traffic signals are becoming widely adopted throughout the country. Similarly, 90 percent of exit signs, another single-color application, are now fabricated with LEDs. Finally, LEDs are becoming common in automotive applications, appearing as center high-mount brake lights, tail lights, instrument panel back lights, interior cabin lighting, and will soon appear in car headlights. Toyoda Gosei, supplier of automotive parts to Toyota and others, states that the energy savings of using LED headlights is equivalent to a 300 kg (660 lb) reduction in the weight of the car.



Present applications of LEDs include traffic lights, exit signs, and building contour lighting.

General illumination is the big goal

For general illumination, full-spectrum white light is required. Today's LEDs must significantly improve to be economically competitive for general lighting. While today's best commercially available white LEDs are twice as efficient as incandescent bulbs (30 lumens per watt vs. 15), they also cost a great deal more and are not yet as efficient as fluorescent lamps (80 lumens per watt). However, 74-lumen-per-watt white LEDs have already been demonstrated in the laboratory.

Better quality and versatility

Solid-state lighting also promises better quality and more versatile sources of lighting, including the ability to tune colors to virtually any shade or tint. Because the light can be controlled with extremely high precision, it is believed that by interfacing it with modern microelectronics, digitally controlled illumination will be achieved. Such "smart light" could even be used to interface computers into networks through the lighting fixtures themselves. Solid-state lighting also offers other desirable qualities, such as light weight, thinness, low heat output, flexibility in installation, lifetimes approaching 10 years and longer, and extreme resistance to mechanical shock.

The $37M NASDAQ outdoor display screen in New York's Times Square, made up of 18 million LEDs.

On the horizon

Solid-state lighting should surpass conventional vacuum tube lighting technologies in both cost and performance within a relatively short time. With sufficient investment in research and development, it will be possible to produce a white LED with an energy efficiency of 150-220 lumens per watt, or 10-15 times the efficiency of incandescents and 2-3 times that of fluorescents. The cost of these highly efficient solid-state lights should become competitive with all other light sources, and they could capture most of the lighting market by 2025.