Energy Savings Estimates of Light Emitting Diodes in Niche Lighting Applications

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ABSTRACT

Solid-state lighting (SSL) has the potential to revolutionize the lighting market through the introduction of more energy efficient light sources. While SSL is just starting to compete for market share in general illumination applications, recent technical advances have made light emitting diodes (LEDs) cost-effective in many colored-light niche applications. LED technology is capturing these new applications because it offers a better quality, cost-effective lighting service compared to less efficient conventional light sources such as incandescent or neon. In addition to energy savings, LEDs offer longer operating life (>50,000 hours), lower operating costs, improved durability, compact size and faster on-time.

This paper summarizes the findings from analysis of nine niche markets where LEDs saved energy in 2002. The markets analyzed include: traffic signals, exit signs, commercial advertising signage, airport taxiway lights, airplane passenger reading lights, miniature holiday lights, railway signals, and vehicle indicator and safety lights on automobiles, trucks and buses. Estimates of energy savings in 2002 due to LED market penetration are presented, as well as the potential energy savings if 100% of these niche markets switched to LEDs. The findings for each application are presented in terms of both site and source (primary) energy savings. The current combined energy savings of LEDs in these niche applications is 9.6 Terawatt-hours (TWh) per year, or the equivalent annual output of a large (1,000 MW) electric power station.[1] In addition to detailed energy savings and market penetration information, this paper discusses other benefits of LEDs in each of the niche applications.

Introduction

In 1969, General Electric introduced the first commercial LED, a gallium phosphide semiconductor with properties that resembled the transistor – high tolerance for shock and vibration and long operating life (GELcore 2002). Since the General Electric breakthrough in 1969, research has focused on developing new LED semiconductor materials to emit all the colors of the spectrum more efficiently. While the efficacy[2] of this first red-color LED was extremely low (approximately 1 lumen per watt), researchers improved this technology over the past three decades, developing the colored LED devices we see today capable of operating at over 100 lumens per watt (Whitaker 2003). LED devices now compete commercially with conventional technologies in colored lighting applications, many of which are discussed in this report.

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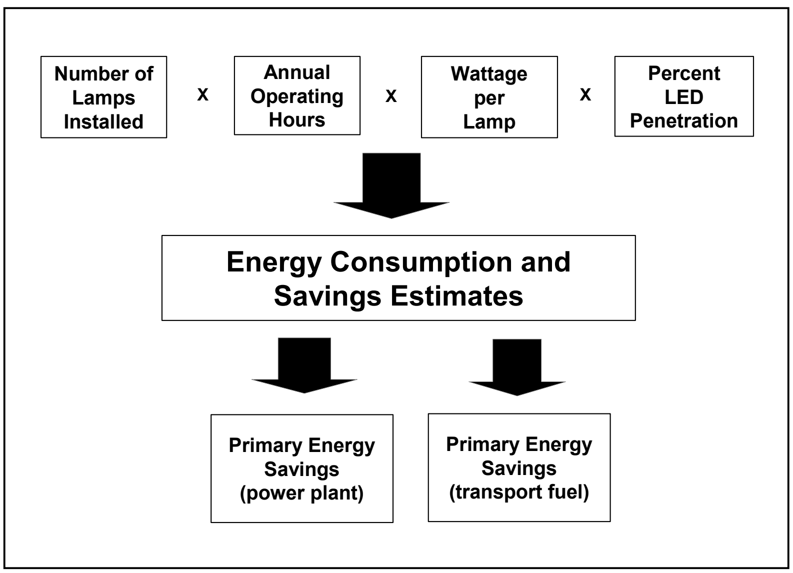
[1] Assumes 1,000 MW electric output, operating at a 90% annual availability.
[2] Efficacy is the metric for efficiency of light producing devices. It is measured in lumens per watt, or lumens of light output per watt of power input.

The Department of Energy commissioned this study to evaluate the energy savings potential of LEDs in nine niche and emerging applications, consisting of three mobile and six stationary applications. In addition to on-board electricity savings, the energy saving impact of LEDs on fuel consumption for mobile applications is presented. For stationary applications, energy savings are presented both in terms of on-site electricity savings in trillion watt-hours (TWh) and primary energy savings at the power station level in trillion British thermal units (TBtu).

Methodology

A general methodology was applied across the niche markets to estimate the national energy consumption and savings of each application. Figure 1 illustrates the four critical inputs used to prepare an estimate of the energy consumption and the energy savings potential of each niche application. These include: number of lamps installed, annual operating hours, wattage per lamp and percent of LED market penetration. Estimates for these four critical inputs originate from literature and market studies, available databases, and interviews with researchers and industry experts.

Figure 1. National Energy Consumption Estimation Methodology



For the mobile niche market applications (e.g., automobile safety and signal lights), the method shown in Figure 1 was used to calculate the national energy consumption per year in terms of on-board electricity savings. This value was converted into fuel (gasoline, diesel and jet fuel) savings using estimates of the conversion efficiency of these vehicles and their electrical systems.

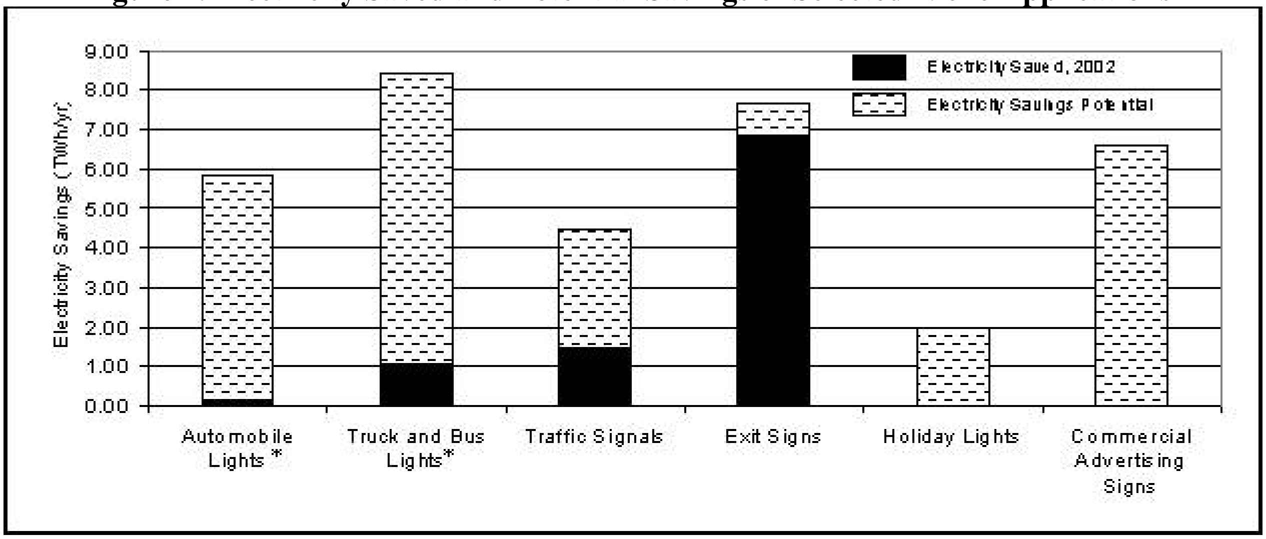
Due to the length constraints of this paper, only summary results are provided.[3]

[3] To review the complete analysis, please refer to the report- "Energy Savings Estimates of Light Emitting Diodes in Niche Lighting Applications," which can be found at http://www.netl.doe.gov/ ssl/PDFs/ Niche%20Final%20 Report.pdf

Results/Discussion

Figure 2 summarizes the electricity savings (at the site) from the six niche markets that represent the greatest savings potential with 100 percent LED penetration.

Figure 2. Electricity Saved and Potential Savings of Selected Niche Applications



*On-board electricity savings on mobile vehicle

In 2002, LED exit signs dominated national electricity savings attributable to LEDs, comprising 71% of the total energy savings from LEDs in 2002. The second most significant niche market in terms of energy savings was traffic signal heads, which represented approximately 15% of the total energy savings from LEDs.

Across the niche markets analyzed, significant opportunities for additional energy savings exist in the mobile transport applications as well as the stationary applications. Presently, approximately 13 TWh of additional on-board electricity savings are possible by increasing the market penetration of LEDs in mobile applications. Similarly, another 12 TWh of site electricity savings are available in other applications that are grid-connected.

The current combined energy savings of LEDs in these niche applications is 9.6 TWh per year, or the equivalent annual output of a large (1,000 MW) electric power station. And, the analysis estimates an additional 25.5 TWh per year if 100% of these niche markets switch to LEDs. This assumes no growth in the energy consumption of these applications after 2002; therefore, savings potential may be even higher as these markets expand.

Mobile Niche Applications

LED sources began penetrating mobile transport-related applications in the early 1990s, with the incorporation of LEDs in the center high mount stop light (CHMSL) (also called the "third brake light") on automobiles, as well as brake and indicator lights on freight trucks and buses. Within a decade, due in part to technological improvements, reduced costs, and long operating lives (reducing maintenance costs), mobile transportation applications are now one of the fastest growing markets for LED devices.

Automobile safety and signal lighting. Automobile designers embraced LED technology, recognizing the flexibility it offers in design due to the small package size, durability, and long operating life. Similarly, safety advocates endorse LED signal lights in mobile applications due to their rapid on-time and system reliability. For example in brake-light applications, LED technology provides a 200-millisecond faster on-time than incandescent lamps, which at highway speeds of 65 MPH equates to 19.1 feet of additional stopping distance (Lumileds, 2000). As a result, LED brake lights can improve safety on our nation's highways.

Although market penetration is low, the energy savings potential of LEDs in automobile lights is significant. Nationally, it is estimated that if 100% of today's automobiles converted to LED lamps, approximately 1.4 billion gallons of gasoline could be saved every year, which is about four days of national consumption.[4]

Combining industry estimates of lamp and signal inventory, wattage, and operating hours, an estimate of the national energy consumption for traffic signal heads can be determined. Table 1 presents this estimate for automobiles in terms of on-board electricity consumed in 2002 and the cumulative electricity savings that would result if 100% of the market switched to LEDs.

Table 1. Automobile Lamp On-Board Electricity Consumption and Savings Estimates

Lamp Application	Annual On-board Electricity, 2002[5]	On-board Electricity Savings, 2002	Potential Additional Electricity Savings	Cumulative Electricity Savings
Automobiles	12.95 TWh/yr	0.172 TWh/yr	5.66 TWh/yr	5.83 TWh/yr

Based on estimated levels of market penetration, LEDs saved approximately 0.17 TWh/yr of on-board electricity in 2002. This is primarily due to the high number of CHMSLs that use LED sources. If the entire fleet of automobiles, approximately 221 million vehicles, switched to LED lights, an additional 5.66 TWh/yr would be saved, for a niche market cumulative energy savings potential of 5.83 TWh/yr. Converting this estimate to gasoline savings, an engine efficiency of 25% and an alternator and system efficiency of 50% was assumed. This equates to a total on-board electric power generation efficiency of 12.5%. Thus, the amount of fuel necessary to generate the annual electricity saved in each car, 26.3 kWh/yr, is about 6.3 gallons per car per year. Across the fleet of motor vehicles, this totals approximately 1.4 billion gallons of gasoline, or about four days of national consumption.[6]

Large truck and bus safety and signal lighting. In addition to energy savings, LEDs have created an opportunity for increased safety on our nation's roadways. LED lamps are well suited for truck and bus safety and signal lighting, where brightness and reliability are crucial. LED brake lights on large trucks provide considerable safety advantages over incandescent lamp performance. The energy savings from LED use in large trucks and buses is significant. As with the use of LED lamps in automobile lighting applications, widespread use of LEDs in this market could reduce oil imports and improve our national energy security. It is estimated that if

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[4] Based on national fuel consumption data collected by the Energy Information Administration. "Adjusted Sales for Transportation Use: Distillate Fuel Oil and Residual Fuel Oil, 2001." Table 23, Energy Information Administration Fuel Oil and Kerosene Sales 2001.

[5] Annual electricity consumption estimate for each application assumes current level of LED market penetration.

[6] Based on national fuel consumption data collected by the Energy Information Administration. "Petroleum Quick Stats." 2003.

100% of today's large trucks and buses used LED exterior lights, approximately 1.1 billion gallons of diesel fuel would be saved each year, about 12 days worth of national consumption.

Table 2 presents the national energy consumption estimate for trucks and buses in terms of on-board electricity consumed and saved in 2002 as a result of LED use, and the cumulative electricity savings that would result if 100% of the market switched to LEDs.

Table 2. Truck and Bus Lamp On-Board Electricity Consumption and Savings Estimate

Niche Application	Annual On-board Electricity, 2002	On-board Electricity Savings, 2002	Potential Additional Electricity Savings	Cumulative Electricity Savings
Buses	0.58 TWh/yr	0.41 TWh/yr	0.21 TWh/yr	0.61 TWh/yr
Large Trucks	11.2 TWh/yr	0.67 TWh/yr	7.15 TWh/yr	7.81 TWh/yr
Total	11.8 TWh/yr	1.07 TWh/yr	7.35 TWh/yr	8.43 TWh/yr

In total, trucks consume approximately twenty times more electricity from lighting than buses. This disparity is due mainly to a larger inventory of trucks (7.9 million vs. 750 thousand buses) and slightly more lamps per vehicle (47 lamps vs. 32 lamps for buses). It is also because the level of LED penetration in the nation's buses is considerably higher than for large trucks. In percentage terms, the level of LED penetration in certain fixtures on buses exceeds many other niche market applications considered in this report.

The on-board electricity savings for these vehicles in 2002, due to the use of LED lamps, was approximately 0.41 TWh/yr for buses and 0.67 TWh/yr for large trucks, or 1.07 TWh/yr in total. If SSL replaced all remaining incandescent lights, a further combined 7.35 TWh/yr could be saved in these markets. Thus, a cumulative total on-board electricity savings potential of 8.43 TWh/yr is possible in this niche market if all large trucks and buses switch to LED lighting.

Similar to automobiles, this on-board electricity savings is converted to more appropriate units for this sector – savings in diesel fuel. The estimated fuel savings calculation is based on the assumption that a reduction in electrical load will always translate into fuel consumption savings. For the analysis, an approximate diesel engine efficiency of 35% and an alternator efficiency of 50% were used. This equates to a total on-board power generation efficiency of 17.5%. The cumulative electricity savings (i.e., 2002 savings plus additional potential electricity savings) for this niche market generates 817.5 kWh/year of savings per bus. Across the fleet of buses, this equates to 81 million gallons of diesel or approximately 0.9 days of U.S. diesel fuel consumption.

Similar to buses, the relationship between the amount of fuel saved from a reduction in electricity consumption for large trucks is developed assuming an engine efficiency of 35% and an alternator efficiency of 50%. Thus, the amount of fuel saved due to the annual reduction of 994.4 kWh per truck equates to 131.5 gallons of diesel fuel saved per truck. Across the fleet of trucks, this totals 1,034 million gallons of diesel or approximately 11.4 days of U.S. diesel fuel consumption. Together, 100% LED safety and signal lighting on trucks and buses could save 1.11 billion gallons of diesel fuel.

Aircraft passenger reading lights. Before aircraft passenger reading lights, LED sources had been used in a limited number of specialized aircraft applications. For example, on select aircrafts, LED lamps illuminated the cockpit instrument panel or the no smoking and fasten seatbelt safety signs in the passenger cabin (Jevelle 2003). Aircraft passenger reading lights represent the first white-light, general-illumination application for LEDs driven by energy savings and other performance benefits.

The use of LED lamps in this application is projected to reduce electricity consumption on board planes, which in turn may contribute to jet fuel savings. The baseline energy consumption for passenger reading lights is approximately 0.00275 TWh/yr. Converting all the passenger reading lamps into LED devices would reduce the on-board electricity consumption by approximately 50%, saving 1.6 GWh/yr (0.0016 TWh/yr) over the baseline incandescent and halogen lamps.

A more useful energy savings metric from the commercial aircraft operator's perspective is achieved by converting these on-board electricity savings into jet fuel. Assuming a jet engine efficiency of 40% and an alternator and system efficiency of 50%, this equates to a total on-board power generation efficiency of 20%. The potential energy savings from 100% LED market penetration converts to approximately 375,000 gallons of jet fuel annually for the fleet of commercial aircraft.

Stationary Transportation Niches

As with the mobile applications, electricity is saved in transportation applications where LED sources are used to replace incandescent, neon, and other less efficacious technologies. The savings for these installations are presented in TWh for the nation, as well as TBtu of primary energy consumption saved at the power plant. This report evaluates three stationary niche market applications: traffic signals, railway signals, and airport taxiway edge lights.

Traffic signal heads. The energy savings potential of LEDs for traffic signals is substantial, and they have already achieved a reasonable level of penetration due to compelling economic value and national market transformation initiatives, such as the ENERGY STAR® program and the Consortium for Energy Efficiency's Energy-Efficient Traffic Signal Initiative. The longer life of LEDs translates into less frequent relamping and lower maintenance costs. Although a red LED traffic signal costs about \$40 compared to \$3 for an incandescent signal, the lower energy consumption and extended operating life (and associated maintenance savings) equate to lower life-cycle costs. For example, the life-cycle cost of ownership of red LED traffic signals is about one-third that of incandescent traffic signal lamps over a seven-year period (CEE 2002).

Combining industry estimates of lamp and signal inventory, wattage, and operating hours, an estimate of the national energy consumption for traffic signal heads can be determined. Traffic signals considered in analysis include: red colored ball, yellow colored ball, green colored ball, red arrow, green arrow, yellow bi-modal arrow, green bi-modal arrow, walking person, and red hand – stop. Table 3 presents this estimate in terms of on-board electricity consumed in 2002 and the cumulative electricity savings that would result if 100% of the market switched to LEDs.

Table 3. Traffic Signal Energy Consumption and Savings Estimate

Niche Application	Annual Electricity, 2002	Electricity Savings, 2002	Potential Additional Electricity Savings	Cumulative Electricity Savings
Traffic Signals	3.41 TWh/yr	1.48 TWh/yr	3.02 TWh/yr	4.50 TWh/yr

The current level of LED traffic signal market penetration decreased national energy consumption by 1.48 TWh/yr, from 4.89 TWh/yr to 3.41 TWh/yr. Converting the remaining stock of incandescent traffic signals to LED will save an additional 3.02 TWh/yr. In terms of primary energy consumption, these estimates translate into 16.2 TBtu/yr of energy savings from existing market penetration, and a further 33.1 TBtu of savings that could be captured if the remainder of incandescent traffic signals convert to LED. Considering both present and potential energy savings, traffic signals could save approximately 4.5 TWh/year, half the annual output of a large (1,000 MW) electric power station.

Railway signal heads. On a national level, the energy savings potential of LEDs in railway signals is relatively small due to the low number of signals as well as fewer operating hours compared to traffic signals. However, the railroad industry favors LED sources because of their longer life, lower maintenance costs, and increased reliability. Slowly, railroads and government entities are beginning to retrofit incandescent lamps with LED lamps (Scheerer 2003).
Railway signal lamps considered in the analysis include: color-lights, position-lights, color-position-lights, searchlight color-lights, grade crossing signals, flashing light, and gate-tip lights.

To date, LED railway signal retrofits decreased national energy consumption by about 0.001 TWh/yr. The potential energy savings with 100% LED market penetration will save a cumulative total of 0.015 TWh/yr, or 0.16 TBtu in primary energy. While the energy savings are significantly smaller than other applications, there are many benefits driving the market towards the adoption of LED railway signal heads, including: longer life, lower maintenance costs, higher reliability, lower life-cycle costs, and higher reliability.

Airport taxiway edge lights. Airport taxiway edge lighting represents a relatively small niche market in terms of energy consumption and energy savings. Although energy savings estimates are not yet quantified for all types of runway lighting, the FAA and LED manufacturers believe there will eventually be energy savings from retrofitting incandescent airport runway lights with LED technology (Smith 2003; Woehler 2003).

Considering all the 14 CFR Part 139 certified airports[7] in the United States, approximately 0.05 TWh/yr of electricity (0.53 TBtu/yr of primary energy) could be saved if all taxiway edge lights convert to LED.

Other Stationary LED Applications

Three other stationary niche market applications were evaluated, including commercial advertising signage, exit signs, and holiday lights. Table 4 presents the energy consumption and savings estimates for the stationary LED applications. In terms of the magnitude of potential on-grid energy savings, commercial signage is the most promising niche application considered in this report, with potential additional savings of 6.61 TWh/yr.

Table 4. Stationary LED Energy Consumption and Savings Estimate

[7] 14 CFR part 139 requires the FAA to issue airport operating certificates to airports that serve scheduled and unscheduled air carrier aircraft with more than 30 seats or that the FAA Administrator requires to have a certificate.

Application	Annual Electricity, 2001	Electricity Savings, 2001	Potential Additional Electricity Savings	Cumulative Electricity Savings
Commercial Signs	10.06 TWh/yr	0.0 TWh/yr	6.61 TWh/yr	6.61 TWh/yr
Exit Signs	2.57 TWh/yr	6.86 TWh/yr	0.80 TWh/yr	7.67 TWh/yr
Holiday Lights	2.22 TWh/yr	0.0 TWh/yr	2.00 TWh/yr	2.00 TWh/yr

Commercial and advertising signs. In terms of the magnitude of potential on-grid energy savings, this niche application is the most promising one identified in this analysis. The current market penetration of LEDs into channel letter signs is assumed to be zero percent, as the technology was only introduced in 2001 (Jevelle 2003).[8]

Table 4, above, presents the energy consumption estimate for commercial advertising signs. Converting all the neon signs in this baseline inventory to LED would save approximately 6.6 TWh/yr, reducing energy consumption from 10.06 TWh/year to 3.46 TWh/yr. In terms of primary energy consumption, these savings estimates translate into 72.5 TBtu per year if 100% of the installed base converts to LED sources.

There are several benefits in addition to energy savings that are driving the adoption of LEDs to illuminate commercial advertising signs, including: minimal light loss, longer life, lower operating voltages, ease of installation and maintenance, and design flexibility.

Exit signs. Due to favorable economics, better performance, enhanced safety capabilities, and marketing programs such as ENERGY STAR® Exit Signs, LED exit signs already captured a significant share of this market, over 80%. Seven percent of exit signs are still incandescent, and a remaining two percent are compact fluorescent (Steele 2003). The number of installed LED exit signs is already more than 26 million and only about 1.6 million incandescent exit signs remain in the market.

LED exit signs contributed 6.86 TWh of electricity savings in 2002. A further 0.80 TWh remains to be converted, to realize the 100% LED energy savings potential of 7.67 TWh/yr. In terms of primary energy consumption, the energy savings in 2002 translates into 75.2 TBtu/yr with a further 8.8 TBtu of annual savings potential. Thus, in total, 84 TBtu/yr could be captured if 100% of the installed base moved to LED.

Holiday lights. Over the last two years, LEDs have started to carve a small niche in the holiday minilight market. While LEDs have significant benefits, such as operating lifetimes more than 30 times longer than traditional miniature lights and energy consumption 90% lower per lamp (WSU 2002), the LED penetration in this market is still in its nascent stages due to a high first cost ($13-$18 per string) and for this analysis was assumed to be zero (Brite-Lite 2004).

[8] Other types of advertising signage (e.g. cabinet signs) are not considered because suitable LED replacements do not exist.

The annual energy consumption of holiday lights can be estimated as the product of the installed base, the operating hours, and the wattage of each lamp. The average wattage of each miniature lamp is 0.4 watts (WSU 2002). For 37.1 billion lamps operating 150 hours per year each consuming 0.4 watts equates to 2.22 TWh of electricity consumption annually, or 24.3 TBtu of primary energy consumption.

An LED mini-lamp consumes only 0.04 watts, which is 90% less than its incandescent counterpart. Therefore, the potential annual energy savings from a total market shift to LED holiday lights are approximately 2.0 TWh, or 21.9 TBtu of primary energy consumption.

Conclusion

LEDs are emerging as a competitive lighting technology, capturing market share in several niche applications from incandescent and neon light sources. Primarily cost-effective in colored-light applications, LEDs proved to be economically viable in many niche markets. Furthermore, LEDs are replacing other sources, because they offer a better quality, more reliable lighting service.

Table 5 summarizes the energy savings analysis, in both electricity consumption and primary (fuel) consumption. Some sectors have estimates of zero percent LED penetration, thus contribute no savings to the total of 9.6 TWh.

Table 5. Energy Consumption and Savings in 2002 of Applications Evaluated

Application	Annual Energy Consumption [9]	LED Market Penetration	Electricity Savings 2002	Fuel/Primary Energy Savings 2002
Mobile Transportation Applications				
Automobile Lights	12.95 TWh	1–2%	0.17 TWh	41.3 Mgal gasoline (4.9 TBtu)
Large Truck and Bus Lights	11.80 TWh	5–7/ 41%	1.07 TWh	142.1 Mgal diesel (19.9 TBtu)
Aircraft Passenger Lights	0.003 TWh	0%	0.0 TWh	0.0 gal jet (0.0 TBtu)
Stationary Transportation Applications				
Traffic Signals	3.41 TWh	30%	1.48 TWh	16.2 TBtu
Railway Signals	0.025 TWh	3–4 %	0.001 TWh	0.007 TBtu
Airport Taxiway Edge Lights	0.06 TWh	1–1.5 %	0.001 TWh	0.007 TBtu
Other Stationary Applications				
Exit Signs	2.57 TWh	80%	6.86 TWh	75.2 TBtu
Holiday Lights	2.22 TWh	0%	0.0 TWh	0.0 TBtu
Commercial Advertising Signs	10.06 TWh	0%	0.0 TWh	0.0 TBtu
Total	**43.1 TWh**	**-**	**9.6 TWh**	**116.1 TBtu**

Note: Mgal = million gallons; primary energy of fuel savings represents energy content of fuel only.

In 2002, LED exit signs dominated national electricity savings, where LEDs have an estimated 80% market penetration. This niche market represents 71% of the total energy savings attributable to LEDs in 2002. The second most significant niche market in terms of energy savings was traffic signal heads. In this application, approximately 30% of the signals are LED,

[9] Annual energy consumption estimate for each application assumes current level of LED market penetration.

and represent approximately 15% of the total energy savings from LEDs. Other applications, such as aircraft passenger lights, holiday lights, and commercial advertising signs, are estimated to have zero LED market penetration. Commercial LED products for these applications are available; however, large-scale market adoption has yet to occur.

Table 6 presents the future energy savings potential from converting the remainder of each market entirely to LEDs, as well as the cumulative (total) potential energy savings. Across the niche markets analyzed, there are significant opportunities for additional energy savings in the mobile transport applications as well as the stationary applications. Presently, approximately 13 TWh of additional on-board electricity savings are possible through the growing market penetration of LEDs in the mobile application sectors. Similarly, another 12 TWh of site electricity savings are available in commercial advertising signs, traffic signals, holiday lights, exit signs and the other applications that are grid-connected. If these opportunities are fully realized, combined with the savings already captured today, approximately 554.2 TBtu of national energy consumption could be avoided. This represents one half of a quad (0.55 Quadrillion Btu, "Quad"), or approximately one half of one percent of total national energy consumption in 2002.

Table 6. Potential and Cumulative Energy Savings of Applications Evaluated

Application	Potential Electricity Savings[10]	Potential Fuel / Primary Energy Savings	Cumulative Electricity Savings[11]	Cumulative Fuel / Primary Energy Savings
Mobile Transportation Applications				
Automobile Lights	5.66 TWh	1.36 Bgal gasoline (164.9 TBtu)	5.83 TWh	1.40 Bgal gasoline (170.0 TBtu)
Large Truck and Bus Lights	7.35 TWh	972.5 Mgal diesel (136.2 TBtu)	8.43 TWh	1.11 Bgal diesel (156.0 TBtu)
Aircraft Passenger Lights	0.002 TWh	0.38 Mgal jet (0.05 TBtu)	0.002 TWh	0.38 Mgal jet (0.05 TBtu)
Stationary Transportation Applications				
Traffic Signals	3.02 TWh	33.1 TBtu	4.50 TWh	49.27 TBtu
Railway Signals	0.014 TWh	0.15 TBtu	0.015 TWh	0.16 TBtu
Airport Taxiway Edge Lights	0.05 TWh	0.53 TBtu	0.05 TWh	0.53 TBtu
Other Stationary Applications				
Exit Signs	0.80 TWh	8.8 TBtu	7.67 TWh	84.00 TBtu
Holiday Lights	2.00 TWh	21.9 TBtu	2.00 TWh	21.88 TBtu
Commercial Advertising Signs	6.61 TWh	72.5 TBtu	6.61 TWh	72.47 TBtu
Total	**25.5 TWh**	**438.0 TBtu**	**35.1 TWh**	**554.2 TBtu**

Note: Mgal = million gallons; Bgal = billion gallons; primary energy of fuel savings represents energy content of fuel only.

Each niche market analyzed in this report covers the particular LED benefits, in addition to energy savings, that are most relevant to a given application. Benefits include:

[10] Potential electricity savings represent the electricity that would be saved if the remainder of each niche market converts to LED sources. For some markets (e.g., airplane passenger lights) this represents the entire installed base as the 2002 penetration is assumed to be zero.

[11] Cumulative electricity savings represent the sum of the current savings estimate (2002) and the potential electricity savings from the conversion of the remainder of each niche market to LED.

1. Reduced Heat Production - Because of their higher relative efficiency in certain applications, the heat generated by LED fixtures is lower. This reduces the need for air-conditioning or heat extraction technologies that may be required, particularly if the LED device is replacing an incandescent light source. Industry is conducting ongoing research into LED heat management, as it is a major engineering challenge in LED product development.[12]
2. Long Operating Life and Lower Maintenance Costs - LED technology offers lamp operating lives that are significantly longer than those of incandescent sources. In certain automobiles, LED tail-lights are being installed that will exceed the operating life of the vehicle – never needing replacement. Research indicates that operating life will continue to improve with technology breakthroughs and advancements. A longer product operating life reduces maintenance costs.
3. Durability – The light production mechanism for LED devices enables it to resist vibration and impact, making it an ideal light source for automobile and truck tail-lights, bridge lights, and aircraft lights. In these applications, hot (incandescent) filaments are more susceptible to failure when they are exposed to vibration or shock while operating.
4. Smaller Package Size – LED devices are an excellent option where size is constrained. For example, more car trunk space is available for automobiles that utilize LED tail lamps. The tail-light fixtures become much thinner (depth into the trunk is reduced), and accessibility panels can be eliminated because the lamps will continue to operate beyond the useful operating life of the automobile.
5. Safety Improvements – LED devices offer several safety advantages, including faster on-times and safer operating voltage. At highway speeds of approximately 65 miles per hour, the 200 millisecond faster on-time equates to an extra 19 feet of stopping distance – the length of a full-size car. LED devices work on lower voltages than competing technologies, such as neon and fluorescent, which require several thousand volts.
6. Light Control – LEDs can make optical design easier because the optics can be built into the LED at the chip level, thereby negating the need for complex luminaire optics. For example, LED automobile headlamps are capable of directing all the light onto the road surface ahead, rather than dazzling an oncoming driver. Or, for aircraft reading lamps, the illuminated area can be tightly defined so as to avoid disturbing other passengers. LED lamps can utilize a concentrating lens constructed from an epoxy encapsulant to direct the light emitted from the LED chip in the desired direction.
7. Lower Operating Cost - LED lamps can consume less energy than their incandescent counterparts and this reduced energy consumption leads in lower operating costs.

In recent years, LEDs entered the lighting market, offering consumers performance and features exceeding those of traditional lighting technologies. LEDs can be found in a range of niche market applications involving colored light emission, such as exit signs, traffic signals, and airport taxiway lights. As LED technology advances–reducing costs and improving efficiency–LEDs will build market share in these and other niche markets.

[12] All heat produced by LEDs is conducted heat, unlike an incandescent source that is predominantly radiated heat.

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