Energy Savings Estimates of Light Emitting Diodes in Niche Lighting Applications

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Foreword

This analysis of niche markets and applications for light emitting diodes (LEDs) was undertaken on behalf of the U.S. Department of Energy to develop a more complete understanding of the energy savings resulting from the use of LEDs and the factors that are motivating consumers to adopt this new technology.

Comments

The Department is interested in receiving input on the material presented in this report. If you have suggestions of better data sources and/or comments on the findings presented in this report, please submit your feedback to Dr. James R. Brodrick by November 30, 2004 at the following address:

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ACEEE	American Council for an Energy Efficient Economy
BNSF	Burlington Northern Santa Fe Railroad
CASE	Codes and Standards Enhancement
CBECS	Commercial Buildings Energy Consumption Survey
CEE	Consortium for Energy Efficiency
CFL	Compact Fluorescent Lamp
CHMSL	Center High Mount Stop Lamp
DS&L	Dayton Signal and Light
DOE	Department of Energy
DOT	Department of Transportation
DSM	Demand Side Management
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FRA	Federal Railroad Administration
ICC	International Codes Council
ITE	Institute of Transport Engineers
LBNL	Lawrence Berkeley National Laboratory
LED	Light Emitting Diode
LRC	Lighting Research Center
MIRL	Medium Intensity Runway Light
NAL	North American Lighting
NCI	Navigant Consulting Incorporated
NEC	National Electrical Code
NEMA	National Electrical Manufacturers Association
NHTSA	National Highway Traffic Safety Administration
NPIAS	National Plan of Integrated Airport Systems
ORNL	Oak Ridge National Laboratory
PG&E	Pacific Gas and Electric
REIL	Runway End Identifier Lights
RPI	Rensselaer Polytechnic Institute
RVR	Runway Visual Range
SAE	Society of Automotive Engineers
SSL	Solid State Lighting
STMG	ST Media Group
SUV	Sport Utility Vehicle
TDZL	Touch Down Zone Lighting
TRD	Transportation Development Center
TWh	Terawatt-hour
USCG	United States Coast Guard
USITC	United States International Trade Commission
W	Watt
WSU	Washington State University

Executive Summary

Light Emitting Diodes (LEDs), a type of Solid State Lighting (SSL), offer the electric lighting market a new and revolutionary light source that saves energy and improves quality, performance, and service. Today, LEDs are competing successfully with conventional, incandescent light sources that use color filters to generate the desired colored light emission, such as those found in traffic signals and exit signs. In these and other applications, LEDs are used because they offer more cost-effective performance than incandescent lamps.

This report presents research findings for twelve different niche and emerging markets where LEDs are competing or are poised to compete with traditional light sources. Traditional light sources such as incandescent, fluorescent, and neon are being challenged by LEDs, which offer lower operating costs and better reliability and performance. This report presents estimates of the energy saved due to estimated current levels of LED market penetration. The "overnight" technical potential energy savings if these markets switched completely to LEDs is also estimated. The markets considered are classified into three groups:

Mobile Transportation Applications
- Automobile Safety and Signal Lighting
- Large Truck and Bus Safety and Signal Lighting
- Aircraft Passenger Reading Lighting
- Lighted Navigational Aids (Water Buoys)

Stationary Transportation Applications
- Traffic Signal Heads
- Railway Signal Heads
- Airport Taxiway Edge Lights
- Navigational Bridge Lights

Other Stationary Applications
- Exit Signs
- Holiday Lights
- Commercial Refrigerated Display Cases
- Commercial Advertising Signs

This study found that the applications where LEDs have the highest level of market penetration are colored-light applications such as traffic signals, exit signs, and truck and bus safety and signal lights. In these installations, LEDs have the advantage of only producing light in the color of interest to the end-user, thus they can do so more efficiently and reliably than filtered full-spectrum sources. The applications where market adoption has started and is poised to grow include automobile safety and signal lights, aircraft passenger reading lights, airport taxiway edge lights, commercial advertising signs and holiday lights. In these, as in all applications, LEDs are being selected not only because they save energy, but because of their long operating life and associated lower maintenance costs. These and other ancillary benefits of using LEDs are discussed in detail in each of the application reviews.

This report presents the findings of analysis on these twelve LED niche markets, addressing four fundamental questions:

- How much energy is consumed by lighting technologies in these applications?
- What is the estimated market penetration of LED technology today?
- What are the energy savings resulting from the current level of LED market penetration?
- What would the energy savings be from 100% LED market penetration?

For the electricity saved in mobile transportation applications, energy savings are reported not only in watt-hours of onboard electricity consumption, but also in primary fuel (e.g., gasoline) savings associated with the lower accessory load on the engine. For stationary transportation and other stationary applications, energy savings are reported in both trillion watt-hours (TWh) of national electricity savings as well as trillion British thermal units (TBtu) of primary energy consumption saved at the power plant level from the avoided electricity.

Figure ES.1 summarizes the electricity savings (at the site) from the six niche markets that represent the greatest savings potential.

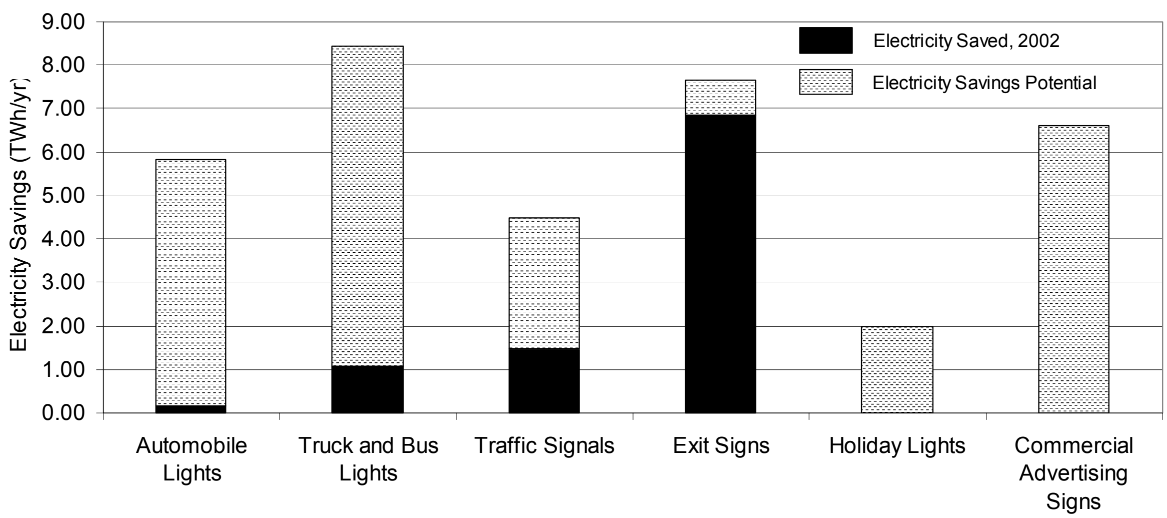

Figure ES.1 Electricity Saved and Potential Savings of Selected Niche Applications

The cumulative total of the electricity savings in 2002 shown in figure ES.1 in these niche markets in this report is 9.6 TWh. Considering only those applications that are grid-connected, approximately 8.3 TWh of electricity consumption was saved in 2002, more than the equivalent output of one large (1,000 MW) electric power station.[1] The balance, approximately 1.24 TWh per year is avoided onboard electricity consumption by automobiles, trucks, and buses. This represents approximately 41 million gallons of gasoline by automobiles and 142 million gallons of diesel fuel by large trucks and buses annually. To put these figures in perspective, the Department of Energy estimates that the total annual energy consumption for all lighting technologies in the U.S. was 765 TWh in 2001[2] (DOE, 2002a). All the stationary applications considered in this report are part of the commercial sector, which was estimated to consume approximately 391 TWh for lighting (DOE, 2002a).

Table ES.1 provides a detailed summary including 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. Three sectors, navigational aids (water buoys), navigation bridge lights, and refrigerated display cases, where inconsistent or had data availability problems that prevented estimates from being prepared, and are omitted from this table. Information on these and all the sectors can be found in the body of the report.

Table ES.1 Energy Consumption and Savings in 2002 of Applications Evaluated

Application	Annual Energy[3]	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.

[1] Assumes 1,000 MW electric output, operating at a 90% annual availability.
[2] This report did not consider “mobile” light sources, such as the energy consumed by automobile, truck, and bus safety and signal lighting.
[3] Annual energy consumption estimate for each application assumes current level of LED market penetration.

As shown in Table ES.1, the electricity savings attributable to LEDs in 2002 are dominated by exit signs, where they have achieved an estimated 80% market penetration. This niche market represents 71% of the total energy savings attributable to LEDs in 2002. The second most significant energy saving niche market in 2002 was traffic signal heads. In this application, approximately 30% of the signals are estimated to incorporate LED technology, representing approximately 15% of the total energy savings from LEDs in 2002. Other applications such as aircraft passenger lights, holiday lights, and commercial advertising signs were estimated to have insignificant market penetration of LEDs. Commercial LED products are available in these markets, however adoption has yet to occur.

Table ES.2 presents the potential energy savings in each market from converting the remainder of the sockets to LED technology. It also presents the cumulative energy savings (i.e., the 2002 savings plus the remaining potential) attributable to LEDs for each market for a complete conversion to LED relative to the conventional lighting technology.

Table ES.2 Potential and Cumulative Energy Savings of Applications Evaluated

Application	Potential Electricity Savings[4]	Potential Fuel / Primary Energy Savings	Cumulative Electricity Savings[5]	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.

[4] 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.
[5] 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.

For mobile transportation applications, large truck and bus lights and automobile lights represent the greatest future savings potential from the adoption of LED sources. And, on a cumulative basis, incorporating savings already achieved in 2002, more than 1.4 billion gallons of gasoline and 1.1 billion gallons of diesel fuel could be saved if the entire fleet of automobiles, trucks, and buses were converted to LED. For automobiles, this represents approximately four days of national gasoline consumption, or approximately 30 days of oil flow in the Alaska pipeline at full capacity. For trucks and buses, the 1.1 billion gallons of diesel represents over twelve days of national consumption.

The commercial advertising signs, traffic signals, and holiday lights represent the top three stationary applications with future savings potential for LEDs. Of these, commercial advertising signs appear to be the most promising, with 6.6 TWh of potential savings.

While greater energy efficiency is an important aspect of LED sources, there are several qualities that compel lighting users to adopt this technology over conventional light sources. These features enable users to enjoy better service, extended operating life, and enhanced safety. The following list describes some of these benefits:

- Reduced Energy Consumption – LED devices can offer a more energy efficient means of producing light, particularly when compared to incandescent sources. In an application such as a traffic signal, an 11W LED red signal head replaces a 140W reflector lamp – a 92% reduction in energy consumption - while complying with the same safety standards. And as solid state lighting technology evolves, the efficiency of these devices will continue to improve, enabling even greater energy savings through conversion to LED.

- Long Operating Life – Commercial and industrial specifiers are generally interested in using a light source that is reliable and lasts a long time. Frequent lamp replacements can be costly from a maintenance perspective, and failed lamps could expose lamp operators to liabilities (e.g., traffic signals or exit signs). In fact, maintenance savings are one of the primary reasons behind market adoption of LEDs in several markets, such as truck and bus signal lighting. Presently, LED technology offers operating lives that are approximately ten times 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 and never creating a risk of non-functional brake lights. Researchers indicate that operating life will continue to improve as the technology develops.

- Durability – the light production mechanism for LED devices is fundamentally different from traditional light sources such as incandescent. LED sources produce light by passing a current through thin layers of a semi-conductive material, which causes the material to emit light. Inherent in this solid-state light production mechanism is the ability of the source to resist vibration and impact, making it an ideal light source for automobile, truck, and bus safety and signal lighting, aircraft passenger reading lights, and navigational bridge lights. In these applications, hot (incandescent) filaments are more susceptible to filament failure when they are exposed to vibration or shock while operating.

- Reduced Heat Production – Since LED devices are more efficient at converting electricity into useful light than incandescent sources, 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 or halogen light source. However, further research needs to address heat management issues, particularly in aircraft reading lights, as heat production shortens LED operating life.

- Smaller Package Size – Due to their compact size, LED devices are an excellent option where size or weight is a concern. For example, automobile trunk space can be expanded in vehicles that utilize LED tail lamps. This is possible because the tail-light fixtures are much thinner (depth into the trunk is reduced), and the accessibility panels can be eliminated because the lamps never need to be replaced.

- Safety Improvements – LED devices offer a faster "on" time, meaning from the time a current is applied, light is emitted faster from an LED source than from an incandescent source. At highway speeds of approximately 65 miles per hour, the faster on-time of 200 milliseconds over some filament lamps equates to an extra 19 feet of stopping distance – the length of a full-size car.

- Light Control – LED devices offer distinct advantages where light encroachment or glare is a problem. For example, LED automobile headlamps have better control of the direction of light onto the road surface ahead with minimal "leakage" to dazzle oncoming drivers. Or, in aircraft passenger reading lights, the illuminated area can be more tightly defined, minimizing disturbance of adjoining passengers who may be trying to sleep or watch a movie.

These and other qualities of LED sources are encouraging the marketplace to adopt LED technology in niche applications today, and general illumination applications in the future. As the market for LED technologies expands, industry will continue to develop manufacturing processes that reduce the cost of LED lamps, which will accelerate market adoption.

1. Introduction

In recent years, light emitting diodes (LEDs) have 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.

1.1. LED Technology Background

In 1968, General Electric invented the first LED, a gallium phosphide semiconductor with properties that resembled the transistor – high tolerance for shock and vibration and long operating life. While the efficacy[6] of this first red-color LED was extremely low (approximately 1 lumen per watt), researchers have developed and improved this technology over the past three decades, developing the colored LED devices we see today that offer more than 100 lumens per watt.

Compared to incandescent or high-intensity discharge lamps, LEDs produce light using a fundamentally different principle. Whereas the traditional light sources produce light by heating an element to incandescence or establishing an electrical arc through a gas amalgam, LEDs emit light from a small semiconducting chip when a current is applied to it. LEDs are semiconductors created by bringing together similar materials with slightly different electronic properties to create a “PN junction”. In a PN junction, the “P” material contains an excess of positive charges (also called holes) due to the absence of electrons. The “N” material contains an excess of negative charges due to the presence of electrons. When a voltage is applied to this PN junction, the electrons and the holes combine, releasing energy that can take the form of light.

Unlike a light source such as the incandescent lamp, LEDs emit light in a narrow wavelength band, making the emission appear colored. That is to say, LEDs can emit infrared, red, yellow, green, blue, or ultraviolet light, but today are not able to emit white light, as that requires the ability to produce a distribution of wavelengths simultaneously which blend together to create white. Since the General Electric breakthrough in 1968, research has focused on developing new LED semiconductor materials to emit all the colors of the spectrum. Research has also improved the efficacy and power handling capability of LED devices themselves, enabling them to now compete with conventional technologies in colored lighting applications. Many of these applications where LEDs compete or are poised to compete are discussed in this report.

White light applications, which LEDs are only just starting to access, are today based on a blue or ultraviolet emitting LED chip emitting light into a phosphor that distributes the light emission across the visible spectrum, creating white-light. Assembling three or more LED chips that emit in the blue, green and red spectral zones can also create white-

[6] Efficacy is a measure of the ability of a light producing device to convert input power into light. It is measured in lumens per watt, or lumens of light output per watt of power input.

light LED packages. In this type of multi-chip design, the individual light emission from each of the chips will blend to create a white-light emission from the package. However, this approach is currently more expensive than the phosphor method. White light can also be created with just two LEDs, (e.g. yellow and blue), when good color rendering is not critical.

1.2. Niche Markets Reviewed

The Department identified twelve LED niche market applications for this study. Shown in Table 1-1, these niche markets are grouped into three general categories: mobile transportation applications, stationary transportation applications, and other stationary applications. The baseline energy consumption of some of these niche markets may be very small, however they were studied to understand some of the benefits of LED technology that are encouraging various markets to convert.

Table 1-1. Summary of Niche Markets Evaluated in this Report

Niche Market	Colored Light	White Light
Mobile Transportation Applications		
Automobile Safety and Signal Lighting	X	X
Large Truck and Bus Lighting	X	X
Aircraft Passenger Reading Lighting		X
Lighted Navigational Aids (Water Buoys)	X	
Stationary Transportation Applications		
Traffic Signal Heads	X	
Railway Signal Heads	X	
Airport Taxiway Edge Lights	X	
Navigational Bridge Lights	X	
Other Stationary Applications		
Exit Signs	X	
Holiday Lights	X	X
Commercial Refrigerated Display Cases		X
Commercial Advertising Signs	X	X

The Department recognizes that the niche markets evaluated in this report do not represent an exhaustive list of all the applications and installations where LED devices can be found today. In addition to these, other popular niche market applications for LED devices include bicycle safety lights (front and back), camping/task head-lamps, flashlights, indicator lights on electronic goods, novelty sneaker flashing lights, and display screen illumination. These other niche applications were not included in this analysis because they are primarily battery-powered and each constitutes too small an application to be evaluated.

1.3. Estimated National Energy Consumption Methodology

This study evaluates the energy savings potential of LEDs in niche and emerging applications. Twelve applications are reviewed, consisting of four mobile and eight stationary niche applications. In addition to onboard electricity savings, the mobile applications assess the energy saving impact of LEDs on fuel consumption. For the stationary applications, energy savings are presented both in terms of onsite electricity savings in trillion watt-hours (TWh) and primary energy savings at the power station level (in trillion british thermal units (TBtu).

A general methodology was applied across the twelve niche markets to estimate the national energy consumption of each market. Figure 1-1 illustrates the four critical pieces used to prepare an estimate of the energy consumption and the energy savings potential of each niche application. These include: the number of lamps installed, the annual operating hours, the wattage per lamp and the percent of LED market penetration.

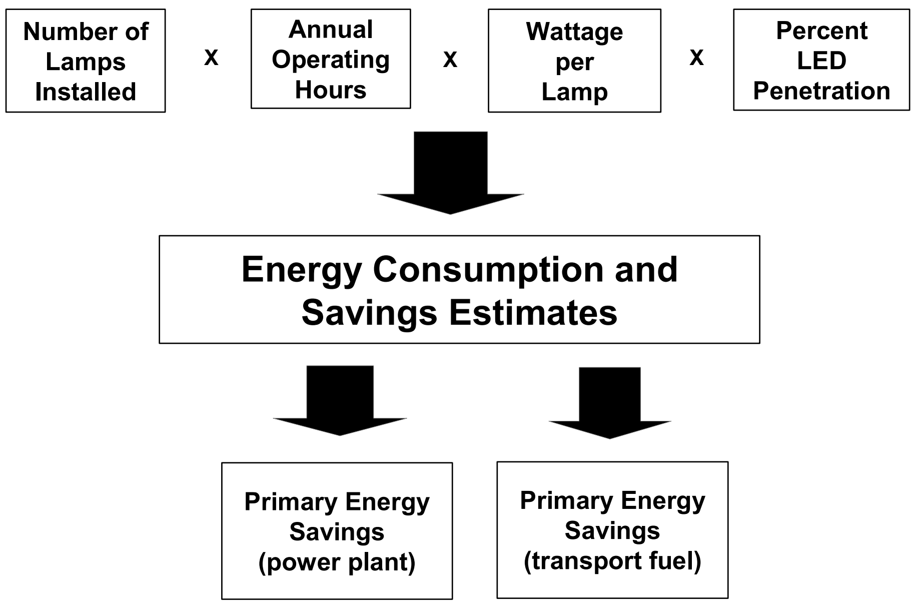

Figure 1-1 National Energy Consumption Estimation Methodology

The four critical pieces were estimated by reviewing literature and market studies, examining available databases, and conducting interviews with researchers and industry experts. The specific sources and any variances on this energy consumption methodology are described at the start of each niche market section.

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

2. Mobile Transportation Applications

LED sources began penetrating mobile transport-related applications in the early 1990s, with the use 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 (producing maintenance savings), mobile transportation applications are now one of the fastest growing markets for LED devices. Automobile designers have embraced the technology, recognizing the flexibility it offers in design due to the small package size and long operating life. Similarly, safety advocates endorse LED signal lights in mobile applications due to their rapid on-time, and never having to worry about a burnt-out tail-light.

For this report, four mobile niche market applications were evaluated: automobiles, large trucks and buses, aircraft passenger reading lights, and lighted navigational aids (commonly know as water buoys). These four applications are all considered "mobile" because they are not connected to the electrical grid, and must rely on electricity generated on-board the vehicles for their light sources. Highly efficient LED sources offer these niche markets lower overall energy consumption, while providing a superior, reliable, and more cost-effective service.

The conversion of the onboard electricity savings in automobiles, trucks, and buses into fuel savings is accomplished using an estimate of the onboard electricity generation efficiency (engine and alternator) for each of the three types of vehicles. For energy savings in aircraft jet fuel, a conversion estimate was provided by an industry source.

2.1. Automobile Safety and Signal Lighting

Although market penetration has been 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. This is equivalent to approximately four days of national gasoline consumption (EIA, 2003).

2.1.1. Introduction

No study was identified that examined the energy consumption of automobile safety and signal lighting; therefore, a number of sources were contacted to prepare a national estimate. Sources researched and contacted for the four critical inputs to the energy consumption and savings estimates are summarized in Table 2-1.

Table 2-1. Critical Inputs for Automobile Lights National Energy Estimates

Critical Input	Notes and Sources
Installed Base of Lamps	National vehicle fleet: Edward Kashuba and Barna Johasz of the Federal Highway Administration, U.S. Department of Transportation. Average number of lamps per automobile: Jianzhong Jiao, North American Lighting.
Annual Operating Hours	Estimates for operating hours of lamps: Jeff Erion, Visteon Advanced Lighting Group. Estimates for operating hours of lamps: Jianzhong Jiao, North American Lighting.
Lamp Wattages	Estimates of the lamp wattages: John Bullough, Lighting Research Center, Rensselaer Polytechnic Institute; Jeff Erion, Visteon Advanced Lighting; Jianzhong Jiao, North American Lighting; John Vines, Dialight.
Lighting Technology Mix	Estimate of the percent penetration LEDs: Jianzhong Jiao, North American Lighting.

2.1.2. Automobile Lamp Installed Base

According to the Federal Highway Administration, there are approximately 221,821,000 registered motor vehicles in the United States. These motor vehicles include passenger cars, vans, pickup trucks and SUVs, but exclude commercial and occupational vehicles (Kashuba, 2003; Johasz, 2003). While the installed number of lights on an automobile can vary between and within motor vehicle classes, an estimate of the average number of lamps for an average motor vehicle was supplied (Jiao, 2003). There are approximately twenty-eight exterior lights on these motor vehicles, as shown in Table 2-2.

Table 2-2: Automobile Exterior Light Installed Base, by Lamp Application

Lamp Application	Average Lamps per Vehicle	Installed Base (lamps)
Headlamps - High Beam	2	443,642,000
Headlamps - Low Beam	2	443,642,000
Front Turn Signals	2	443,642,000
Front Parking Lamps	2	443,642,000
Rear Stop Lamps and Turn Signals	4	887,284,000
Rear Tail Lamps	4	887,284,000
CHMSL, Exterior Mount [A]	1	88,728,000
CHMSL, Interior Mount [B]	1	133,093,000
License Plate	2	332,732,000
Reverse Indicator	2	443,642,000
Side Marker	2	443,642,000
Fog Lamps [C]	2	133,093,000
Daytime Running Lamps [D]	2	133,093,000
Totals:	**28 lamps**	**5,257,159,000**

[A] Approximately 40% of motor vehicles are equipped with exterior mounted CHMSLs.
[B] Approximately 60% of motor vehicles are equipped with interior mounted CHMSLs.
[C] Approximately 30% of motor vehicles are equipped with fog lamps (Jiao, 2003).
[D] Approximately 30% of motor vehicles are equipped with daytime running lamps (Jiao, 2003).

Automobile interior lights were not considered in this analysis. There are a range of estimates of the number of interior lights from as few as 6 to as many as 300 (Godwin, 2003). And, unlike exterior lights, interior lights are not regulated by safety standards and in many cases are considered aesthetic. Furthermore, with the exception of dashboard lights, the operating hours of most interior lights are considerably shorter than those on the exterior of vehicles. Interior lights are a driving distraction at night, and tend only to operate when someone enters or exits the vehicle. For these reasons, the analysis will focus on exterior lights.

2.1.3. Automobile Lamp Operating Hours

Estimates for the operating hours of each of the safety and signal lights are provided in Table 2-3. The low beam, parking, tail, license plate, and side marker lights operate for approximately 240 hours per year (Erion, 2003). High beams operate for approximately 24 hours per year (Erion, 2003), and fog lamps operate approximately 120 hours per year (Jiao, 2003). The operating time for turn signals, reverse lamps, and brakes vary widely with the demographics and driving habits of each vehicle operator. Estimates of 2 minutes per day for reverse lamps, 5 minutes per day for turn signals and 10 minutes per day for brake lights were generated for use in the analysis. Daytime running lamps are operational for all driving time when the low or high beams are not in use, or approximately 19 minutes per day (Jiao, 2003). The approximate operating time for each lamp, in both minutes per day and hours per year, is shown in Table 2-3.

Table 2-3: Estimated Operating Hours of Exterior Automobile Lights

Lamp Application	Operating Time (minutes/day)	Operating Time (hours/year)
Headlamps - High Beam	3.9	24
Headlamps - Low Beam	39.5	240
Front Turn Signals	5	30
Front Parking Lamps	39.5	240
Rear Stop Lamps and Turn Signals	10	61
Rear Tail Lamps	39.5	240
CHMSL, Exterior Mount	10	61
CHMSL, Interior Mount	10	61
License Plate	39.5	240
Reverse Indicator	2	12
Side Marker	39.5	240
Fog Lamps	19.7	120
Daytime Running Lamps	19	116

Sources: Erion, 2003; Jiao, 2003.

2.1.4. Automobile Lamp Average Wattages

The estimated average wattage for each of the motor vehicle lamp applications is provided in Table 2-4. Estimates of incandescent and LED wattages are shown, as well as percent energy savings associated with the switch to LED lamps. At present, there are no commercially available LED replacements for fog lamps, so the corresponding energy savings for this lamp is zero (Vines, 2003).

An approximation of the wattage consumption while driving at night can be calculated by adding the low beam headlamps, front parking lamps, tail combination, and license plate lamps, totaling approximately 162 watts. If all of these lamps were switched to LED, the wattage consumption would be approximately 93 watts, a savings of 43% for this situation.

Table 2-4: Estimated Wattages of Automobile Lamps

Lamp Application	Incandescent Wattage	LED Wattage	Percent Savings with LED
Headlamps – High Beam	65 watts	50 watts	23%
Headlamps – Low Beam	55 watts	40 watts	27%
Front Turn Signals	25 watts	8 watts	68%
Front Parking Lamps	8 watts	1.5 watts	81%
Rear Stop Lamps & Turn Signals	26 watts	8 watts	69%
Rear Tail Lamps	7 watts	2 watts	71%
CHMSL, Exterior Mount	18 watts	2 watts	89%
CHMSL, Interior Mount	36 watts	5 watts	86%
License Plate	4 watts	1 watt	75%
Reverse Indicator	25 watts	2.5 watts	90%
Side Marker	3 watts	1 watt	67%
Fog Lamps	40 watts	not available	0%
Daytime Running Lamps	40 watts	31 watts	27%

It should be noted that the LED wattages shown in Table 2-4 represent products available in 2002. As research and development continues to advance this technology, the wattages of LED substitutes in automobile lamps will decline, increasing the energy savings potential. This expectation is particularly true for LED headlamps, which presently only offer a 27% improvement over incandescent.

This analysis is based on an incandescent baseline, and does not consider HID headlamps. Although the current market penetration of HID headlamps is low (~1%), the market is poised to grow. Over the coming years, the baseline wattage for headlamps may be reduced, perhaps affecting the potential energy savings of retrofitting with LED lamps (Bullough, 2003a).

2.1.5. Automobile Lamps Energy Saving Potential

LEDs have already begun to capture market share from traditional mobile light sources, due to their durability, efficiency, and enhanced safety qualities. Estimates of the current level of market penetration of LEDs are relatively high for CHMSLs, but very low to non-existent for other applications. The estimated penetration of LED lamps for the CHMSL in new vehicles is approximately 30% to 45%, while for older vehicles it's approximately 20% (Jiao, 2003). For this analysis, a simple average of 35% was used. In all other vehicle lamps, the level of LED penetration is much lower, ranging from 0% to 2% (Jiao, 2003). For this analysis, it was assumed that 2% of the vehicle stock has LED turn signals, parking lamps, rear stop and turn lights, and side marker lights. It was further assumed that there is no market penetration of LED in headlamps, daytime running lamps (prototypes only), license plate lamps, reverse indicator lamps, and fog lamps.

The estimated national energy consumption combines the installed base, operating hours, wattages, and current level of LED penetration. Table 2-5 presents the estimated baseline energy consumption, and the potential electricity savings over the 2002 consumption figures if the entire market switched to LED sources.

Table 2-5: Automobile Lamp Energy Consumption and Savings Estimates

Lamp Application	Annual Electricity 2002 (TWh/yr)	Electricity Savings 2002 (TWh/yr)	Potential Electricity Savings (TWh/yr)	Cumulative Electricity Savings (TWh/yr)
Headlamps - High Beam	0.69	0.000	0.16	0.16
Headlamps - Low Beam	5.86	0.000	1.60	1.60
Front Turn Signals	0.34	0.005	0.23	0.23
Front Parking Lamps	0.86	0.014	0.70	0.72
Rear Stop & Turn Signals	1.39	0.015	0.96	0.97
Rear Tail Lamps	1.52	0.017	1.09	1.11
CHMSL, Exterior Mount	0.07	0.030	0.06	0.09
CHMSL, Interior Mount	0.20	0.088	0.16	0.25
License Plate	0.32	0.000	0.25	0.25
Reverse Indicator	0.13	0.000	0.12	0.12
Side Marker	0.32	0.004	0.20	0.20
Fog Lamps	0.64	0.000	0.00	0.00
Daytime Running Lamps	0.62	0.000	0.14	0.14
Total:	**12.95**	**0.172**	**5.66**	**5.83**

Based on the estimated levels of LED market penetration, approximately 0.17 TWh/yr of onboard electricity was saved in 2002. This is primarily from the high number of CHMSLs that use LED sources. If the entire fleet of automobiles were to switch to LED lights, an additional 5.66 TWh/yr would be saved, for a niche market cumulative energy savings potential of 5.83 TWh. To put this in a more convenient metric for this sector, the electricity savings potential shown in Table 2-6 converts the findings into annual fuel consumption savings.

Table 2-6: Converting Electricity to Fuel Savings for Automobiles

Variable	Value
Number of vehicles	221,821,000 cars
Total potential energy savings from load reduction (TWh)	5.83 TWh
Energy savings per vehicle (kWh/vehicle/year)	26.3 kWh / car
Alternator efficiency	50%
Engine efficiency	25%
'Primary' energy saved per vehicle (estimate)	210 kWh / car
Energy content of gasoline (kWh/gallon)	33.4 kWh/gallon
Gallons gasoline saved per car	6.3 gallons / car
Total gallons gasoline savings, 100% LED penetration	**1,397 million gallons**

The relationship between the amount of fuel saved from a reduction in onboard electricity consumption is a theoretical estimate, based on an engine efficiency of 25% and an alternator and system efficiency of 50%. This equates to a total onboard 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 gasoline consumption (EIA, 2003).

2.1.6. Technology Benefits in Addition to Energy Savings

In addition to energy savings, there are several complimentary benefits that compel automobile manufacturers to start using LED technology for safety and signal lighting on their vehicles. Some of these benefits include:

1. *Quick on-time*. When a current is applied, LEDs are able to emit light faster than incandescent lamps. When LED technology is used in brake-light applications, it provides a 170 to 200-millisecond faster turn-on time than incandescent lamps. At highway speeds of 65 MPH, this equates to 19.1 feet of additional stopping distance (LumiLeds, 2000). As a result, use of LED brake lights may reduce the number of accidents, fatalities, and associated economic costs. Also, many researchers believe that compared to filtered incandescent lamps, the luminous characteristics of LEDs may increase the neural stimulus to the brain. LED lamps could produce even more rapid reactions with associated safety benefits.

2. *Compact size*. The small, compact design of LED assemblies enables them to fit into areas where traditional incandescent bulbs cannot. And, the operating life of some of today's LED sources exceeds that of the vehicle itself, using the operating hour assumptions in Table 2-3. LEDs also eliminate the need for bulb replacement access panels, saving additional trunk space.

3. *Warranty cost savings to the manufacturer*. Due to their extended operating life, LEDs also eliminate the need for incandescent bulb replacements under

manufacturer's warranties (Godwin & Vines, 2003). Turn, tail, or stop lamps do not require high temperature plastics or heat shields and can be thin enough to eliminate the need for additional clearance in the car body (Jennato, 2003).

4. *Reliability*. The long lifetime of LED exterior lights compared with incandescent lamps makes the technology more reliable. Manufacturers anticipate that customers will not need to service this part of the automobile for its complete operating lifetime.

5. *Design Flexibility*. Due to their compact size and relatively low operating voltage requirements, LEDs can be arranged to create new, interesting, and unique visual designs incorporating function and style.

2.2. Large Truck and Bus Safety and Signal Lighting

The energy savings potential due to LED use in large trucks and buses is significant, and LEDs have achieved a reasonable level of penetration in these types of vehicles today. As with the use of LED lamps in automobile lighting applications, widespread use of LEDs in this market will directly reduce oil imports and improve our national energy security. It is estimated that if 100% of today's large trucks and buses used LED exterior lights, approximately 1.1 billion gallons of diesel fuel would be saved every year. This is equivalent to approximately 12 days of U.S. diesel fuel consumption (EIA, 2002).

2.2.1. Introduction

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, as brightness and reliability are crucial. The use of LED brake lights on large trucks provides considerable safety advantages due to their performance under voltage dips that diminish incandescent lamp performance. A recent study found that voltages across large truck signal lamps can drop to around 5.5 volts, considerably lower than the 12 volts normally required for normal lamp operation (Lumileds, 2000). At this level, the turn-on time of incandescent bulbs increases by a factor of two (UMTRI, 1993).

No study was identified that examined the energy consumption of large truck and bus safety and signal lighting; therefore, a number of sources were contacted to prepare a national estimate. Sources researched and contacted for the four critical inputs to the energy consumption and savings estimates are summarized in Table 2-7.

Table 2-7: Critical Inputs for Trucks and Buses National Energy Estimates

Critical Input	Notes and Sources
Installed Base of Lamps	Estimated number of vehicles: Edward Kashuba and Barna Johasz of the Federal Highway Administration, U.S. Department of Transportation. Average number of lamps per vehicle: National Highway Traffic Safety Administration
Annual Operating Hours	Estimates for both large trucks and buses: John Vines, Dialight; Bradley Van Riper, Truck-Lite.
Lamp Wattages	Estimates of average lamp wattages: John Vines, Dialight; Bradley Van Riper, Truck-Lite.
Lighting Technology Mix	Estimates of LED market penetration: John Vines, Dialight; Bradley Van Riper, Truck-Lite.

2.2.2. Installed Lamp Base for Large Trucks and Buses

The installed base of safety and indicator lamps on large trucks and buses is the product of the number of vehicles in service and the average number of lamps per vehicle. Due to the considerable number of lamp applications on large trucks and buses, tables that show the lamp applications in detail are given in Appendix A of this report.

There are approximately 750,000 registered buses in the United States (Kashuba, 2003; Johasz, 2003). The average number of exterior lamps per bus was derived from the minimum lighting requirements for buses, published by the National Highway Traffic Safety Administration (NHTSA, 2002). The list of lamp applications, number of lamps per bus, and installed base of lamps appear as the first three columns in Appendix A, Table A.1. In total, buses have approximately 32 exterior lights, resulting in an installed base of 24 million lamps.

There are approximately 7.9 million single unit two-axle, six-tire or more and combination trucks registered in the United States (Kashuba, 2003; Johasz, 2003). The average number of exterior lamps per truck is also determined by the minimum lighting requirements (NHTSA, 2002). Similar to buses, the list of lamp applications, number of lamps per vehicle, and installed base of lamps appear as the first three columns in Appendix A, Table A.2. In total, large trucks have an average of 47 lamps per vehicle, resulting in an installed base of 284 million lamps.

2.2.3. Lamp Operating Hours for Trucks and Buses

The operating hours for lamps on buses are based on estimates from industry sources. Experts estimated the marker, clearance, identification, and tail lamps of buses operate on average 12 to 14 hours per day (Vines, 2003). The turn, stop, and hazard signals for buses operate approximately 1 hour per day, and the reverse indicator lamps on buses operate just 10% of that time, or 6 minutes per day. (Van Riper, 2003). High beam headlamps on public transit buses are rarely used, but some tour buses use their high beams as much as 9% of the vehicle's operating time. Thus, on average, high beam headlamps are assumed to operate approximately 50 minutes per day (Van Riper, 2003).

The operating hours for lamps in large trucks are also derived from industry sources. For trucks, the marker, clearance, identification, and tail lamps are estimated to operate approximately 10 hours per day (Vines, 2003). Operating hours for turn, stop, and hazard signals are split due to driving conditions. Industry sources estimate that approximately 65% of the fleet operate these lamps for 8 minutes per day while 35% operate them for about 66 minutes per day (Van Riper, 2003). The reverse indicator lamps operate approximately 10% of the estimated turn, stop, and hazard signal time, or approximately 1 to 6 minutes per day (Van Riper, 2003).

More details of the operating hour estimates used in the calculation can be found in Appendix A, in Table A.1 for buses and Table A.2 for large trucks. In both instances, the operating hours per day appear in column 4 and the operating hours per year appear in column 5.

2.2.4. Average Wattages for Lamps used in Large Trucks and Buses

Estimates of the average wattage for each of the lamp applications were prepared based on consultation with industry experts (Vines, 2003; Van Riper, 2003). For buses, the wattages vary across the applications, from less than 5 watts to as many as 65 watts. The front identification and clearance lights, license plate light, and all marker lights are approximately 4.6 watts. The stop lamps, rear turn signal / hazard warning lamps, and reverse indicator lamp are approximately 28 watts. The low beams are approximately 55 watts and the high beams are 65 watts (operated simultaneously with low beams).

For trucks, the wattages estimated are approximately the same as those used for buses, although the number of some of the lamps installed on the average vehicle is higher. Front identification and clearance lights, the license plate light, and all marker lights are approximately 4.6 watts. The stop lamps, rear turn signal / hazard warning lamps, and reverse indicator lamps are approximately 28 watts. Similarly, the low beams are approximately 55 watts and the high beams are 65 watts.

2.2.5. Energy Savings Potential for Trucks and Buses Niche Market

The exterior lights of many large trucks and buses have already been retrofitted or installed with LED signal lamps. The market penetration of LED lamps in new trucks is approximately 20%, and the retrofit market penetration is approximately 5% (Vines, 2003). In the bus market, the level of market penetration of LEDs is very high – approximately 75% to 90% of the external lights on buses (Vines, 2003). To date however, LEDs have not been used to replace headlamps on either trucks or buses. This is due to the fact that LED headlamps are still assembled as prototypes and have not gone into commercial production yet.

Combining the industry estimates of lamp (vehicle) inventory, wattage, and operating hours, an estimate of the national energy consumption can be determined. Table 2-8 presents this estimate for trucks and buses in terms of onboard electricity consumed in 2002 and the cumulative electricity savings that would result if 100% of the market switched to LEDs (note that some applications have done so already, and are included in this estimate).

Table 2-8: Truck and Bus Lamp Energy Consumption and Savings Estimate

Niche Application	Annual Electricity 2002 (TWh/yr)	Electricity Savings 2002 (TWh/yr)	Potential Electricity Savings (TWh/yr)	Cumulative Electricity Savings (TWh/yr)
Buses	0.58	0.41	0.21	0.61
Large Trucks	11.2	0.67	7.15	7.81
Total	**11.8**	**1.07**	**7.35**	**8.43**

On an aggregate basis, trucks consume approximately twenty times more electricity from lighting than buses. This disparity is due in part to a higher inventory of large trucks (7.9 million vs. 750 thousand buses) and slightly more lights per vehicle (47 lamps vs. 32

lamps for buses). It is also because the level of market penetration of LED lamps used on the nation's inventory of buses is considerably higher than that of large trucks. In percentage terms, the level of LED penetration in certain fixtures on buses exceed many of the other niche market applications considered in this report.

The electricity savings on-board the vehicles in 2002 due to the use of LED lamps is approximately 0.41 TWh/yr for buses and 0.67 TWh/yr for large trucks. In total then, approximately 1.07 TWh/yr were saved in 2002 due to LED lighting already operating in the field. And, if all the remaining incandescent lights were to convert to SSL, a further 7.35 TWh/yr could be saved in both markets. Thus, as shown in Table 2-8, a cumulative total electricity savings potential of 8.43 TWh/yr is possible in this niche market if 100% of the market switches to LED lighting. This represents a savings potential of 1.1 billion gallons of diesel fuel annually.

Similar to automobiles, this on-board electricity savings is converted to more useful 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 onboard power generation efficiency of 17.5%. Table 2-9 provides details on the calculation of fuel savings from on-board electricity savings for buses.

Table 2-9: Converting Electricity to Fuel Savings for Buses

Variable	Value
Number of Vehicles	750,000 buses
Total Potential Energy Savings from Load Reduction (TWh)	0.61 TWh
Energy Savings per Vehicle (kWh/vehicle)	817.5 kWh/bus
Alternator Efficiency	50%
Engine Efficiency	35%
"Primary" Energy Saved per Vehicle	4,671 kWh/bus
Energy of Diesel (kWh/gallon)	43.2 kWh/gallon
Gallons Saved per Bus	108 gallons / bus
Total Gallons Saved (millions)	81 million gallons / year
Total Gallons Consumed per Day (millions)	91 million gallons / day
Days of Consumption Reduced	**0.9 days**

Thus, the cumulative electricity savings (i.e., 2002 savings plus additional potential electricity savings) for this niche market generates an 817.5 kWh/year 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 (EIA, 2002).

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%. Table 2-10 provides the fuel estimate calculation for large trucks.

Table 2-10: Converting Electricity to Fuel Savings for Trucks

Variable	Value
Number of Vehicles	7,900,000 trucks
Total Potential Energy Savings from Load Reduction (TWh)	7.81 TWh
Energy Savings per Vehicle (kWh/vehicle)	994.4 kWh/truck
Alternator Efficiency	50%
Engine Efficiency	35%
"Primary" Energy Saved per Vehicle	5,682 kWh/truck
Energy of Diesel (kWh/gallon)	43.2 kWh/gallon
Gallons Saved per Truck	131.5 gallons/truck
Total Gallons Saved (millions)	1,034 million gallons
Total Gallons Consumed per Day (millions)	91 million gallons / day
Days of Consumption Reduced	**11.4 days**

Thus, the amount of fuel saved due to the annual reduction of 994.4 kWh per truck equates 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 (EIA, 2002). Together, trucks and buses could save 1.11 billion gallons of diesel fuel, which equates to 156 TBtu in energy content of diesel fuel.

2.2.6. Technology Benefits in Addition to Energy Savings

Due to the high value put on the safety and reliability of signal lighting for these commercial vehicles, as well as the benefits associated with reduced maintenance costs, the sector has already experienced a relatively strong market shift LED signal lights. In addition to energy savings, these and other benefits that encourage bus and truck manufacturers to incorporate and retrofit their vehicles with LED signal lights are listed below:

1. *Long Operating Life* - One of the main reasons commercial trucking companies and bus operators switch to LED is that they can reduce maintenance costs associated with preserving the road-worthiness of their fleets (Van Riper, 2003). Additionally, since there are so many lights on a typical tractor and trailer, the greater durability (vibration resistance) and longer operating lives of LEDs can reduce any liabilities or fines associated with failed tail or indicator lamps.

2. *Quick On-Set Time* - A quick turn-on time is crucial for exterior brake lights on large vehicles in order to prevent accidents. As discussed earlier, this can translate into approximately 20 feet of additional stopping distance for vehicles following

the truck or bus.

3. *Safety Braking* – Another advantage of LEDs is that their low energy consumption makes more power (current) available for the antilock braking system, which in turn, could contribute to safer braking practices under slippery conditions (Van Riper, 2003).

4. *Cost Savings To The Manufacturer* - LED design enables high-speed manufacturing processes to be used in assembly (Jennato, 2003). Due to their vehicle lifetime reliability, LEDs also eliminate the need for warranty-based replacement of incandescent bulbs, thus creating additional savings for the bus or truck manufacturer (Godwin, 2003; Vines, 2003).

2.3. Aircraft Passenger Reading Lights

This niche market represents the first white-light, general-illumination application for LEDs, driven by energy savings and other performance benefits. Most of the niche markets considered in this report concentrate on colored light installations. 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.

2.3.1. Introduction

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). These initial installations represented the industry's initial experimentation with white-light LED devices, which promise a longer operational life than halogen lamps, greater vibration tolerance, less heat generation, and a smaller package size (Jevelle, 2003).

Manufacturers are now actively working to develop an LED-based fixture that can be used to replace the halogen and incandescent reading lamps used in virtually all of today's commercial aircraft fleet. Product development work is focused on creating a package that can match the lumen output of halogen and incandescent sources. At current efficiency levels, LED passenger reading lamps consume 50% less electricity than halogen sources (Goodrich Hella, 2003). As white-light LED lamps become more efficient, the percent energy savings is expected to increase.

There is no study available that provides the energy consumption for aircraft passenger reading lamps; therefore, a number of sources were contacted to prepare a national estimate. As with the other niche market assessments, there were four critical inputs used in preparing the energy consumption and savings estimates, summarized in Table 2-11.

Table 2-11: Critical Inputs for Aircraft Passenger Reading Lights Energy Estimates

Critical Input	Notes and Sources
Installed Base of Lamps	Number of Planes, Number of Seats per Plane: Federal Aviation Administration, 1997.
Annual Operating Hours	Hours of Flight Service: Federal Aviation Administration, 1997. Aircraft Occupancy: Department of Transportation, 2002. Passenger Use of Reading Light: John Craig, The Boeing Company
Lamp Wattages	Halogen Lamp Wattages: David Walker, Welch Allyn; Goodrich Hella. LED Lamp Wattages: Goodrich Hella, 2003a & 2003b; David Walker, Welch Allyn.
Lighting Technology Mix	Percentage Market Penetration: David Walker, Welch Allyn; Paula Jevelle, LEDtronics.

In reviewing a draft of this analysis, a manufacturer expressed concern whether today's LED technology could provide sufficient light for this application. The main issue is the approximate distance (five feet) between the light source and the passenger's reading material (Walker, 2003). Over this distance, light disperses, reducing illuminance for the passenger. However, Airbus, the European aircraft manufacturer, has tested LED prototypes and found that the products offer satisfactory performance. Airbus has started using LED passenger reading lights on certain aircraft, including an A330-300 series aircraft delivered to Northwest Airlines in July 2003 which will enter service this autumn (Walker, 2003).

2.3.2. Installed Base and Operating Hours of Aircraft Passenger Reading Lights

The Federal Aviation Administration (FAA) tracks the annual in-flight hours of commercial aircraft, by manufacturer and model. For instance, data are recorded on the cumulative annual flight hours for all Boeing 747 aircrafts, inclusive of all airlines and all flights in a given year. The most current data available are for 1996[7]. In the absence of more recent data, these values are used in the analysis to represent current annual flight hours. The number of seats (and thus reading lamps) by type of aircraft was obtained from the manufacturers' websites.[8] These data are summarized in Table 2-12, which apportions the approximately 1.9 billion seat-hours of aircraft passenger travel in 1996 by aircraft. To calculate the baseline energy consumption, the available seat hours of service are adjusted for load factor (passengers per plane) and utilization rate (portion of flight when passengers choose to operate the reading light).

[7] Although this data is six years before 2002, the cumulative number of passenger enplanements was approximately 560 million in both 1996 and 2002 (DOT, 2002a & 2002b), therefore this detailed data was used to prepare the 2002 travel estimate.

[8] Several smaller aircraft with a negligible number of flying hours (<10,000 hours) were not included in the energy savings estimate calculation.

Table 2-12: Number of Seats and Total Flight Hours for Commercial Aircraft

Classification	Manufacturer	Model	Number of Seats (lamps)	Total Flight Hours
Turbojet- 4 Engine	Boeing	B707	141	7,814
	Boeing	B747	416	576,063
	British Aerospace	BAE146	70	45,722
	Douglas[9]	DC8	117	304,923
Turbojet- 3 Engine	Boeing	B727	106	1,443,603
	Douglas	DC-10/MD11	285	682,265
	Lockheed	L1011	230	252,277
Turbojet- 2 Engine	Airbus	A330	266	137,969
	Airbus	A310	220	37,265
	Airbus	A320	150	315,645
	Boeing	B737	177	2,825,711
	Boeing	B757	201	1,308,237
	Boeing	B777	328	42,918
	Canadair	CL-600	40	107,279
	Douglas	DC-9/MD-80	75	2,803,885
	Fokker	F28	90	356,958
Turboprop-4 Engine	DeHavilland	DHC7	50	10,697
Turboprop-2 Engine	Beech	BE99	15	10,697
	Beech	BE1900	9	405,293
	British Aerospace	Jetstream	18	370,659
	DeHavilland	DHC6	37	20,064
	DeHavilland	DHC8	40	304,138
	Embraer	EM120	30	479,034
	Saab-Fairchild	SF340	33	421,967
	Short	SD3	35	23,740
	S.N.I.A.S.	ATR42	42	201,635
	S.N.I.A.S.	ATR72	64	97,819
	Swearingen	SA227	15	132,657
	Cessna	C402	7	70,916
Total	**All Aircraft**	**All Models**	**1,871,514,000 seat hours/year**	

Source: Federal Aviation Administration, 1997

An estimate of the occupancy rate, or load factor, of those seats was obtained from the Department of Transportation (DOT). The DOT found that the average load factor for all domestic flights in 2001 was 69% (DOT, 2002c), meaning that, on average, seats on all U.S. flights were 69% occupied. An estimate of the percent of in-flight time that a passenger chooses to operate their reading light was obtained from the Payload Electrical Group at Boeing Aircraft. This group of experts estimated the percentage of in-flight time that a passenger chooses to use the reading light at approximately 10-25% of total

[9] Now owned by Boeing.

flight time (Craig, 2003). This estimate is not a strict analysis of the installed fleet, but an estimate based on industry experience. For this niche market analysis, a midpoint of 18% was used to calculate the operating hours. Applying the adjustment for occupancy and the adjustment for utilization of reading lamps, the annual number of seat-hours of reading-lamp operation in the entire commercial aircraft fleet was calculated to be approximately 239,180,000.

2.3.3. Average Wattage of Aircraft Passenger Reading Lights

While the business jet subgroup already has a high percentage of LED reading lamps, the much larger commercial aircraft fleet uses halogen lamps virtually exclusively (Walker, 2003).[10] Typical wattage ranges for aircraft reading lights are shown in Table 2-13. A midpoint of these ranges was used as the average wattage when calculating energy consumption and savings.

Table 2-13: Installed Reading Lamp Wattage by Type

Reading Lamp	Wattage Range	Estimated Average Wattage
Halogen	10.0 to 11.5 Watts	10.75 Watts
Incandescent	16 to 21 Watts	18.5 Watts
LED	5.0 to 6.0 Watts	5.5 Watts

Sources: Walker, 2003; Jevelle, 2003; Goodrich Hella, 2003.

2.3.4. Energy Savings Potential of Aircraft Passenger Reading Lights

Baseline energy consumption is calculated as the product of the total number of passenger seat flight hours, the overall load factor (69%), and the percentage of time a passenger typically uses their reading light (18%). The energy consumption and LED savings potential in aircraft passenger reading lights is presented in Table 2-14. These on-board electricity savings are then converted to an estimate of jet fuel savings for the fleet of commercial aircraft.

Table 2-14: Aircraft Passenger Light Energy Consumption and Savings Estimate

Niche Application	Annual Electricity 2002 (TWh/yr)	Electricity Savings 2002 (TWh/yr)	Potential Electricity Savings (TWh/yr)	Cumulative Electricity Savings (TWh/yr)
Aircraft Passenger Reading Light	0.00275	0.0	0.0016	0.0016

10 Regional jet manufacturers, such as Embraer and Bombardier, generally use halogen for reading lamps, though other types, such as incandescent, may be used (Walker, 2003). In regional turboprops, a small fraction of the seat-flight hour metric, experts estimate that half the reading lights are halogen and the other half are incandescent (Walker, 2003). For this analysis, the market penetration of incandescent reading lamps is treated as zero percent.

Thus, 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 onboard electricity consumption by approximately 50%, saving 1.6 GWh/yr (0.0016 TWh/yr) over the baseline incandescent and halogen lamps.

A better energy savings metric from the commercial aircraft operators perspective is to convert these on-board electricity savings into jet fuel. The relationship between electrical power and the fuel consumption rate of an aircraft is complex. The primary variables are the efficiency of the jet engine (varies by model), the stage of flight, the ambient conditions during flight, and the conversion efficiency of the alternator and the inverter, as the reading lights operate on DC power. Allowing for these variables, an idealized estimate[11] of approximately 0.046 to 0.050 gal/kWh is used as a conversion rate for onboard electrical use to jet fuel consumption (Craig, 2003). Assuming a jet engine efficiency of 40% and an alternator and system efficiency of 50%, this equates to a total onboard power generation efficiency of 20%. Thus, the potential energy savings of 100% LED market penetration converts to approximately 375,000 gallons of jet fuel annually for the fleet of aircraft.

However, this fuel saving estimate may require further consideration. The Department is aware that some models of LED passenger reading lights weigh a few ounces more per system when compared to a halogen lamp baseline. This additional weight is due to the insertion of a heat sink and additional controlling circuitry (Walker, 2003). When summed over the number of seats of an aircraft, this could amount to a weight increase of 20-80 pounds[12], which would reduce the aforementioned fuel savings. That said, the circuitry, lens, and cooling fans are incorporated into the LED designs to improve the quality of the light produced. LED systems weighing less than halogen systems do exist, but with a decrease in the light performance and overall system quality (McLaughlin, 2003). Additionally, in new aircraft designs, because LEDs consume 50% less power, smaller control wire and onboard power generation systems can be reduced, partly offsetting the few ounces of additional weight per system (McLaughlin, 2003).

The calculations presented here represent a conservative estimate of the energy savings potential of LEDs in this application, with the potential savings being much greater. First, the energy efficiency of white-light LED devices is currently about twice that of halogen, and research and development is expected to improve efficacy six-fold over the next decade, creating even greater energy savings potential in the future (OIDA, 2002). In 2012, instead of a 50% reduction in wattage, LEDs are expected to offer airlines a greater than 90% reduction in wattage.

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[11] An idealized estimate of 0.046 gal/KWhr to 0.050 gal/KWhr can be used as a conversion factor from electrical load to jet fuel consumption. However, this estimate assumes a 100% efficient conversion, ignoring losses from the engine, alternator, and electrical system.

[12] Based on an estimate of 4 ounces more per LED system, compared to halogen, and 80-340 seats per aircraft.

2.3.5. Technology Benefits in Addition to Energy Savings

Along with energy savings, LED passenger reading lamps have other advantages, including:

1. *Longer Lifetime* – Even with today's technology, LED passenger reading lights have a longer operating lifetime (15,000 hrs) than their halogen counterparts (2,000 hrs) (Goodrich Hella, 2003a and 2003b). HPX hybrid halogen lamps, used in Boeing aircraft, have a lifetime of up to 10,000 hours (Walker, 2003). The operating lifetime of white-light LEDs is projected to increase over the next ten years to exceed 100,000 hours of service in 2012 (OIDA, 2002). As the operating lifetime of LED extends, the maintenance savings associated with replacing fewer passenger reading lamps will become a more significant factor.

2. *Less Light Leakage* - Due to the optical characteristics and the ability to control the light produced by the LED chip, lumen flux is easier to regulate and will create less light encroachment on the surrounding passengers.

3. *Lower Operating Temperature* - Compared to halogen lamps, LED sources do not project heat (infrared light) onto the passengers, operating at a cooler temperature, improving passenger comfort (McLaughlin, 2003).

2.4. Lighted Navigational Aids (Water Buoys)

The market transition to LED light sources in lighted navigational aids, more commonly know as water buoys, was not found to create energy savings, as with the other mobile transportation applications. This is because all lighted navigational aids are powered by photovoltaic cells, operating completely independently of the power grid. Use of LEDs on these distributed power systems is frequently accompanied by a downsizing in the photovoltaic array and battery, further reducing costs. But because the electricity source is renewable and independent in the first place, estimating the energy savings for this application is not relevant. Nevertheless, the use of LED sources in lighted navigational aids offers distinct safety advantages over incandescent sources. These include increased visibility in poor weather, extended operating life, and increased reliability in extreme environmental conditions.

2.4.1. Introduction

Waterway lighted navigational aids operate in isolation to demarcate a shipping perimeter or obstacle that should be avoided. Up until the 1960s, the United States Coast Guard (USCG) used acetylene gas to operate the light beacons mounted atop these navigational aids, as they had to operate independently of the electrical grid. Since that time, navigational aid lighting has transitioned to solar power (photovoltaics), in combination with lead acid batteries (Grasson, 2003). Although initially expensive, over time such solar systems are much less costly to operate since they avoid the maintenance costs of refueling necessary to operate gas-powered systems (Browning, 2003). These systems incorporate a photovoltaic panel and battery to store the electricity generated as well as an incandescent light whose operation is controlled by a photocell, from dusk to dawn.

In this application, the energy savings from greater LED use enables the operation of these systems with smaller solar arrays and battery packs. Thus, lighted navigational aids were identified as a niche application where LEDs are replacing the conventional technology, but since the baseline energy consumption was already derived from renewable sources, energy savings do not accrue to the nation.

During the past several years, the USCG has begun field trials with LEDs by replacing 3% of the incandescent lamps on their navigational aids with LED technology. (Grasson, 2003). LED-illuminated navigational aids offer several advantages over incandescent ones, particularly lower power consumption and longer operating life. By drawing approximately half as much power while providing the same critical service, LED sources enable the USCG to use smaller photovoltaic arrays and storage batteries.

Moreover, LED sources last several times longer than incandescent lamps, extending the time period between maintenance calls. The USCG realized the energy savings potential of LED systems over incandescent lamps, as well as the ability of the LED source to improve the visibility of the water buoy signal in heavy seas (Grasson, 2003).

The lower power consumption also improves reliability, enabling lighted navigational aids to operate for longer periods without needing sunlight to charge the batteries. LED sources are also better suited to handle vibration and hostile environments, such as those found at sea, making LEDs the natural choice for this application.

2.4.2. Technology Benefits in Addition to Energy Savings

The USCG field trials with LED lamps indicated they are more cost effective than incandescent lamps (Grasson, 2003). Recognizing the advantages, the USCG anticipates changing an increasing percentage of their coastal lighted navigational aids to operate on LEDs. The Coast Guard is now also working to modify the minimum performance safety standards for private navigational aids, which presently do not allow for LEDs (Grasson, 2003).

In addition to some of the advantages of LED lighted navigational aids cited above, including long operating hours and smaller, less expensive photovoltaic-battery power supplies, the USCG are transitioning to LED for the following reasons:

1. *Conspicuity* -Due to the concentration of light spectrum wavelength and focused control of light emission, LED devices can offer better visibility warning of submerged dangers for passing ships - the primary function of lighted navigational aids.

2. *High Tolerance for Temperature Variation* - Operational reliability in all weather conditions is critical. LED lamps have proven more durable and reliable, even in extremely cold conditions. Before it started using LED lamps, the Canadian Coast Guard used to replace all its lighted navigational aids seasonally with a summer and a winter model, each optimized for certain weather conditions. Now, they simply use one LED model and avoid changing their lighted navigational aids (TRD, 2002).

3. *Energy Efficient* - Through the higher efficacy of LEDs, less expensive power systems (photovoltaic cells and battery storage) are required, bringing down the overall system cost significantly, even though the LED signal light is more expensive than an incandescent lamp.

4. *Vibration Tolerant* – The LED chip is not susceptible to damage from vibration and other rough conditions that may be experienced at sea, making it more reliable than incandescent lamps in this application.

3. Stationary Transportation Niches

As with the mobile applications, electricity is saved in stationary transportation niche markets 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 station level.

For this report, four stationary niche market applications were evaluated: traffic signal heads, railway signal heads, navigation bridge lights, and airport taxiway edge lights. These four applications are all considered "stationary" because they are connected to the electrical grid. Although railway signals and bridge navigation lights represent very small energy savings opportunities, they employ the same technology for similar applications as traffic signal heads and airport taxiway edge lights.

3.1. Traffic Signal Heads

The energy savings potential of LEDs for traffic signals is substantial, and LEDs have already achieved a reasonable level of penetration due to national market transformation programs such as the Environmental Protection Agency's and the Department of Energy's ENERGY STAR® program and the Consortium for Energy Efficiency's (CEE's) Energy-Efficient Traffic Signal Initiative. Estimated primary energy savings in 2003 from the current level of LED penetration into the traffic signal market is 16.2 TBtu. Nationally, it is estimated that if remaining incandescent traffic signals were converted to LEDs, a further 33.1 TBtu of primary energy would be saved annually. On a cumulative basis, if all of the previously incandescent traffic signals were converted to LED, approximately 4.5 TWh of electricity, or about 49.3 TBtu of primary energy would be saved.

3.1.1. Introduction

Traffic signals are an integral part of the transportation system in the United States, safely regulating the movement of vehicles and people. Installed primarily in urban areas, where vehicular and pedestrian traffic is concentrated, these signals operate 24 hours per day.

For nearly the entire 20th century, traffic signals utilized incandescent light sources, as they were the only type of light source that could achieve the minimum performance requirements established by the Department of Transportation for light intensity. There are different performance standards for incandescent and LED traffic signals. However, in the past five to ten years, technology advances enabled LEDs to achieve the brightness, reliability, and control to compete in this niche market.

Today, LEDs are emerging as the technology of choice for traffic signal illumination. Municipalities all across the nation are retrofitting and installing new LED traffic signal heads. And, with continuing reductions in price and improvements in efficiency and performance, LED lamps offer a colored-light source that satisfies code requirements and displaces incandescent lamps. While they are initially more expensive than incandescent lamps, the long term cost savings and better quality of LEDs significantly outweigh the higher initial costs (Schmeltz, 2003). The market for traffic signals is clearly moving in the direction of LED light sources (Durgin, 2003; Larocca, 2003).

There is no single published study available of energy consumption for traffic signal lamps; therefore, a number of sources were contacted to prepare a national energy consumption estimate. As with the other niche market assessments, there are four critical inputs used in preparing the energy consumption and savings estimates, summarized in Table 3-1.

Table 3-1. Critical Inputs for Traffic Signals National Energy Estimates

Critical Input	Notes and Sources
Installed Base of Lamps	Number of Signalized Intersections: Gary Durgin, Dialight; Chris Larocca, GELcore; and Steve Bacilieri, Leotek. Number of Pedestrian Signals: Gary Peterson, LEDtronics.
Annual Operating Hours	Estimates for Flashing Time: Chris Larocca, GELcore. Estimates for Pedestrian Signals: U.S. Lighting Market Characterization, Volume I: National Lighting Inventory and Energy Consumption Estimate, Department of Energy, 2002a. Estimate for Three Colored-Ball Signals: Margaret Suozzo, ACEEE.
Lamp Wattages	Estimates of the Lamp Wattages: Bob Atkins, Cooper Lighting; Steve Bacilieri, Leotek Electronics; Gary Durgin, Dialight; Chris Larocca, GELcore.
Lighting Technology Mix	Estimate of the Percent Penetration LEDs: Steve Bacilieri, Leotek Electronics; Gary Durgin, Dialight; Richard Dixon, Compound Semiconductor; Robert Steele, Strategies Unlimited.

3.1.2. Installed Base of Traffic Signals

In the United States, there are approximately 312,500 signalized intersections.[13] At each intersection, up to three types of traffic signals, including the three-colored ball, arrow, and bi-modal arrow, can be found for the purposes of controlling traffic flow. In addition, approximately 75%, or about 234,400 intersections, also have pedestrian crossing signals (Peterson, 2003). The most common types of pedestrian crossing signals are a walking person and an orange hand.

To determine the installed base of each type of signal, data were acquired from existing studies, manufacturers, and the Institute of Transport Engineers (ITE). The collected data from each source were then averaged to get the estimated number of signals per intersection. This estimate was multiplied by the corresponding number of signalized or pedestrian-signalized intersections to approximate the total number of signals in the U.S.

[13] The approximation of the number of signalized intersections is the average of values provided by Gary Durgin, Dialight; Chris Larocca, GELcore; and Steve Bacilieri, Leotek.

Table 3-2 provides the average number of signals per intersection and the estimated total (Bacilieri, 2003; Cheeks, 2003; Crenshaw, 2003; Durgin, 2003; Larocca, 2003; Peterson, 2003).

Table 3-2: Estimated Number of Traffic Signals in the United States, 2003

Signal Type	Lamp Color	Average Number per Intersection	Estimated Number of Traffic Signals
Three-Colored Ball	Red	9.7	3,031,250
	Yellow	9.7	3,031,250
	Green	9.7	3,031,250
Arrow	Red	3.0	937,500
	Green	3.0	937,500
Bi-Modal Arrow	Yellow	1.0	312,500
	Green	1.0	312,500
Walking Person	White	8.0	1,875,000
Hand	Orange	8.0	1,875,000
Total			**15,343,750**

3.1.3. Operating Hours for Traffic Signals

Traffic signals operate 24 hours per day year-round, amounting to an annual operating cycle of 8,760 hours. Among these signals, less than two percent change to flashing mode for four to six hours at night (Larocca, 2003). For this reason, the impact of flashing time on a traffic signal's operational time is fairly negligible and thus signals are treated as being continuously on. In three-colored ball signals, the red lamp is illuminated 55% of the time over a 24-hour period, the green lamp 42%, and the yellow lamp 3% (Suozzo, 1998). Red and green arrows are estimated to operate approximately 9% of the time (DOE, 2002a). The assumption for the operating hours of pedestrian signals was modeled with each of the "walk" and "don't walk" signals off half the time, on one-quarter, and flashing for one-quarter of the time (DOE, 2002a). Thus, pedestrian signals, such as white walking people and orange hands, are each illuminated about 31% of the time, or 7.5 hours per day (DOE, 2002a). The corresponding operating hours per year for each signal type and lamp color are presented in Table 3-3.

Table 3-3: Traffic Signal Operating Hours by Lamp Type and Color

Signal Type	Lamp Color	Utilization Factor	Operating Hours (hours/yr)
Three-Colored – Ball	Red	55%	4,818
	Yellow	3%	263
	Green	42%	3,679
Arrow	Yellow	9%	815
	Green	9%	815
Bi-Modal Arrow	Red	9%	815
	Green	9%	815
Walking Person	White	31%	2,716
Hand	Orange	31%	2,716

3.1.4. Average Wattage for Traffic Signal Lamps

Because they operate by shining full-spectrum light through a colored filter, incandescent lamps consume the same energy regardless of the color of the signal ball or arrow. As there are different luminous intensity standards for different diameter signals, the size of the signal ball (generally standardized around 8 and 12 inch diameters) will impact the wattage of the lamp, and thus the energy consumption (Bullough, 2003a). Nationally, it is estimated that about 70% of three-colored ball signals are 12-inch and the remainder are 8-inch (Durgin, 2003). Incandescent arrow and pedestrian signals are typically 12-inch.

LED light sources produce colored light (no color filter required), and the operating wattage does vary with light color, as the LED chip is made of different materials, which produce the different colors. Incandescent and LED wattages from four signal manufacturers were used to prepare average wattages for this analysis. The findings are presented in Table 3-4 along with the weighted average of the 8-inch and 12-inch wattages for each type and color of traffic signal (Atkins, 2003; Bacilieri, 2003; Durgin, 2003; Larocca, 2003).

Table 3-4: Traffic Signal Wattage for Incandescent and LED Lamps by Color

Signal Type	Lamp Color	Incandescent Wattage			LED Wattage		
		8-inch	12-inch	Avg.	8-inch	12-inch	Avg.
Three-Colored – Ball	Red	81	140	122	7	11	10
	Yellow	81	140	122	12	20	18
	Green	81	140	122	8	13	12
Arrow	Red	-	135	135	-	7	7
	Green	-	135	135	-	9	9
Bi-Modal Arrow	Yellow	-	135	135	-	7	7
	Green	-	135	135	-	9	9
Walking Person	White	-	135	135	-	8	8
Hand	Orange	-	135	135	-	8	8

3.1.5. Potential Energy Savings for Traffic Signals

Due to their energy saving benefits and reduced maintenance costs of LEDs, as well as market transformation programs highlighting these advantages, approximately 30-33% of the traffic signal market has already moved to LEDs (Durgin, 2003; Bacilieri, 2003). Red signal heads have seen the highest level of market penetration at 39%, while green signal heads are approximately 29% LED (Steele, 2003a). Because of their low duty-cycle, yellow LED traffic signals have a much longer payback period. This, coupled with the stringent luminosity specifications for yellow LED signals (Bullough, 2003a) results in a low market penetration, assumed to be around 2%. Table 3-5 outlines the market penetration by type and lamp color (Steele, 2003a; Dixon, 2002).

Table 3-5: Traffic Signal Percent LED Penetration by Type and Lamp Color

Signal Type	Lamp Color	Installed Base of LED Signals
Three-Colored Ball	Red	39%
	Yellow	2%
	Green	29%
Arrow	Red	35%
	Green	35%
Bi-Modal Arrow	Yellow	35%
	Green	35%
Walking Person	White	30%
Hand	Orange	30%

With about a 30% market share, more than 4 million traffic signals already use LED sources while 11.3 million have not been converted. Table 3-6 describes the installed base of incandescent and LED traffic signals and their corresponding energy consumption.

Table 3-6: Traffic Signal Energy Consumption and Savings Estimate

Niche Application	Annual Electricity 2002 (TWh/yr)	Electricity Savings 2002 (TWh/yr)	Potential Electricity Savings (TWh/yr)	Cumulative Electricity Savings (TWh/yr)
Red colored ball	1.14	0.64	1.00	1.64
Yellow colored ball	0.10	0.00	0.08	0.08
Green colored ball	1.00	0.36	0.87	1.23
Red arrow	0.06	0.04	0.06	0.10
Green arrow	0.07	0.03	0.06	0.10
Yellow bi-modal arrow	0.02	0.01	0.02	0.03
Green bi-modal arrow	0.03	0.01	0.02	0.03
Walking person	0.49	0.19	0.45	0.65
Red hand - stop	0.49	0.19	0.45	0.65
Total:	**3.41**	**1.48**	**3.02**	**4.50**

The current level of LED traffic signal market penetration has 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 per year today for 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 are converted to LED. Considering both present and future energy savings, traffic signals could save approximately 4.5 TWh/year, half the annual electrical output of a large (1,000 MW) electric power station.

3.1.6. Technology Benefits in Addition to Energy Savings

There are several benefits outside of energy savings that are driving the adoption of LED technology in this application. In addition to saving more than 16.2 TBtu per year, and potentially a further 33.2 TBtu when the market reaches saturation, LED traffic signals offer other advantages over traditional traffic signals. These include:

1. *Longer Life* - Since LED traffic signals generate very little heat, they have a seven-year life expectancy compared to about one year for incandescent lamps (Schmeltz, 2003).

2. *Lower Maintenance and Life-Cycle Costs* - The longer life of LEDs translates into less frequent relamping and lower maintenance costs. Although a red LED traffic signal costs about $75 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 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).

3. *Reduce Daytime Peak Demand*- Besides saving money over the signal's lifetime, LEDs are an effective way to reduce peak energy demand since the signals operate during daylight hours.

4. *Enhanced Safety and Reliability* - In addition to the economic benefits, LED traffic signals offer several features that enhance safety (Schmeltz, 2003; Durgin, 2003). Because they are made up of many small diode light sources rather than a single filament, LED traffic signals are less likely to fail simultaneously, creating a safety hazard.

5. *Battery Back-Up Capability* - Traffic signals that include red, green, and yellow LEDs consume around one-tenth as much power as with incandescent sources (see Table 3-4). For this reason, battery back-up power supplies are available which can operate during power failures to ensure smooth flow of vehicular traffic. While no ITE-complying yellow LED signal heads are available, many agencies use yellow LED signals for battery back-up reasons in emergency situations. For instance, if yellow LED signals were used in flashing mode, work crews would have a few extra hours to handle emergency situations (Bullough, 2003b).

3.2. Railway Signal Heads

On a national level, the energy savings potential of LEDs in railway signals is relatively small. The energy savings are low due to the number of installations as well as fewer operating hours compared to traffic signals. To date, LED railway signal retrofits have decreased national energy consumption by about 0.001 TWh per year. The potential energy savings with 100% LED market penetration will only save a cumulative total of 0.015 TWh a year, or 0.16 TBtu in primary energy. This stands in sharp contrast to traffic signals, which would save 49.27 TBtu if all units were converted to LED - 300 times more energy savings.

3.2.1. Introduction

A railway signal is composed of an incandescent reflector lamp emitting light through a clear lens or colored filter. The potential energy savings of retrofitting this baseline technology with LED is small compared to traffic signals, in part, due to the lighting control equipment of the railway signal. Traditional railway signals have fault detection circuits that monitor the current draw to determine whether a lamp is operational. When the current drops below a certain threshold, this indicates a lamp failure. Since LEDs typically draw approximately 90% less energy when used in a colored light application, the fault detection circuits register a failed lamp when an LED signal head has been installed (Scheerer, 2003). To circumvent this problem without the expense of replacing all the signal controls circuitry, LED signal heads that incorporate resistors to consume additional energy have been developed in order to make them compatible with these fault detection circuits (GELcore, 2003). On a system basis however, instead of the 90% energy savings that LEDs offer over incandescent traffic signals, the savings in this sector are closer to 55% to 60% because of the resistors.

In addition to the lower efficiency, another reason for the relatively small energy savings potential are the much lower number and shorter operating cycles of railway signals compared to traffic signals. Regardless, 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).

There is no study available of energy consumption for railway signal lamps; therefore, a number of sources were contacted to prepare a national energy consumption estimate. As with the other niche market assessments, there are four critical inputs used in preparing the energy consumption and savings estimates, summarized in Table 3-7.

Table 3-7. Critical Inputs for Railway Signals National Energy Estimates

Critical Input	Notes and Sources
Installed Base of Lamps	Number of Wayside Signals: Bill Goodman, Federal Railway Administration. Estimate of Breakdown of Wayside Signals: Dominic Balthazar, GELcore. Estimate of Signal Crossings: Dominic Balthazar, GELcore; Department of Transportation; Bill Goodman, Federal Railway Administration; Mark Jones, Federal Railway Administration; Mark Rea, Lighting Research Center, RPI, 2002.
Annual Operating Hours	Estimates for Wayside Signals: Bill Goodman, Federal Railway Administration. Estimates for Grade Crossing Signals: Dominic Balthazar, GELcore; Bill Goodman, Federal Railway Administration; Allen Kuhn, Burlington Northern Santa Fe Railroad and National Operational Lifesaver Program; William Scheerer, GE Transportation Systems.
Lamp Wattages	Estimates of Lamp Wattages: Dominic Balthazar, GELcore; William Scheerer, GE Transportation Systems.
Lighting Technology Mix	Estimates of the Percent Penetration LEDs: Dominic Balthazar, GELcore; Allen Kuhn, Burlington Northern Santa Fe Railroad and National Operation Lifesaver Program.

3.2.2. Installed Base of Railway Signals

In the United States, there are approximately 109,651 miles of railroad with wayside signals. At a distance of about 2 miles apart, each side of the track has approximately 54,826 wayside signals for a total of 109,651 signals (Goodman, 2003). Of all the types of wayside signals, color-light signals represent the majority, or 85%. Position-light signals, which use a single color of light, represent about 5.5% of the total. These signals are no longer used frequently, and are gradually being replaced by color-light signals. Color-position light signals represent about 5.5%, while searchlight signals are about 4% of the total number of wayside signals (Balthazar, 2003).

In addition, there are approximately 62,000 public grade crossing intersections in the U.S. (DOT, 2003c). Some public grade crossings have as few as 8 signals per intersection while others have as many as 30, depending on the number of intersecting roads and the type of active warning device installed. Standard flashing light signal crossings with gates have an average of 14 signals, including 6 pairs of alternately flashing signals and 2 continuously lit gate-tip signals, for a total of 868,000 such signals in the U.S. (Goodman, 2003; Kuhn, 2003; Jones, 2003; Rea, 2000).

Table 3-8: Number of Railway Signals in the United States

Signal Type	Percentage of Wayside Signals	Average per Intersection	Estimated Number of Railway Signals
Color-Light	85.0%	-	93,203
Position-Light	5.5%	-	6,031
Color-Position-Light	5.5%	-	6,031
Searchlight	4.0%	-	4,386
Flashing Light	-	12 per intersection	744,000
Gate-Tip Light	-	2 per intersection	124,000

3.2.3. Operating Hours for Railway Signals

Wayside signals operate an average of 4.5 hours per day (Goodman, 2003). Each wayside signal contains three to nine lamps with only three, at most, operating at any given time. Grade crossing signals operate one hour per day in rural areas and up to three hours per day within city limits (Balthazar, 2003; Goodman, 2003). Considering that almost 35% of all grade crossing signals are within city limits, a weighted average gives an operating cycle of 1.7 hours per day. When a standard flashing light signal crossing with gates is activated, only half of the signals are operational, six alternating flashers and one non-flashing gate tip signal. The gate tip signal operates for the full operating cycle, while the flashing signals flash approximately 53 times per minute (Kuhn, 2003; Scheerer, 2003). Therefore, the flasher signals are lit for 1.5 hours per day.

Table 3-9: Railway Signal Operating Hours by Type

Signal Type	Lamps per Signal or Intersection	Lamps Operating Simultaneously	Operating Hours (hours/day)	Operating Hours (hours/yr)
Color-Light	3	1	4.50	1,643
Position-Light	9	3	4.50	1,643
Color-Position-Light	6	3	4.50	1,643
Searchlight Color-Light	3	1	4.50	1,643
Grade Crossing Signals[14]	14			
Flashing Light[15]	12	6	1.5	543
Gate-Tip Light	2	1	1.7	621

[14] For grade crossing signals, the number of lamps per signal and number of lamps operating at a time are the average for the standard flashing light signal crossing with gates, a type of grade crossing.

[15] Gate tip lights and flashing lights are lights on standard flashing light signal crossings.

3.2.4. Average Lamp Wattage for Railway Signals

Wayside signals are typically 5 to 8 inches in diameter and their incandescent lamps consume about 18 watts each. Grade crossing signals are typically larger, about 8 to 12 inches in diameter. The 8-inch incandescent lamps consume 18 watts or 25 watts, while the 12-inch lamps consume 25 watts each (Scheerer, 2003).

LED lamps for railway signals have wattages that are about 55-60% less than incandescent lamps. Wayside signals can be retrofitted with LED lamps that use 4 to 8.5 watts, depending on the signal type and color, while grade crossing signals can be retrofitted with 7 to 12 watt LED lamps (Balthazar 2003; Scheerer, 2003). Table 3-10 provides further detail on the incandescent and LED wattages for each type of railway signal.

Table 3-10: Railway Signal Wattage for Incandescent and LED Lamps

	Incandescent Wattage			LED Wattage		
Signal Type	**Low**	**High**	**Weighted Average**	**Low**	**High**	**Weighted Average**
Color-Light	18	18	18.0	4	8.5	7.23
Position-Light	18	18	18.0	4	8	7.19
Color-Position-Light	18	18	18.0	4	8	7.24
Searchlight Color-Light	18	18	18.0	4	8.5	7.23
Flashing Light	18	25	24.3	7	12	10.6
Gate-Tip Light	18	25	24.3	7	12	10.6

3.2.5. Potential Energy Savings of Railway Signals

LED market penetration in gate-tip lights has been 10 to 15% due in part to government entities co-financing the conversion to LEDs. Contrasting with this level of market penetration, grade crossing flashing signals have only seen a 2 to 4% conversion to LEDs for both the 8 and 12-inch signals (Kuhn, 2003). Similarly, LEDs used in wayside signals have only seen about a 1 to 1.5% LED market penetration, in part because these are not co-financed, but also because the energy savings (around ten watts per lamp) are not sufficient to justify the market shift (Balthazar, 2003). Using these values, the average market penetration percentages used in the analysis are shown in Table 3-11.

Table 3-11: Railway Signal Percent LED Penetration by Type

Signal Type	Average LED Penetration in Installed Base
Color-Light	1.25%
Position-Light	1.25%
Color-Position-Light	1.25%
Searchlight Color-Light	1.25%
Flashing Light	3.0%
Gate-Tip Light	12.5%

This relatively low percentage market penetration is evident in the estimate of the installed base. There are approximately 40,000 LED railway signal lights, out of a complete market potential of 978,000 sockets. Table 3-12 provides the annual energy consumption and savings estimates by application in railway signal lighting.

Table 3-12: Railway Signal Energy Consumption and Savings Estimate

Application	Annual Electricity 2002 (GWh/yr)	Electricity Savings 2002 (GWh/yr)	Potential Electricity Savings (GWh/yr)	Cumulative Electricity Savings (GWh/yr)
Color-Light	3.28	0.02	1.95	1.98
Position-Light	0.53	0.00	0.32	0.32
Color-Position-Light	0.53	0.00	0.32	0.32
Searchlight Color-Light	0.15	0.00	0.09	0.09
Flashing Light	9.65	0.17	5.37	5.53
Gate-Tip Light	10.43	0.79	5.53	6.32
Total:	**24.58**	**0.99**	**13.58**	**14.57**

The cumulative consumption of all railway signal lighting is approximately 24.6 GWh/yr (0.025 TWh/yr). In 2002, approximately 1 GWh/yr is being saved because of current levels of penetration of SSL devices in this sector. If the entire railway signal and safety lighting market were to switch to LED, the total energy consumption would be 14.57 GWh/yr, or about 0.16 TBtu in primary energy savings.

3.2.6. Technology Benefits in Addition to Energy Savings

The potential energy savings from LEDs may be small, but, as with traffic signals, there are benefits that provide additional incentives for railway signal and safety lighting engineers to gradually transition to LED sources. These benefits include:

1. Longer life
2. Lower maintenance costs
3. Lower life-cycle costs
4. Enhanced safety

5. Higher reliability
6. Faster on-set times

As railway signal and safety lighting serves a similar purpose to traffic signals, the benefits highlighted in the prior section provide a sufficient description of how these advantages encourage the market to move toward LED technology.

3.3. Airport Taxiway Edge Lights

Airport taxiway edge lighting represents a relatively small niche market in terms of energy consumption and energy savings. Considering all the 14 CFR Part 139 airports[16] in the United States, approximately 0.05 TWh/yr of electricity (0.53 TBtu of primary energy) could be saved if all the taxiway edge lights were converted to LED.

3.3.1. Introduction

Airport administrations follow strict guidelines established by the Federal Aviation Administration in order to ensure the safe transit of air traffic. Lighting is an integral component of airport safety systems, providing guidance, signaling, and demarcation of aircraft runways and taxiways. The general categories include airport lights, which are taxiway and runway lights (elevated and inpavement), and approach lights (medium and high intensity) (Woehler, 2003). Airport taxiways and runways can be configured with edge, centerline, threshold/end, stop bar, and runway guard lights. The following list identifies the main categories of airport runway safety lights (Woehler, 2003).

- *Taxiway*- Taxiway edge lighting systems are configurations of lights that define the lateral limits of the taxiing path. Taxiway lights emit blue light of medium intensity (FAA, 1998).

- *Runway*- Runway lights can be low (LIRL), medium (MIRL), or high intensity (HIRL) depending on the airport size and classification. Airports with no planned approach procedures have LIRLs (Rea, 2000). Non-precision approach instrument runways have MIRLs, runway end identifier lights (REILs), or precision approach path indicator (PAPIs) systems. The MIRLs and HIRLs along the edge emit white light, except in the caution zone. In the caution zone, yellow lights are substituted for white lights (FAA, 1998).

- *Threshold* - Threshold lights emit green light to indicate the landing threshold to aircraft, while the red threshold lights mark the ends of the runway to a departing aircraft (FAA, 1998).

- *Approach* - Approach lights consist of a medium intensity approach lighting system – without flashers (MALS), with sequenced flashers (MALSF), or an omnidirectional approach lighting system (ODALS). There are also high intensity approach light systems for airports with lower visibility.

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[16] The FAA issues airport operating certificates to airports that serve scheduled and unscheduled commercial flights with more than 30 seats under the law contained in 14 CFR part 139. These "part 139" airports represent the largest and most frequently used the United States, and they all incorporate runway and taxiway lighting systems. See Appendix B for additional information on part 139 certified airports.

The number of lights at an airport varies greatly with the size of the airport, the frequency of airport traffic, the visibility and/or weather rating of the area in which the airport is situated, and the length of the runways.

Although LED replacements are commercially available for taxiway lights, the brightness of LEDs has not yet reached the necessary threshold to service runway or approach lights. These lights must provide several thousand-candela beam strength, whereas taxiway lights are only required to provide 2cd for elevated edge and 200cd for taxiway centerline fixtures. More research and development will be necessary to enable LEDs to reach the performance requirements for runway and approach lights. For the purposes of this analysis, only taxiway lighting is considered. Taxiway lighting consists of taxiway edge lights and occasionally also taxiway centerline lights. Taxiway centerline lights are installed in some airports and not others, and no estimate of the breakdown was available. It was recommended that the analysis focus on taxiway edge lights, which are required by the FAA for all Part 139 airports, as these lights can provide a robust minimum baseline estimate of the energy savings potential of LEDs with today's technology (Henderson, 2003).

No national inventory of taxiway lighting could be located; therefore, a number of sources were researched and experts contacted to prepare a national energy consumption estimate. As with the other niche market assessments, there are four critical inputs used in preparing the energy consumption and savings estimates, summarized in Table 3-13.

Table 3-13. Critical Inputs for Airport Lighting National Energy Estimates

Critical Input	Notes and Sources
Installed Base of Lamps	Number of Airports: FAA, 2003. Length of Runway: Fltplan.com, 2003. Lamps per Length of Runway: FAA, 150/530-24A and Advisory Circular 150/530-28.
Annual Operating Hours	Estimates for Operating Hours: Ed Runyoun, Siemens Airfield Solutions; Megan Knox, Siemens Airfield Solutions; Savita Choudhry, Titan; Doug Woehler, Dialight; Jack Henderson, Crouse-Hinds.
Lamp Wattages	Estimates of the Lamp Wattages: Ed Runyon, Siemens Airfield Solutions; Megan Knox, Siemens Airfield Solutions; Doug Woehler, Dialight.
Lighting Technology Mix	Estimate of the Percent Penetration LEDs: Ed Runyon, Siemens Airfield Solutions; Richard Smith, FAA; Doug Woehler, Dialight.

3.3.2. Installed Base of Airport Lights

There are approximately 5,286 public airports and 14,286 private-use airports (AFB, 2003). The combined total of nearly 20,000 airports includes civil and joint-use civil-military airports, heliports, STOLports, and seaplane bases in the U.S. and its territories.

However, not all of these airports have lighted, or even paved, runways and taxiways. Thus, this analysis focuses instead on 14 CFR Part 139 certified airports. These are the large commercial airports found all around the U.S. which serve scheduled and unscheduled aircraft with more than 30 seats. Part 139 airports are required to meet certain safety standards, including being outfitted with taxiway and runway lights for nighttime service (FAA, 2003a). There are approximately 590 Part 139 certified airports, as listed alphabetically by state in Appendix C (FAA, 2003b).

In order to estimate the installed base of taxiway lamps, the summed length of all taxiways for Part 139 certified airports is divided by the maximum longitudinal spacing of lighting permitted by the FAA. Taxiway length varies considerably by airport, and no reasonable average length could be obtained. Thus, for the purposes of this analysis, a minimum taxiway length, assumed to be twice the total length of an airport's runway, was used, as runways are flanked by taxiways on either side. It is recognized that actual taxiway length will likely be longer than this, but no estimate was available. Cumulative national runway length for all Part 139 certified airports in the continental US is 8.7 million feet (see Appendix C). Thus, the estimated minimum amount of taxiway length for Part 139 certified airports is 17.4 million feet.

The maximum longitudinal spacing of taxiway lamps is dictated by the FAA in *Advisory Circular 150/530-24A* and *Advisory Circular 150/530-28* (FAA, 1998a; FAA, 1998b). Generally, the number and type of ground lighting and other visual aids required at an airport are based on the conditions under which the facility typically operates. The level of safety lighting required at an airport is dictated by its runway visual range (RVR). The runway visual range is the "maximum distance in the direction of takeoff or landing at which the runway can be seen from a position above a specified point on its center line at a height corresponding to the average eye level of pilots at touch-down" (DTIC, 2003). Table 3-14 presents the maximum allowed longitudinal spacing for lighting on taxiways, and its variation with RVR and taxiway segment type.

Table 3-14: Maximum Longitudinal Spacing for Taxiway Edge Lights

	Maximum Longitudinal Spacing for Fixtures	
	RVR > 1,200	RVR < 1,200
Radius of Curved Centerline		
75 ft.-399 ft.	25 ft.	12.5 ft.
400 ft.- 1,199 ft.	50 ft.	25 ft.
> 1,200 ft.	100 ft.	50 ft.
Acute Angled Exits		
	50 ft.	50 ft.
Straight Segments		
	100 ft.	50 ft.

Source: FAA, 1998b.

An intermediate value of 75 feet is used as the longitudinal spacing of taxiway edge lights for this analysis. The taxiway length is multiplied by two in order to account for lights on both sides of the taxiway. As illustrated in Table 3-15, the estimated installed base of taxiway lamps is approximately 464,000.

Table 3-15: Estimated Installed Base of Taxiway Lamps

Variable	Value
Total Runway Length (Part 139 airports)	8,703,542 ft.
Total Minimum Taxiway Length (double runway)	17,407,084 ft.
Lit Taxiway Edge Length (lights both sides of taxiway)	34,814,168 ft.
Maximum Longitudinal Spacing of Edge Lights	75 ft.
Estimated Installed Base of Edge Lights	464,000 units

3.3.3. Operating Hours of Airport Lights

Taxiway lights operate approximately twelve hours per day, or 4,380 hours per year (Runyon, 2003; Knox, 2003), but this number can vary with airport location and weather conditions and may be even higher in cold regions, where lights are operated to prevent icing (Henderson, 2003).

3.3.4. Average Lamp Wattage for Airport Lights

Estimates of the wattages of installed incandescent lamps were prepared in consultation with industry experts and stakeholders. Wattages in any given application are similar, but may vary by manufacturer (Woehler, 2003). Typical wattages are provided in Table 3-16.

Table 3-16: Incandescent and LED Wattage for Taxiway Lights

Application	Type	Incandescent Wattage	LED Wattage
Taxiway	Inpavement	45W	7W
	Elevated	30W	7W

Sources: Runyon and Knox, 2003; Smith, 2003.

It is estimated that 5% of the taxiway edge lights are inpavement/surface mount and 95% are elevated fixtures (Woehler, 2003). Thus, the installed-base weighted average incandescent wattage is 31W and for the LED 7W.

3.3.5. Potential Energy Savings of Airport Taxiway Lamps

The estimates provided by industry indicated a very low level (less than 2%) of market penetration of LED technology to date. The incandescent fixtures that have been replaced with LEDs are primarily at the very large commercial airports. The LED market penetration of taxiway edge and centerline fixtures is approximately 1-1.5% at large airports but only about 0.5% at medium and small airports (Runyon, 2003). The LED market penetration of inpavement taxiway fixtures is approximately 0.5% for large airports and 0.25% for medium and small airports (Runyon, 2003).

Table 3-17 describes the installed base of incandescent and LED taxiway edge lights and their corresponding energy consumption. The current level of LED taxiway market penetration has decreased national energy consumption by 0.001 TWh/yr. Converting the remaining stock of airport taxiway lamps to LED will save an additional 0.05 TWh/yr of electricity, or about 0.53 TBtu of primary energy at the power station. Thus, some energy is being saved today, but the energy savings potential remains largely un-tapped for this niche application.

Table 3-17: Airport Taxiway Energy Consumption and Savings Estimate

Application	Annual Electricity 2002 (TWh/yr)	Electricity Savings 2002 (TWh/yr)	Potential Electricity Savings (TWh/yr)	Cumulative Electricity Savings (TWh/yr)
Taxiway Lights	0.06	0.001	0.05	0.05

It should be noted that in areas prone to freezing rain and ice accumulation, heaters must be installed in conjunction with LED systems to avoid the build-up of ice on the LEDs. In these areas, normally the waste heat emitted from incandescent sources melts the ice and prevents build-up. In some cases, the heater can offset the energy savings gained by switching to LED. For instance, a 45W incandescent taxiway light retrofitted with a 7W LED would lose almost the entire 38W of energy savings if a heater were added (Smith, 2003). However, if heating can be controlled remotely, it could be utilized only when necessary – e.g., in winter months during bad weather episodes.

Although energy savings estimates have not been quantified for the remaining parts of airport lighting systems, the FAA and LED manufacturers believe that there will eventually be energy savings from retrofitting incandescent airport runway lights with LED technology (Smith, 2003; Woehler, 2003).

3.3.6. Technology Benefits in Addition to Energy Savings

There are several benefits that are driving the adoption of LED sources in airport taxiway lights. LEDs offer the following advantages over incandescent lighting:

1. *Longer Life* - LED taxiway lamps were originally covered by five-year warranties, which have been extended to seven and ten years, due to improved performance (Smith, 2003). In comparison, incandescent bulbs installed in airport lighting applications have lifetimes as short as six months to one year (Smith, 2003).

2. *Lower Maintenance Costs* - Airports are seeing significant cost and maintenance savings after installing LEDs, due to a decrease in the frequency of relamping arising from the longer operating life of LEDs. LEDs also

increase the availability of taxiways by reducing the amount of access necessary for maintenance (Siemens, 2002b; Henderson, 2003).

3. *Reliability* - LEDs are maintaining their lumen output even as their age increases (Smith, 2003).

4. *Durability* - LED lamps are more durable than incandescent lamps when exposed to the environment (Pollock, 2003).

5. *No Lumen Loss Due to Filtering* - The colored filters that must be used with incandescent lamps result in significant lumen transmission loss, which does not happen with LED lamps (Pollock, 2003).

3.4. Navigational Bridge Lights

Due to a lack of available data, it was determined that a reasonable estimate of the baseline energy consumption and energy savings potential of switching to LEDs could not be determined for navigational bridge lights. Fundamental data gaps exist on the number and type of bridges as well as the wattages of existing bridge navigational lights.

3.4.1. Introduction

Bridges over navigable waterways where there is significant nighttime navigation are required to have navigation lights to delineate safe passage routes for vessels. The United States Coast Guard (USCG) has established performance requirements for bridge navigation lights. For example, they must be visible from a distance of one nautical mile from sunset to sunrise and in times of reduced visibility (USCG, 2002).

There is no single published study available of energy consumption for bridge navigation lamps. Although a reasonable energy savings estimate could not be determined, a number of sources were contacted. As with the other niche market assessments, there were four critical inputs used in evaluating the energy consumption and savings estimates, summarized in Table 3-18.

Table 3-18: Critical Inputs for Navigational Bridge Lights Energy Estimates

Critical Input	Notes and Sources
Installed Base of Lamps	Number of Bridges over Navigable Waterways: United States Coast Guard Bridge Administration Program, 2003. Number of Lights per Bridge: USCG Bridge Administration Program, 2003; Ira Krams, Automatic Power.
Annual Operating Hours	Estimates for Operating Hours: United States Coast Guard Bridge Administration Program, 2003.
Lamp Wattages	Estimates of the Lamp Wattages: Ira Krams, Automatic Power; Butch Comeaux, Tideland Signal.
Lighting Technology Mix	Estimate of the Percent Penetration of LEDs: Ira Krams, Automatic Power; Selina Funnell, Carmanah Technologies.

3.4.2. Installed Base and Wattages for Navigational Bridge Lights

The USCG estimates that there are approximately 20,000 bridges over navigable waterways in the United States (Martin, 2003; Jauffman, 2003). Navigational bridge light requirements for fixed bridges establish six lights as the minimum number necessary to demarcate the navigation path. The typical pattern configuration for a fixed bridge is three lights positioned to be visible upstream and three lights positioned to be visible downstream. On each side of the bridge, two red lights are used to mark the piers, supports, or channel limits of the navigable portion of the bridge, and one green light marks the centerline of the channel under the bridge. For a movable bridge, the lighting is more complex. There are three common types of movable bridges: vertical lift, bascule, and swing. The minimum number of lights for these bridges is 5, 8, and 10, respectively (USCG, 2003). Most fixed bridges use six navigation lights, while movable bridges use an average of eight (Krams, 2003). However, statistics are not maintained on the breakdown of fixed and movable bridges.

Operating wattages of signal lamps vary greatly by manufacturer. Two leading manufacturers of bridge navigational lamps, Automatic Power, Inc. and Tideland Signal, sell incandescent light fixtures that differ greatly in wattage. Automatic Power offers a 69W-based system (Krams, 2003) while Tideland's fixtures range from 6.6 to 9.2W (Comeaux, 2003). Similar variations in wattage exist for LEDs, ranging from Automatic Power's 6W LED replacement to Tideland's 1.8W lamp, and Carmanah Technologies 0.45W option. This level of variability makes it difficult to arrive at a reasonably sound estimate of the baseline inventory, necessary to calculate energy consumption and determine the energy savings potential.

The USCG has approved the use of LED lamps for this application and LED navigational lights are available as replacements for incandescent fixtures. But LED lamps have not achieved much market penetration, as bridge owners and managers have been slow to adopt them (Krams, 2003; Funnell, 2003).

Thus, while a reasonable inventory of bridges is known and the minimum number of navigational aid lights per bridge, the variability in the wattage of both the incandescent (baseline technology) and the more efficient LED technology prevented the preparation of an energy savings estimate from this niche market. According to the Coast Guard, bridge owners are starting to transition to LED devices for their navigational aid lights, driven partly by energy savings, but primarily by maintenance savings, as discussed below.

3.4.3. Technology Benefits of LED Bridge Navigation Lights

Generally, bridges are fitted with incandescent light sources to comply with regulations on the demarcation of navigable waterways. Bridge owners and operators have been slow to adopt LED replacement technology, probably due to the low overall operating cost of these lamps relative to other, more critical, costs associated with a bridge, such as structural and roadway surface maintenance. There are, however, several advantages to choosing LED sources over incandescent in this application, including:

1. *Longer Lifetime* - The longer operating life of LED navigation bridge lights reduces maintenance and relamping costs compared to incandescent sources. Carmanah technologies guarantees its LED bridge navigation lights for three years compared to an incandescent lifetime of 1,000 hours, which is only a few months of use (Comeaux, 2003). It also reduces the risk of any liability on the part of the bridge manager associated with a failed signal lamp.

2. *Better Visibility* - Due to the properties of an LED lamp, light is only projected in the intended direction, enabling it to utilize the lumens produced more efficiently. By contrast, incandescent lamps emit light on all sides, so only half of that light is directed away from a fixture's mounting surface (i.e., the bridge). As a result, higher wattages are needed to achieve the one-mile visibility requirement.

3. *Durability* - LED sources are well suited to roadway and railroad bridges because they are vibration tolerant and will continue working under conditions that might cause the filament of an incandescent lamp to fail.

4. Other Stationary Applications

For the "other" stationary niches, electricity is saved by installing LEDs in applications currently supplied by traditional light sources, such as incandescent or neon. The savings for these installations are presented in TWh for the nation, as well TBtu of primary energy consumption saved at the power station level.

Four stationary niche market applications were evaluated: exit signs, holiday lights, commercial refrigerated display cases, and commercial advertising signs. These four applications are all considered "stationary" because they are fixed installations and are connected to the electrical grid. Commercial refrigerated display cases were not found to offer any energy savings with LEDs at this time, however significant energy savings have already been secured through exit signs, and strong potential remains for commercial advertising signs and holiday lights. Indeed, the emerging application of commercial advertising signs appears to be the most promising stationary application evaluated, offering the largest, commercially available potential for electricity savings.

4.1. Exit Signs

Since their introduction in 1985, LED exit signs have become the most common type of exit sign installed because of lower energy consumption and lower maintenance costs than other types of lighting. National promotional initiatives such as ENERGY STAR® have helped to raise business awareness and expand market penetration. In terms of primary energy savings, 75.2 TBtu per year are currently saved from existing LED exit signs, and a further 8.8 TBtu of savings could be captured if the remaining conventional sources in the installed base were to switch to LED. In total, the energy savings from 100% market saturation with LED exit signs would be approximately 84 TBtu per year.

4.1.1. Introduction

Buildings designed for public occupancy require exit signs that continuously operate to demarcate routes of egress in the event of an emergency. Building safety standards mandate certain performance requirements for those exit signs; for example, self-luminous signs must have a minimum of 0.06 foot lamberts (0.21 candelas per square meter) (DOL, 2002).[17] For many years, exit signs relied on incandescent light sources to achieve visibility requirements. However, in the last 20 years, other sources such as compact fluorescent and LED have started being used, due to their lower life-cycle costs.

Today, LED has emerged as the technology of choice for exit sign illumination. Thanks in part to the technology advancements of the last decade, LED has become a highly reliable, energy efficient colored-light source that satisfies code requirements while reducing energy consumption and maintenance costs.

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[17] Please see Appendix E for an extraction from the Federal Register pertaining to this Final Rule passed by the Department of Labor.

To prepare a national estimate of the energy savings potential of LED exit signs, estimates of the installed base, operating hours, and average wattage were assembled. These estimates draw upon publicly available literature as well as consultative interviews with manufacturers and research experts. As with the other niche market assessments, there are four critical inputs used in preparing the energy consumption and savings estimates, summarized in Table 4-1.

Table 4-1. Critical Inputs for Exit Signs National Energy Estimates

Critical Input	Notes and Sources
Installed Base of Lamps	Number of Exit Signs: U.S. Lighting Market Characterization, Volume I: National Lighting Inventory and Energy Consumption Estimate, DOE, 2002a.
Annual Operating Hours	Exit signs operate continuously - 8,760 hours per year.
Lamp Wattages	Estimates of the Lamp Wattages: PG&E, 2000; Efficiency Maine, 2003; E-Source, 2002; Virginia Department of Mines and Minerals, 1998; Light Panel, 2003.
Lighting Technology Mix	Estimate of the Percent Penetration LEDs: NEMA, 2003; Robert Steele, Strategies Unlimited

4.1.2. Installed Base of Exit Signs

The installed base inventory is derived from the *U.S. Lighting Market Characterization Volume I: National Lighting Inventory and Energy Consumption Estimate* (DOE, 2002a). This study takes building audit and sub-metering data on lighting in commercial and industrial buildings and extrapolates the information to the nation as a whole, based on the building inventories published by the Energy Information Administration. Exit signs were one of the lighting fixtures tracked in the building audits conducted in the 1990s, which numbered more than 25,000 buildings. Extrapolating these inventories, by building type, to a national level produces an estimated installed base of approximately 33 million exit signs, shown in Table 4-2 (DOE, 2002a).

Table 4-2: Number of Exit Signs in the United States

Sector	Estimated Number of Exit Signs
Commercial Exit Signs	29,508,000
Industrial Exit Signs	3,559,000
Total National Inventory	**33,067,000**

Source: DOE, 2002a

4.1.3. Operating Hours of Exit Signs

Exit signs, by building safety code requirement, operate 24 hours per day year-round, amounting to an annual operating cycle of 8,760 hours.

4.1.4. Average Lamp Wattage of Exit Signs

The wattage of installed exit signs varies both by the light source (e.g., incandescent, compact fluorescent, LED) and within a given light source. For example, incandescent exit signs can be found which range between 14 and 50 watts for a two-sided sign (LightPanel, 2003) and LED fixtures can be found between 2W and 10W, also for two-sided signs. For this application, LED sources produce light in the color spectrum required (e.g., red or green). This method differs from that of incandescent or compact fluorescent light sources, which produce full-color spectrum light, and then have a color filter that adsorbs all the colors except red or green. Table 4-3 provides the range of wattages identified for each light type, along with an estimated average valued used in the energy savings calculation.

Table 4-3: Exit Sign Wattage by Lamp Type

Source	Low	High	Estimated Average
Incandescent	14 watts	50 watts	32 watts
Compact Fluorescent	10 watts	24 watts	17 watts
Light Emitting Diode	2 watts	10 watts	6 watts

Sources: PG&E, 2000; Efficiency Maine, 2003; Virginia Department of Mines and Minerals, 1998; Light Panel, 2003

4.1.5. Energy Savings Potential of Exit Signs

Due to highly favorable economics, better performance, enhanced safety capabilities, and marketing programs such as ENERGY STAR® Exit Signs, LED exit signs have already captured a significant share of this market. Table 4-4 presents available estimates of the most recent shipment apportionments and one expert's estimate of the installed base. The relatively high level of saturation in the installed base would seem to indicate that LED exit signs, which were introduced in 1985, have achieved high levels of penetration.

Table 4-4: Exit Sign Percent Market Share by Lamp Type

Source	Shipment Estimate, 2002	Estimated Installed Base
Incandescent	7.16 percent	4.8 percent
Compact Fluorescent	1.95 percent	15 percent
Light Emitting Diode	90.89 percent	80 percent

Sources: (NEMA, 2003; Steele, 2003a)

With an 80% market share, 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.

Table 4-5: Exit Sign Energy Consumption and Savings Estimate

Application	Annual Electricity 2002 (TWh/yr)	Electricity Savings 2002 (TWh/yr)	Potential Electricity Savings (TWh/yr)	Cumulative Electricity Savings (TWh/yr)
Exit Signs	2.57	6.86	0.80	7.67

Already, LED exit signs have contributed 6.86 TWh/yr of national energy savings. 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/year with a further 8.8 TBtu of savings potential. Thus, in total, 84 TBtu/yr could be captured if 100% of the installed base moved to LED.

4.1.6. Technology Benefits in Addition to Energy Savings

There are several additional benefits beyond energy savings that are driving the market to adopt LED technology in this application. In addition to saving about 75.2 TBtu per year, and potentially a further 8.8 TBtu when the market reaches saturation, LED exit signs offer advantages over traditional exit signs that compel building owners and managers to shift to LED sources. These include:

1. Reliability and durability – longer operating life,
2. Lower operating and maintenance costs,
3. Improved safety for occupants / tenants – eliminates uneven illumination,
4. Smaller package size,
5. Ease of use with battery backup, and
6. Competitive on a first-cost basis.

LED exit signs have considerably lower operating costs than other types of signs and last much longer. According to E-Source, LED signs typically cost less than $5 a year to operate, depending on the model and local utility costs (E Source, 2002). LED lamps are also expected to last 20 to 80 years, while incandescent lamps must be replaced every four months and fluorescent lamps every one to two years. Total costs over a ten-year period, including first cost, energy, and maintenance will be approximately $380 for incandescent signs and about $65 for LED signs.

Even on a first cost basis, which can be an important purchasing determinant, LEDs have become competitive. While incandescent signs without battery backup are still marginally less expensive than LED signs, the price for both types of signs with battery backup is about the same because the incandescent system requires a much larger battery. LED first costs have fallen in part due to the red LED being a relatively mature and well-understood technology.

Finally, LED signs can be easier to see, providing increased safety to building occupants. According to Facilitymanagement.com, "LED-lighted exit signs...eliminate uneven illumination noted on lamp-lighted signs. Most manufacturers arrange LEDs in a dot formation along the letters of the sign. These dots reflect out, unseen from outside the fixture. Newer designs position the LEDs in a row formation on each side of the fixture's interior. This produces brighter, more even illumination of the sign."

4.2. Holiday Lights

Even though the holiday season is just a few weeks of the year, the conversion of miniature holiday lights from incandescent to LED sources would generate considerable energy savings. The potential annual energy savings of a complete market shift to LED holiday lights is approximately 21.9 TBtu of primary energy consumption. Along with significant energy savings, the adoption of LED sources would be accompanied by other benefits, including a longer operating lifetime as well as a safer and more durable product.

4.2.1. Introduction

Holiday lights serve an aesthetic function, using colored and white light to build a certain mood or evoke positive feelings and emotions. Holiday lights operate for a limited part of the year, typically around the holiday season in December and early January. These lights can be found both donning the thirty-four million holiday trees sold annually in the U.S. (UIE, 2003) as well as decorating the exteriors of residential and commercial buildings. The lights, a symbol of the yuletide season, are also commonly used at retail outlets and shopping malls.

Due to their intermittent use annually, energy efficiency has not been a significant market driver. Historically, users who wanted to control the energy consumption would move to smaller, lower wattage lamps or use timers to regulate on-time. Now, LED holiday lights, based on LED technology, are available. Due to their natural aptitude to produce a spectrum of colored light, depending on the chip substrate, LED technology is well suited to this application and may gradually replace conventional incandescent lights over time, saving significant energy and money.

There is no single published study available of energy consumption for holiday lights; therefore a number of sources were contacted to prepare a national energy consumption estimate. As with the other niche market assessments, there are four critical inputs used in preparing the energy consumption and savings estimates, summarized in Table 4-6.

Table 4-6. Critical Inputs for Holiday Lights National Energy Estimates

Critical Input	Notes and Sources
Installed Base of Lamps	Number of Miniature Holiday Lights: Unites States International Trade Commission (USITC), 2003. David Allen, Forever Bright.
Annual Operating Hours	Estimates for Operating Hours: Jim Bruno, Forever Bright; Department of Energy.
Lamp Wattages	Estimates of the Lamp Wattages: Washington State University (WSU), 2002; Jim Bruno, Forever Bright.
Lighting Technology Mix	Estimate of the Percent Penetration of LEDs: Jim Bruno, Forever Bright.

4.2.2. Installed Base and Operating Hours of Holiday Lights

There are several different types of holiday lights, such as miniature lights, C-6, and C-7 lights, which each have different sized bulbs and lamp wattages. LED replacements exist today for incandescent miniature and C-6 lamps. As there is virtually no domestic production of holiday lights (Bruno, 2003), it was assumed for this analysis that all holiday lights are imported. The United States International Trade Commission (USITC) tracks the imports of "lighting sets of a kind used for Christmas trees," of which, approximately 159.4 million sets are imported each year (USITC, 2003). Of this total, the estimated number of imported miniature light sets is 123.6 million, or about 78% of total holiday light imports (USITC, 2003). These are average values from the past three years, as shown in Table 4-7, below. The remaining imported lights are a combination of all other types of holiday lamps (C-6, C-7, C-9, and icicle). However, due to the lack of disaggregated data on these other lamp types, and the difference in their respective wattages, only the potential energy savings of miniature lights is calculated. The ultimate energy savings would likely be even higher if other lighting configurations such as icicle lights, rope lights, and other specialty lights were included in the analysis.

Table 4-7: Imports of Holiday Lights, 2000-2002

Lights	2000	2001	2002	Three-Year Average
Imports of Miniature Lights	147,547,000	111,564,000	111,873,000	123,661,000
Imports of Other Lights	34,634,000	26,055,000	46,068,000	35,586,000
Total Imports	**182,181,000**	**137,619,000**	**157,941,000**	**159,247,000**

The installed base of miniature holiday lights can be estimated by considering the typical lifetime of the lamps, which determines how long a particular string may remain in service. The typical lifetime of a string of miniature lights is three years (DOE, 2002b; Bruno, 2003). This estimate is based on the assumption of 5 hours of operation per day, 30 days a year, or 150 hours per year[18]. After 3 years, or 450 hours, approximately one third to one half of the bulbs will have failed, resulting in the disposal of the entire string. Multiplying the average annual sales over the past three years by the three-year typical lifetime yields an installed base of 370 million miniature light strands. Each strand is assumed to be a 100-lamp strand, since the percentage of mini-light strands with a different number of lamps is small (Allen, 2003). At 100 lamps per strand, the installed base of holiday lamps is 37.1 billion.

4.2.3. Energy Savings Potential of Holiday Lights

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

[18] This estimate of operating hours is considered low because it does not take into account holiday lights that are used in commercial applications such as shopping malls, store displays, city streets, or hotel and motel decorations. When used in these applications, the daily operating hours are increased and operation can span the whole year, not just the holiday season.

each miniature lamp is 0.4 watts (WSU, 2002). Thus, 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 in terms of primary energy consumption.

Over the past two years, LEDs have started to carve a small niche in the holiday light 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, and for this analysis was assumed to be zero.

Table 4-8: Holiday Lights Energy Consumption and Savings Estimate

Application	Annual Electricity 2002 (TWh/yr)	Electricity Savings 2002 (TWh/yr)	Potential Electricity Savings (TWh/yr)	Cumulative Electricity Savings (TWh/yr)
Holiday Lights	2.22	0.0	2.00	2.00

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

4.2.4. Technology Benefits in Addition to Energy Savings

In addition to the dramatic energy savings potential identified in Table 4-8, there are benefits to end-users from selecting LED holiday lights.

1. *Longer Operating Life* – Manufacturers guarantee their products for 5 years, and project that they should last up to 20 holiday seasons (Forever Bright, 2003). This fact, coupled with the significant energy savings, helps to offset the higher first cost of LED holiday lights. And, as the technology continues to evolve, the payback period will shorten, increasing the market share of LEDs.

2. *Safety Due to Higher Operating Efficiency* - Another significant advantage of LED holiday lights is their higher operating efficiency. LEDs emit less heat than their incandescent counterparts, making them safer to mount on trees, wreaths, and other combustible material in the house. They also draw 90% less current, making lights operating in tandem or on extension cords safer, due to lower power consumption.

3. *Durability* - LED holiday lights are manufactured in an epoxy plastic resin instead of a glass bulb, thus, they are more resistant to shattering or impact damage during installation or disassembly.

4.3. Commercial Refrigerated Display Cases

There are no potential energy savings from LEDs in commercial refrigerated display cases; thus, while this niche market is identified here, it constitutes a future potential rather than a present one. Presently, commercial refrigerated display cases are most commonly illuminated by electronic ballast T-8 linear fluorescent lamps, at efficacies in excess of 70 lumens per watt. Full-spectrum white-light LEDs have yet to achieve this level of performance.

4.3.1. Introduction

While today's white-light LED systems are not yet able to match fluorescent's efficacy or color rendering, their performance is rapidly improving. Industry analysts expect them to be used within the next few years for this emerging application.

The most common light source for refrigerated display cases is fluorescent lighting. However, at this lower temperature operating environment, fluorescent lamps have difficulty achieving their optimum performance. When operated at room temperature, fluorescent lamps provide about 80 lumens per watt (lpw), but operating at refrigeration temperatures, their efficacy drops by about 20%. Also, the lack of optical control and misdirected light makes this light source less than ideal for merchandising, since approximately 40% of the fluorescent light is wasted. The compounding factors of operating environment temperature and lack of optical control drop the system efficiency to approximately 38 lumens per watt (Narendran, 2003a). And, besides being an inefficient light source, fluorescent lamps will generate heat inside the refrigerated space and reduce the efficiency of the cooling system. However, despite its drawbacks, fluorescent lighting is currently the best lighting alternative for this application.

While still in its nascent stages of development, white-light LED light systems have an efficacy of about 30 lpw. While this performance is approaching the efficiency of linear fluorescent lighting in this application, LED systems are much more expensive on a first cost basis (Narendran, 2003a). However, unlike fluorescent lamps, LED light sources actually improve their efficacy at cooler temperatures. And, as the efficacy improves over time, the heat production of LEDs will decline, making them better suited to refrigerated display case applications.

4.3.2. Technology Benefits of LEDs in Commercial Refrigerated Display Cases

Although they presently have slightly higher energy consumption than fluorescent lights in refrigerated display cases, white LED lamps still offer several advantages that will make them suitable to this emerging application when researchers achieve the price and performance level expected by the market. LED light sources for commercial refrigerated display cases offer several benefits and features to storeowners that set them apart from fluorescent or any other light source considered for this application. These features can help improve the marketing and enhance the sales of products displayed. These benefits include:

1. *Smaller Package Size* - The small package size of the LED lamps allows them to be placed in multiple locations throughout the display case directly illuminating the merchandise. The small package size also provides more shelf space for products to be displayed.

2. *Directional Illumination* – The LED sources can be targeted to illuminate particular parts of the packaging or prices in the display case, calling customer's attention to aspects of the display case that may result in a sale.

3. *Adjustable Color* - Storeowners could also easily alter the intensity and color of the LED light to augment particular colors in the products. Recent marketing studies have shown that these features offer enhanced appeal to the human eye compared to other lighting systems. Study subjects strongly preferred display cases with LED lighting systems at half the illumination levels of fluorescent systems (Narendran, 2003b).

4. *Increased durability*- The rugged plastic encasement of LEDs provides resistance to the impact of constantly opening and closing doors.

5. *Longer operating life* - This, along with the other advantages, could translate into quick payback for the customer.

These features, both financial and aesthetic, will make LED light sources a compelling alternative to fluorescent when their efficacy rises and their first cost declines.

4.4. Commercial Advertising Signs

In terms of the magnitude of potential on-grid energy savings, this niche application is the most promising considered in this report. The energy that would be saved from 100% of the installed base of neon signs switching to LED is approximately 72.5 TBtu of primary energy.

4.4.1. Introduction

Advertising signs play an important role in our national economy, helping customers to locate retailers and service providers, identify products they may want to buy, or simply determine if a shop is open for business. Colorful, actively lit signage attracts the attention of customers and works to generate business for the establishment. Historically, advertising signs have relied on incandescent, fluorescent, or neon light sources for illumination. Recently, LED sources have started making inroads into this market, gradually replacing the traditional sources, particularly neon.

According to a 2002 state of the industry report published by *Signs of the Times* magazine, the number of companies offering signs that incorporate LED technology is increasing, as are the shipments of signs based on this light source (SOT, 2003). The publication's survey of manufacturers found that in 2002 approximately 48% of commercial signage companies offered products that incorporate LED illumination sources, up from 32% in 2001. The survey also found that shipments of signs that incorporate LED sources increased from 3.9% to 6.2% of total shipments over the same time period, a 59% increase. At the same time, shipments of neon, fluorescent, incandescent, and fiber-optic illuminated signs decreased slightly (SOT, 2003).

The energy savings estimate is based on LED replacement of electrically lit neon signage. The signs encompassed in this estimate include shaped neon-tubes and channel lettering signs. Other types of signs are not considered because suitable LED replacements do not yet exist. One of the new advertising options offered by LED sources are outdoor video screens and message display boards. In applications such as the NASDAQ building in Times Square, New York, LEDs enable advertisers to actively engage their audience through video monitors and digital displays with news and other moving images presented in color on a billboard-sized screen. For this energy savings estimate, however, LED billboard screens are not considered, as this is a new application and does not represent a replacement of a less efficient technology.

There is no single published study available of energy consumption for illuminated signs, therefore a number of sources were contacted to prepare a national energy consumption estimate. As with the other niche market assessments, there are four critical inputs used in preparing the energy consumption and savings estimates, summarized in Table 4-9.

Table 4-9. Critical Inputs for Commercial Advertising Signs Energy Estimates

Critical Input	Notes and Sources
Installed Base of Lamps	Number of Electric Signs: Annual Survey of Manufacturers, Department of Commerce; *Signcraft* Magazine, 2003; *Signs of the Tim*es Magazine, STMG, 2003. Percentage of Neon Signs: *Signs of the Times* Annual State of the Industry Report, 2003. Average Sign Price: Interface Signs, Commercial Signs.
Annual Operating Hours	Estimates for Operating Hours: Signweb.
Lamp Wattages	Estimates of LED Lamp Wattages: Joseph Melchiors, General Electric; Paula Jevelle, LEDtronics; SloanLED. Estimates of Neon Wattages: Universal Lighting, 2003.
Lighting Technology Mix	Estimate of the Percent Penetration LEDs: Paula Jevelle, LEDtronics.

4.4.2. Installed Base and Baseline Energy Consumption of Commercial Signs

The number of signs sold per year, and presumably displayed, can be calculated by taking the total annual sales of the electric signage industry and dividing by an average sign price. In addition, signs were assumed to have an average operating life of 15 years (D&R, 2003). Thus, the estimated installed base is the summation of the total number of signs sold in that time period (1987-2001).

The annual sales figure of electric signs was available from two different sources: the Department of Commerce's Annual Survey of Manufacturers (ASM) and from a sign industry trade magazine, *Signs of the Times*. For years when both estimates were available, an average was taken; otherwise, the ASM value was used. The ASM provides annual sales data from 1987 to 2001, but another trade magazine, SignCraft, estimates that the value reported by the ASM is actually only 50% of total sales of all sign shops (SignCraft, 2003). As a result, the ASM sales numbers were multiplied by two for this estimate. Another source of this information is *Signs of the Times* magazine, which conducts an annual industry survey of the electrical signage retailing industry. Analysts from this magazine who have studied these annual surveys prepared an estimate of the installed base of commercial advertising signs in the U.S.

After speaking to a number of sign manufacturers, an average price per sign of $5,000 was selected. It was assumed the average sign price was constant over the fifteen-year period, adjusted for inflation. The installed base is given in Table 4-10.

Table 4-10: Electric Signs Annual Sales, Average Price, and Estimated Installed Base

Year	Total Sales - *Signs of the Times* ($Billion)	Total Sales – ASM, *Sign Craft* ($Billion)	% Difference in Sources	Inflation Adjusted Average Sign Price ($)	Estimated # of Signs Sold
1987	-	2.40	0%	$3,010	798,302
1988	-	2.69	0%	$3,120	862,196
1989	3.57	2.62	36%	$3,260	950,079
1990	3.20	2.71	18%	$3,420	863,752
1991	3.00	2.67	12%	$3,620	782,865
1992	3.12	2.57	22%	$3,780	752,090
1993	3.39	2.75	23%	$3,890	789,692
1994	3.70	3.23	15%	$4,010	864,239
1995	4.10	3.55	16%	$4,120	928,058
1996	4.30	3.88	11%	$4,240	964,434
1997	4.60	4.12	12%	$4,340	1,004,864
1998	5.00	3.79	32%	$4,450	987,715
1999	5.40	5.03	7%	$4,520	1,153,537
2000	5.60	4.84	16%	$4,620	1,130,356
2001	5.40	4.79	13%	$4,780	1,065,892
2002	-	-	-	$4,920	
2003	-	-	-	$5,000	
				Total Installed:	**13,898,072**

Source: Signs of the Times, 1989-2001; DOC, 1987-2001.

The installed base of 13.9 million represents all electric signs, including signs illuminated from neon, fluorescent, and HID sources. Since currently, LED replacements only exist for neon signs, the potential market that is suitable for replacement is actually much smaller. Along with annual sales figures, *Signs of the Times* magazine also provides information on how signs are illuminated, classified by lighting type. In 2002, 41.3% of signs used neon as their mode of illumination creating an installed base of approximately 5.7 million (SOT, 2003). The neon illuminating these signs could be replaced by LEDs. In the absence of any data for the prior years, this proportion of neon signs was assumed constant over the 15-year period. LED products for channel letter signs have only been introduced into the market in the last two years (Jevelle, 2003), therefore, the market penetration for 1987-2001 is 0%.

The term “neon” actually refers to more than just neon gas and generally extends to include any inert gas that emits color when ionized. Different gases produce different colors: neon glows bright red, and a mix of argon and mercury creates a blue/white color. Neon tubing is produced in varying sizes, from 8mm in diameter to 25mm, with a current rating of either 30milliamps (ma) or 60milliamps. The most common type of neon tubing is 15 mm, 60 ma (Universal Lighting Technologies, 2003). For calculations in this report, the most common neon—red tube, 15mm—was selected for the baseline energy estimate. The average wattage per foot of LED strip is 1.03W (GELcore, 2003; SloanLED, 2002; LEDtronics, 2003). The average nominal installation for a sign is 160 ft. of tubing (Melchiors, 2003; SloanLED, 2003). Channel letter signs are assumed to operate 9 hours per day, 365 days per year. Thus, the operating hours for channel letter lighting are estimated to be 3,285 hours per year.

Table 4-11: Electric Sign Installed Base, Operating Hours, and Power Consumption

Source	Installed Base (units)	Operating Hours (hours/yr)	Average Wattage (W/ft.)	Nominal Installation (feet)	Power Consumption per Sign (W)
LED	0	3,285	1.03	160	164
Neon	5,739,904	3,285	3.0	160	480

Source: Melchiors, 2003; Jevelle, 2003; Sloan LED, 2003; Universal Lighting, 2003.

4.4.3. Energy Savings Potential of Commercial Advertising Signs

The current market penetration of LEDs into channel letter signs is assumed to be zero percent, as the technology was just introduced two years ago (Jevelle, 2003). Table 4-12 presents the energy consumption estimate for commercial advertising signs, based on the aforementioned data and inventory estimates.

Table 4-12: Commercial Signs Energy Consumption and Savings Estimate

Application	Annual Electricity 2001 (TWh/yr)	Electricity Savings 2001 (TWh/yr)	Potential Electricity Savings (TWh/yr)	Cumulative Electricity Savings (TWh/yr)
Commercial Signs	10.06	0.0	6.61	6.61

Thus, 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 converted to LED sources.

4.4.4. Technology Benefits in Addition to Energy Savings

There are several benefits in addition to energy savings that are driving the adoption of LEDs to illuminate commercial advertising signs. These include:

1. *Minimal Light Loss* - LEDs emit colored light and light loss can be minimized by matching the color of the LED chip emitter to the color of the translucent covering. Furthermore, light emitted from an LED device is more directional and controlled, meaning that photons generated by an LED source will emerge better through the translucent panel. By contrast, neon and fluorescent lights have a 360 degree emission range, which results in light loss as the light is dispersed to the back of the sign.

2. *Longer Lifetime* - LED operating hours (100,000 hrs) meet or exceed those of neon (10,000 to 25,000 hrs) and fluorescent (Dayton Signal and Lighting, 2002).

3. *Safety* - The operating voltages of LEDs are low and are typically direct current. By contrast, neon sources require 12,000-15,000 volts of alternating current.

4. *Ease of Installation and Maintenance* - Skilled neon workers are required to install and repair neon signage. However, LEDs are more robust and flexible, and could be installed by general electrical and lighting contractors.

5. *Design Flexibility* - The small size of LEDs and their mounting surface (generally the conductor cable supplying power) enable flexible arrangements in any desired pattern for commercial signage.

5. Conclusion

In the last few years, LEDs have emerged 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 have proven to be an economically viable replacement in applications such as traffic signal heads, where the LED light source can be more than 20 times as expensive as the incandescent light source it replaces. Furthermore, substitutions like these are taking place, without subsidies or coupon schemes, because LEDs make financial sense and offer customers a better quality, more reliable lighting service.

Niche applications evaluated in this report cut across motor vehicles, stationary indoor, and outdoor installations. In the motor vehicle sector, LED technology is being used on automobiles, buses, and trucks as brake and indicator (signal) lighting. At trade shows, LED headlights have been demonstrated, but at this time, but no vehicles currently incorporate them. In aircraft, LED technology is poised to supplant the halogen and incandescent passenger reading lights after further improvements in the efficacy of white LEDs. Although this application is small in terms of energy consumption, it represents the first entrée of LEDs into white-light general illumination applications on a large scale.

In the stationary outdoor installations, LEDs can be found in traffic signals, railway signals, airport taxiway lights, and bridge navigational lights. In all of these applications, LEDs are replacing incandescent lamps, which typically produce colored light using a color-filter lens or encasement. LEDs have the advantage of only producing light in the desired emission color, enabling them to do so using less energy. To date, approximately 1.48 TWh of electricity are saved everyyear because of the LED traffic signals that have replaced incandescent technology.

Finally, in the indoor applications, exit signs, commercial signage, and holiday lights represent the three most significant niche market opportunities for LEDs. Of these, commercial signage represents the largest annual energy consumption at approximately 10 TWh/yr. If LED technology were to replace all the colored neon lighting in commercial signs across the United States, approximately 6.6 TWh could be saved annually. Exit signs represent the niche application where LED technology has the highest level of market penetration. LED exit signs have been commercially available for more than ten years, and now constitute approximately 80% of the installed base.

Figure 5-1 presents the energy savings in 2002 from the niche applications considered in this analysis. The six niche applications appearing in this diagram represent those markets where LEDs have some level of market penetration (with some close to zero percent). The other six markets either have an assumed market penetration of zero percent, or were not quantified due to data quality or availability issues.

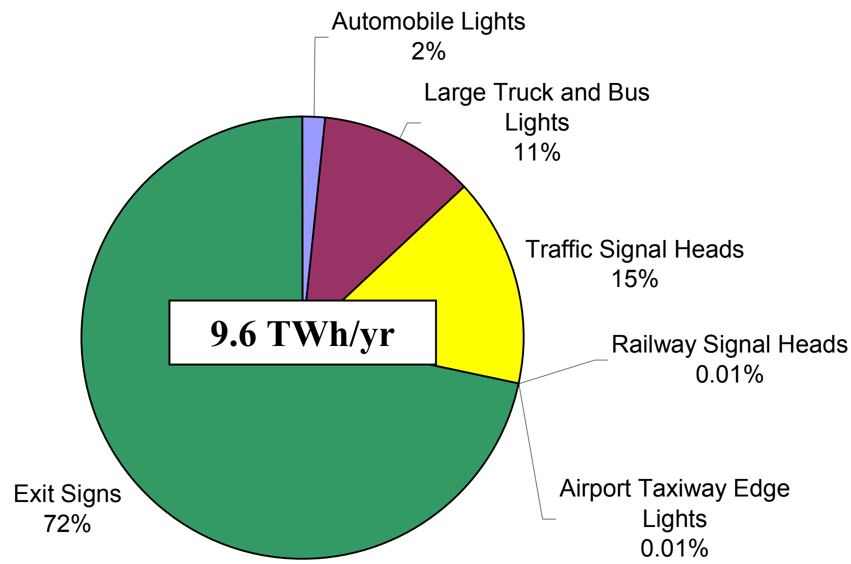

Figure 5-1. Site Electricity Savings in 2002 Attributable to LED Market Penetration

Clearly exit signs are the dominant energy saver from an LED perspective in 2002. Other niches, such as traffic signals – the second most significant energy saver – produce only one fifth as much energy savings as exit signs. Some sectors such as railway signals and runway lights are small markets and have low levels of penetration, thus contribute less than one-tenth of one percent to the 2002 savings.

Figure 5-2 apportions the electricity savings if 100% of these markets convert to LED technology. This total represents the combined 2002 energy savings and future potential energy savings if the remainder of each market converts to LED. This savings estimate may be understated, because it fixes LED technology at today's performance levels. Over the coming years, researchers and manufacturers will continue to develop and commercialize more energy efficient, higher quality LED devices. This trend means that as more market share is captured in the future, the LED technology adopted will have better performance characteristics, and contribute to even more significant energy savings. This situation is particularly true for white-light LED technology, which today operates at around 30 lumens per watt, twice as good as incandescent, but only half as much as fluorescent. White-light LED technology is presently the focus of many research initiatives around the United States and abroad, and continued advancements in efficacy, package, lumen output, operating life, and other critical performance metrics are anticipated. Thus, if the entire commercial air fleet switches to white-light LED passenger reading lights, the energy savings will be greater because instead of 30 lumen per watt replacements, the aircraft manufacturers may be installing 60 lumen per watt lamps – doubling the savings.

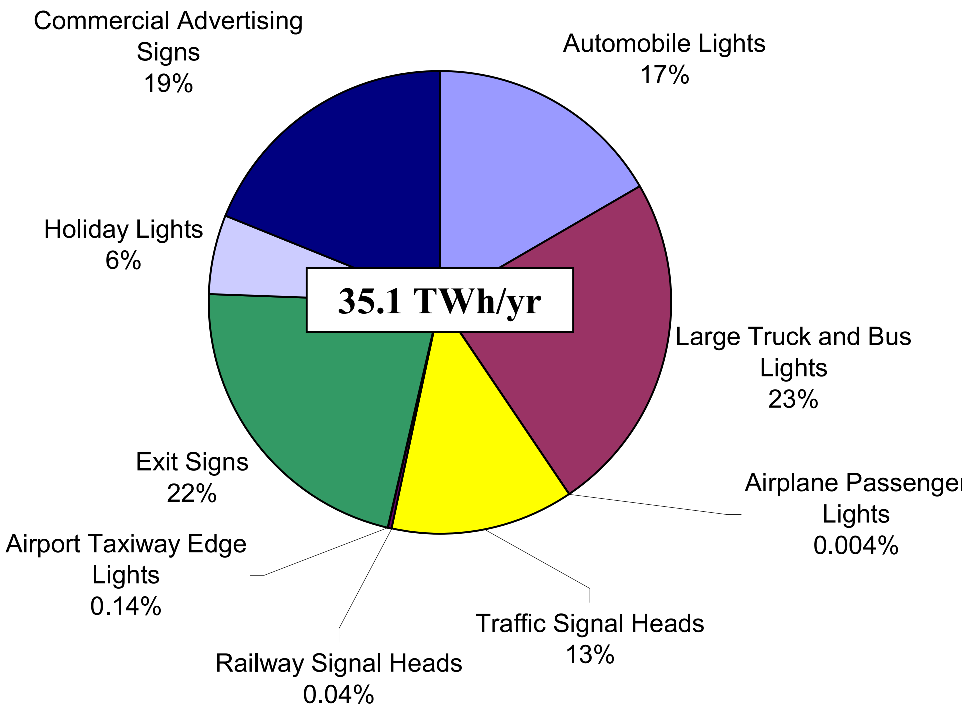

Figure 5-2. Cumulative Site Electricity Savings With 100% LED Market Penetration

Combining the niche markets for automobile lights and large truck and bus lights, nearly 40% of the maximum potential of 35.1 TWh/yr is available on mobile applications. These energy savings will not be realized as avoided power plant generation, but rather as reductions in fuel consumption. For automobiles, in terms of gasoline, this represents a savings potential of 1.4 billion gallons – approximately four days worth of national gasoline consumption. For trucks and buses, in terms of diesel fuel, this represents approximately 1.1 billion gallons – more than twelve days worth of national diesel consumption.

Table 5-1 summarizes the current energy savings of the analysis in detail, 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. Energy savings estimates were not be prepared for three sectors analyzed: navigational aids (water buoys), navigational bridge lights, and refrigerated display cases. This was due to inconsistent or unavailable data, as well as LEDs not being ready for one of these sectors.

Table 5-1. Energy Consumption and Savings in 2002 of Applications Evaluated

Application	Annual Energy[19]	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, electricity savings attributable to LEDs are dominated by exit signs, 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 energy saving niche market in 2002 was traffic signal heads. In this application, approximately 30% of the signals are estimated to be LED, representing approximately 15% of the total energy savings from LEDs in 2002. Other applications, such as aircraft passenger lights, holiday lights, and commercial advertising signs are estimated to have zero market penetration of LEDs. Commercial LED products for these applications are available, however market adoption has yet to occur.

Table 5-2 presents the future energy savings potential from converting the remainder of each market entirely to LEDs. It also presents the cumulative (total) energy savings that would result from the energy savings in 2002 and the additional energy savings from the conversion of each market to 100% LED.

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

Table 5-2. Potential and Cumulative Energy Savings of Applications Evaluated

Application	Potential Electricity Savings[20]	Potential Fuel / Primary Energy Savings	Cumulative Electricity Savings[21]	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.

Across the niche markets analyzed, there are significant opportunities for energy savings in the mobile transport applications as well as the stationary applications. Presently, approximately 13 TWh of on-board electricity savings are pending greater 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 to day, 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.

5.1. Benefits and Capturing Market Share

LEDs offer many benefits that have enabled them to capture market share from conventional light sources. As discussed earlier, LEDs are proving successful at capturing market share in colored-light applications such as traffic signals and exit signs.

[20] 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.
[21] 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.

Each niche market analyzed in this report covers the particular LED benefits that are most relevant to a given application. They are summarized here.

Saving Energy - LED devices can offer a more energy efficient means of producing light, particularly when compared to incandescent sources. In an application such as a traffic signal, an 11W LED red signal head replaces a 140W reflector lamp while maintaining the same brightness and safety standards – a 92% reduction in energy consumption. As LED technology evolves, the efficacy, or efficiency of converting energy input into light output, continues to improve.

Reduced Heat Production - Because of their relatively higher efficiency, 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 or halogen light source. However, further research needs to address the heat management issue, as it is one of the major engineering concerns in LED product development.

Long Operating Life - LED technology offers operating lives that are approximately ten times 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 and never risking non-functional brake lights. Researchers indicate that operating life will continue to improve with technology breakthroughs and advancements.

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 a vibration or shock while emitting light.

Smaller Package Size – LED devices are an excellent option where size and/or weight are concerns. For example, more automobile 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. In aircrafts too, having smaller, thinner and more energy efficient passenger reading lamps will save fuel while providing more space in the overhead storage compartments.

Safety Improvements – LED devices offer several safety advantages, including faster "on" times and safer operating wattage. At highway speeds of approximately 65 miles per hour, the faster on-time of 200 milliseconds equates to an extra 19 feet of stopping distance – the length of a full-size car. Finally, LED devices operate on lower voltages than competing technologies such as neon and fluorescent, which operate on several thousand volts.

Light Control – LED devices also offer distinct advantages where light encroachment or glare is a problem. For example, LED automobile headlamps are capable of directing all the light on the road surface ahead, rather than dazzling the oncoming driver. Or, for aircraft reading lamps, the illuminated area can be tightly defined so as to avoid disturbing other passengers who may be trying to sleep or watch a film. LED lamps can utilize a concentrating lens constructed from an epoxy encapsulant to focus and direct the light emitted from the LED chip in the desired direction.

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7. Appendices

Appendix A. Large Trucks and Buses Lighting Energy Consumption Tables

Appendix B. Description of Part 139 Certified Airports

Appendix C. List of Part 139 Certified Airports and Runway Lengths

Appendix D. Solid State Exit Signs. Department of Labor, Occupational Safety and Health Administration Final Rule.

Appendix A: Buses and Trucks Energy Consumption Tables

Table A.1 Bus Exterior Lamps, Including Inventory, Operating Hours, Wattages, and Energy Consumption

Lamp Application	Lamps per Vehicle	Lamps Installed Base	Operating Time (hrs/day)	Operating Time (hr/year)	Wattage Incandescent	Wattage Incandescent for 50% fleet	Wattage LED	Percent Improvement Wattage	Current Market Penetration LED	Energy Incandescent (GWh/yr)	Energy LED (GWh/yr)
Front Identification Lights	3	2,250,000	13.0	4,745	4.62	9.24	1.12	76%	90%	74.00	11.95
Front Clearance Lights	2	1,500,000	13.0	4,745	4.62	9.24	1.12	76%	90%	49.29	7.98
High Beam Headlamp	2	1,500,000	0.84	307	65		50.0	0%	0%	29.88	22.98
Low Beam Headlamp (part of high beam)	2	1,500,000	13.0	4,745	55		40.0	0%	0%	391.23	284.53
Front Park	2	1,500,000	13.0	4,745	6.14		1.40	77%	30%	440	9.96
Front Turn/Signal Hazard Warning Lamps	2	1,500,000	1.1	400	26.88		10.5	61%	50%	16.13	6.30
Front Side Marker	2	1,500,000	13.0	4,745	4.62	9.24	1.12	76%	90%	49.29	7.97
Intermediate Side Markers	2	1,500,000	13.0	4,745	6.14	12.29	1.12	82%	90%	65.56	7.97
Rear Side Markers	2	1,500,000	13.0	4,745	4.62	9.24	0.42	91%	90%	49.29	2.99
Rear Clearance	2	1,500,000	13.0	4,745	4.62	9.24	0.42	91%	90%	49.29	2.99
Rear Identification Lamp	3	2,250,000	13.0	4,745	4.62	9.24	0.42	91%	90%	74.0	4.48
Stop Lamps	2	1,500,000	1.1	400	28.35		0.42	99%	90%	17.01	0.25
Tail Lamps	2	1,500,000	13.0	4,745	6.48		0.42	94%	90%	46.09	2.99
Rear Turn Signal/Hazard Warning Lamps	2	1,500,000	1.1	400	28.35		0.42	99%	50%	17.01	0.25
Reverse Indicator Lamp	1	750,000	0.1	40	28.35		6.75	76%	40%	0.85	0.20
License Plate Lamp	1	750,000	13.0	4,745	4.62		0.68	85%	5%	16.43	2.40
Total	32	24,000,000	147	53,742	283		146			989	376.17

Sources: VanRiper, 2003; Vines, 2003; NHTSA, 2002

Table A.2 Truck Exterior Lamps, Including Inventory, Operating Hours, Wattages, and Energy Consumption

Lamp Application	Lamps per Vehicle	Lamps Installed Base	Operating Time (hr/day)	Operating Time (hr/year)	Wattage Incandescent 1	Wattage Incandescent 2[22]	Wattage LED	Percent Wattage Improvement	Current Market Penetration LED	Energy Incandescent (GWh/yr)	Energy LED (GWh/yr)
Trailer Lamps											
Front Clearance Lamps	2	15,715,400	10.0	3,650	4.62	9.24	1.12	76%	15%	398	64
Front Side Markers	2	15,715,400	10.0	3,650	4.62	9.24	1.12	76%	20%	398	64
Intermediate Side Markers	2	15,715,400	10.0	3,650	6.14	12.29	1.12	82%	10%	529	64
Side Turn (part of mid-marker lamp)	0	0	0.5	170	26.88		1.12	96%	5%	0	0
Rear Side Markers	2	15,715,400	10.0	3,650	4.62	9.24	0.42	91%	20%	398	24
Rear Clearance	2	15,715,400	10.0	3,650	4.62	9.24	0.42	91%	15%	398	24
Rear Identification	3	23,573,000	10.0	3,650	4.62	9.24	0.42	91%	15%	596	36
Stop Lamp	2	15,715,400	0.5	170	28.35		0.42	99%	23%	76	1
Rear Turn Signal/Hazard Warning	2	15,715,400	0.5	170	28.35		0.42	99%	5%	76	1
Tail Lamps (part of stop & turn lamps)	2	15,715,400	10.0	3,650	6.48		0.42	94%	23%	372	24
License Plate Lamp	1	7,857,700	10.0	3,650	4.62		0.68	85%	5%	133	20
Tractor Lamps											
Cab Roof Identification Lights	3	23,573,000	10.0	3,650	4.62	9.24	1.12	76%	8%	596	96
Cab Roof Clearance Lights	2	15,715,400	10.0	3,650	4.62	9.24	1.12	76%	8%	398	64
High Beam Headlamp	2	15,715,400	2.2	790	65.0		50	0%	0%	805	620
Low Beam Headlamp(part of high beam)	2	15,715,400	10.0	3,650	55.0		40	0%	0%	3155	2300
Front Park	2	15,715,400	10.0	3,650	6.14		1.40	77%	3%	352	80
Front Turn/Hazard Warning Lamps	2	15,715,400	0.5	170	26.88		10.50	61%	5%	73	29
Front Side Marker	2	15,715,400	10.0	3,650	4.62	9.24	1.12	76%	8%	398	64
5th Wheel Light (Upper Marking)	2	15,715,400	10.0	3,650	26.88		6.75	75%	1%	1542	387
Rear Markers	2	15,715,400	10.0	3,650	6.14	12.29	1.12	82%	8%	528	64
Stop Lamp	2	15,715,400	0.5	170	28.35		0.42	99%	8%	77	1
Rear Turn/Hazard Warning Signal	2	15,715,400	0.5	170	28.35		0.42	99%	5%	77	1
Tail Lamp (part of stop/turn lamp)	2	15,715,400	10.0	3,650	6.48		0.42	94%	8%	372	24
Reverse Indicator Lamp	1	7,857,700	0.1	20	28.35		6.75	76%	2%	4	1
License Plate Lamp	1	7,857,700	10.0	3,650	4.62		0.68	85%	5%	133	19.4
	47	283,740,600	175	63,891	420		160			11,882	4,068

Sources: VanRiper, 2003; Vines, 2003; NHTSA, 2002

[22] Several applications are designed with an additional incandescent bulb, which doubles the ampage 50% of the time.

Appendix B. Description of Part 139 Certified Airports.

Excerpt from FAA Website; (FAA, 2003a)

What is Part 139 Certification?

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. This part does not apply to airports at which air carrier passenger operations are conducted only by reason of the airport being designated as an alternate airport.

Airport Operating Certificates serve to ensure safety in air transportation. To obtain a certificate, an airport must agree to certain operational and safety standards and provide for such things as firefighting and rescue equipment. These requirements vary depending on the size of the airport and the type of flights available. The regulation, however, does allow the FAA to issue certain exemptions to airports that serve few passengers annually and for which some requirements might create a financial hardship. The FAA is currently revising part 139 and expects to announce the new rule in Fall 2003.

The FAA issues two types of Airport Operating Certificates:

Airport Operating Certificate. A certificate, issued under part 139, for operation of an airport serving scheduled air carrier operations with aircraft having a seating capacity of more than 30 passengers. Fully certificated airports must maintain an Airport Certification Manual (ACM) that details operating procedures, facilities, and equipment and other appropriate information.

Limited Airport Operating Certificate. A certificate, issued under part 139, for the operation of an airport serving unscheduled air carrier operations with aircraft having a seating capacity of more than 30 passengers. Limited certificated airports must maintain an Airport Certification Specification (ACS) that details operating procedures, facilities, and equipment and other appropriate information. The ACS is similar in content to the ACM but slightly abbreviated due to the nature of the limited certificate.

In the United States, there are approximately 436 airports holding Airport Operating Certificates, 127 holding Limited Airport Operating Certificates, and 83 military airports holding Airport Operating Certificates under an FAA exemption.

Basic Phases of a Part 139 Inspection

To ensure that airports with Airport Operating Certificates are meeting the requirements of part 139, approximately 35 FAA Airport Certification Safety Inspectors conduct certification inspections. These inspections typically occur annually, but the FAA can also make unannounced inspections. Certification inspections generally include the following steps:

- **Pre-inspection review** of office airport files and airport certification manual.

- **In-briefing with airport management.** Organize inspection time schedule, meet with different airport personnel.

- **Administrative inspection of airport files, paperwork, etc.** Also includes the updating of the Airport Master Record (FAA Form 5010) and review of the Airport Certification Manual/Specifications (ACM/ACS), Notices to Airmen (NOTAM), airfield self inspection forms, etc.

- **Movement area inspection.** Check the approach slopes of each runway end; inspect movement areas, in order to ascertain condition of pavement, markings, lighting, signs, abutting shoulders, and safety areas; observe ground vehicle operations; ensure the public is protected against inadvertent entry and jet or propeller blast; check for the presence of any wildlife; check the traffic and wind direction indicators.

- **Aircraft rescue and fire fighting inspection.** Conduct a timed-response drill; review aircraft rescue and firefighting personnel training records, including annual live-fire drill and documentation of basic emergency medical care training; check equipment and protective clothing for operation, condition, and availability.

- **Fueling facilities inspection.** Inspection of fuel farm and mobile fuelers; check airport files for documentation of their quarterly inspections of the fueling facility; review certification from each tenant fueling agent concerning completion of fire safety training.

- **Night inspection.** Evaluate runway/taxiway and apron lighting and signage, pavement marking, airport beacon, wind cone, lighting, and obstruction lighting for compliance with part 139 and the ACM/ACS. A night inspection is conducted if air carrier operations are conducted or expected to be conducted at an airport at night or the airport has an instrument approach.

- **Post inspection briefing with airport management.** Discuss findings; issue Letter of Correction noting violations and/or discrepancies if any are found; agree on a reasonable date for the correction of any violations, and give safety recommendations.

Compliance with Part 139

If the FAA finds that an airport is not meeting its obligations, it often imposes some kind of administrative action. It can also impose a financial penalty for each day the airport continues to violate a part 139 requirement. In extreme cases, the FAA might revoke the airport's certificate or limit the areas of an airport where air carriers can land or take off.

Appendix C. Runway Lengths for Part 139 Certified Airports

Table C.1 Cumulative Runway Length for Part 139 Certified Airports

State	City	Airport Code	Runway Length (ft.)
AL	ANNISTON	ANB	7,000
AL	BIRMINGHAM	BHM	15,330
AL	DOTHAN	DHN	13,498
AL	HUNTSVILLE	HSV	17,806
AL	MOBILE	BFM	18,221
AL	MOBILE	MOB	12,897
AL	MONTGOMERY	MGM	13,020
AL	MUSCLESHOALS	MSL	10,693
AL	TALLADEGA	ASN	6,002
AL	TUSCALOOSA	TCL	10,500
AR	FAYETTEVILLE/SPRINGDALE/	XNA	8,800
AR	FORTSMITH	FSM	13,002
AR	HOTSPRINGS	HOT	10,204
AR	JACKSONVILLE	LRF	15,500
AR	LITTLEROCK	LIT	8,273
AR	TEXARKANA	TXK	11,800
AZ	BULLHEADCITY	IFP	7,520
AZ	FLAGSTAFF	FLG	6,999
AZ	FORTHUACHUCASIERRAVISTA	FHU	21,652
AZ	GLENDALE	LUF	19,916
AZ	GRANDCANYON	GCN	8,999
AZ	KINGMAN	IGM	13,556
AZ	MARANA	MZJ	6,850
AZ	PAGE	PGA	7,699
AZ	PHOENIX	PHX	29,590
AZ	PHOENIX	IWA	29,903
AZ	PRESCOTT	PRC	16,804
AZ	TUCSON	DMA	13,643
AZ	TUCSON	TUS	26,404
AZ	YUMA	YUM	34,398
CA	BAKERSFIELD	BFL	11,129
CA	BURBANK	BUR	12,337
CA	CARLSBAD	CRQ	4,897
CA	EDWARDS	EDW	23,013
CA	LONGBEACH	LGB	27,540
CA	LOSALAMITOS	SLI	13,900
CA	LOSANGELES	LAX	41,440
CA	ONTARIO	ONT	22,398
CA	OXNARD	OXR	4,577
CA	PALMSPRINGS	PSP	13,452
CA	PALMDALE	PMD	24,003
CA	POINTMUGU	NTD	16,600
CA	RIVERSIDE	RIV	16,410
CA	SANBERNARDINO	SBD	10,001
CA	SANDIEGO	NZY	15,500
CA	SANDIEGO	SAN	7,590
CA	SANTAANA	SNA	8,588
CA	SANTABARBARA	SBA	14,100
CA	SANTAMARIA	SMX	11,434

State	City	Airport Code	Runway Length (ft.)
CA	VICTORVILLE	VCV	22,188
CA	ARCATA/EUREKA	ACV	10,497
CA	CHICO	CIC	9,729
CA	CONCORD	CCR	14,221
CA	CRESCENTCITY	CEC	10,004
CA	FAIRFIELD	SUU	21,993
CA	FRESNO	FAT	16,110
CA	MAMMOTHLAKES	MMH	7,000
CA	MERCED	MCE	5,903
CA	MODESTO	MOD	9,370
CA	MONTEREY	MRY	10,129
CA	OAKLAND	OAK	25,031
CA	PASOROBLES	PRB	10,709
CA	REDDING	RDD	12,065
CA	SACRAMENTO	SMF	17,201
CA	SANFRANCISCO	SFO	38,620
CA	SANJOSE	SJC	21,394
CA	SANLUISOBISPO	SBP	8,060
CA	SANTAROSA	STS	10,117
CA	SOUTHLAKETAHOE	TVL	6,507
CA	STOCKTON	SCK	14,109
CA	VISALIA	VIS	6,559
CO	AKRON	AKO	7,000
CO	ALAMOSA	ALS	11,719
CO	ASPEN	ASE	7,006
CO	AURORA	BKF	11,000
CO	COLORADOSPRINGS	COS	32,433
CO	CORTEZ	CEZ	7,205
CO	DENVER	DEN	76,000
CO	DURANGO	DRO	9,201
CO	EAGLE	EGE	8,000
CO	FORTCOLLINS/LOVELAND	FNL	10,773
CO	GRANDJUNCTION	GJT	16,003
CO	GUNNISON	GUC	12,200
CO	HAYDEN	HDN	10,000
CO	LAMAR	LAA	11,305
CO	MONTROSE	MTJ	18,497
CO	PUEBLO	PUB	22,877
CO	TELLURIDE	TEX	6,870
DC	WASHINGTON	DCA	16,984
DC	WASHINGTON	IAD	33,502
DE	WILMINGTON	ILG	18,796
DE	DOVER	DOV	22,505
FL	COCOABEACH	XMR	10,000
FL	COCOABEACH	COF	12,723
FL	DAYTONABEACH	DAB	19,696
FL	FORTLAUDERDALE	FLL	20,390
FL	FORTMYERS	RSW	12,000
FL	GAINESVILLE	GNV	11,659
FL	JACKSONVILLE	JAX	17,701
FL	KEYWEST	EYW	4,801
FL	LAKELAND	LAL	13,500
FL	MARATHON	MTH	5,008

State	City	Airport Code	Runway Length (ft.)
FL	MARYESTHER	HRT	9,600
FL	MELBOURNE	MLB	18,482
FL	MIAMI	MIA	39,251
FL	NAPLES	APF	11,400
FL	OCALA	OCF	9,917
FL	ORLANDO	MCO	34,009
FL	ORLANDO	SFB	22,080
FL	PANAMACITY	PFN	11,192
FL	PENSACOLA	PNS	13,003
FL	PUNTAGORDA	PGD	15,914
FL	SARASOTA/BRADENTON	SRQ	13,365
FL	STAUGUSTINE	SGJ	41,511
FL	STPETERSBURG-CLEARWATER	PIE	22,907
FL	TALLAHASSEE	TLH	14,076
FL	TAMPA	MCF	11,420
FL	TAMPA	TPA	26,301
FL	TITUSVILLE	TIX	12,320
FL	VEROBEACH	VRB	15,792
FL	WESTPALMBEACH	PBI	18,913
GA	ALBANY	ABY	11,801
GA	ATHENS	AHN	9,522
GA	ATLANTA	ATL	39,891
GA	AUGUSTA	AGS	14,003
GA	BRUNSWICK	BQK	8,001
GA	COLUMBUS	CSG	10,994
GA	FORTBENNING(COLUMBUS)	LSF	8,202
GA	MACON	MCN	11,502
GA	MARIETTA	MGE	14,000
GA	ROME	RMG	10,497
GA	SAVANNAH	SVN	11,375
GA	SAVANNAH	SAV	16,353
GA	VALDOSTA	VAD	17,300
GA	VALDOSTA	VLD	15,536
GA	WARNERROBINS	WRB	12,001
IA	BURLINGTON	BRL	11,552
IA	CEDARRAPIDS	CID	13,876
IA	CLINTON	CWI	8,904
IA	DESMOINES	DSM	18,004
IA	DUBUQUE	DBQ	12,823
IA	FORTDODGE	FOD	10,949
IA	MASONCITY	MCW	12,003
IA	OTTUMWA	OTM	11,063
IA	SIOUXCITY	SUX	15,601
IA	WATERLOO	ALO	19,805
ID	BOISE	BOI	19,763
ID	COEURDALENE	COE	12,800
ID	HAILEY	SUN	6,602
ID	IDAHOFALLS	IDA	13,051
ID	LEWISTON	LWS	11,513
ID	POCATELLO	PIH	16,206
ID	TWINFALLS	TWF	11,927
IL	ALTON/STLOUIS	ALN	14,601
IL	BELLEVILLE	BLV	17,801

State	City	Airport Code	Runway Length (ft.)
IL	BLOOMINGTON/NORMAL	BMI	13,500
IL	CARBONDALE/MURPHYSBORO	MDH	14,168
IL	CHAMPAIGN/URBANA	CMI	23,716
IL	CHICAGO	MDW	25,267
IL	CHICAGO	ORD	62,023
IL	DECATUR	DEC	12,098
IL	MARION	MWA	11,503
IL	MATTOON/CHARLESTON	MTO	13,380
IL	MOLINE	MLI	21,290
IL	MOUNTVERNON	MVN	9,647
IL	PEORIA	PIA	17,503
IL	QUINCY	UIN	17,622
IL	ROCKFORD	RFD	18,199
IL	SPRINGFIELD	SPI	20,299
IL	STERLING/ROCKFALLS	SQI	10,399
IN	ANDERSON	AID	8,414
IN	BLOOMINGTON	BMG	10,076
IN	COLUMBUS	BAK	11,400
IN	ELKHART	EKM	10,501
IN	EVANSVILLE	EVV	14,566
IN	FORTWAYNE	FWA	24,002
IN	GARY	GYY	10,603
IN	INDIANAPOLIS	IND	28,805
IN	INDIANAPOLIS	MQJ	9,401
IN	LAFAYETTE	LAF	10,513
IN	MUNCIE	MIE	11,498
IN	SOUTHBEND	SBN	18,713
IN	TERREHAUTE	HUF	20,221
IN	VALPARAISO	VPZ	11,000
KS	DODGECITY	DDC	10,979
KS	GARDENCITY	GCK	13,000
KS	GOODLAND	GLD	10,800
KS	GREATBEND	GBD	12,548
KS	HAYS	HYS	6,500
KS	HUTCHINSON	HUT	16,456
KS	LIBERAL	LBL	12,823
KS	MANHATTAN	MHK	10,801
KS	SALINA	SLN	29,787
KS	TOPEKA	FOE	19,802
KS	WICHITA	IAB	24,000
KS	WICHITA	ICT	23,903
KY	BOWLINGGREEN	BWG	10,106
KY	COVINGTON/CINCINNATI,OH	CVG	31,000
KY	FORTCAMPBELL/HOPKINSVILLE	HOP	16,300
KY	LEXINGTON	LEX	10,503
KY	LOUISVILLE	SDF	25,379
KY	OWENSBORO	OWB	11,494
KY	PADUCAH	PAH	10,498
LA	ALEXANDRIA	AEX	16,353
LA	BATONROUGE	BTR	16,964
LA	BOSSIERCITY	BAD	11,756
LA	FORTPOLK	POE	4,109
LA	LAFAYETTE	LFT	16,961

State	City	Airport Code	Runway Length (ft.)
LA	LAKECHARLES	CWF	10,701
LA	LAKECHARLES	LCH	11,700
LA	MONROE	MLU	17,508
LA	NEWIBERIA	ARA	13,002
LA	NEWORLEANS	NEW	12,854
LA	NEWORLEANS	MSY	20,371
LA	SHREVEPORT	SHV	14,177
MD	BALTIMORE	BWI	30,503
MD	CAMPSPRINGS	ADW	19,055
MD	HAGERSTOWN	HGR	8,506
MD	SALISBURY	SBY	10,500
ME	PORTLAND	PWM	11,801
ME	PRESQUEISLE	PQI	13,434
MI	ALPENA	APN	14,032
MI	BATTLECREEK	BTL	18,856
MI	DETROIT	DET	8,399
MI	DETROIT	DTW	57,701
MI	DETROIT	YIP	34,900
MI	ESCANABA	ESC	11,501
MI	FLINT	FNT	18,958
MI	GAYLORD	GLR	9,579
MI	GRANDRAPIDS	GRR	23,501
MI	HANCOCK	CMX	11,697
MI	IRONMOUNTAINKINGSFORD	IMT	10,312
MI	IRONWOOD	IWD	6,501
MI	KALAMAZOO	AZO	12,756
MI	LANSING	LAN	15,853
MI	MARQUETTE	SAW	12,370
MI	MENOMINEE	MNM	11,100
MI	MUSKEGON	MKG	14,702
MI	PELLSTON	PLN	11,907
MI	PONTIAC	PTK	11,200
MI	SAGINAW	MBS	14,402
MI	SAULTSTEMARIE	CIU	12,201
MI	TRAVERSECITY	TVC	11,608
MN	BEMIDJI	BJI	12,297
MN	BRAINERD	BRD	12,819
MN	DULUTH	DLH	15,851
MN	GRANDRAPIDS	GPZ	11,193
MN	HIBBING	HIB	9,833
MN	INTERNATIONALFALLS	INL	9,507
MN	MINNEAPOLIS	MSP	28,218
MN	ROCHESTER	RST	14,833
MN	STCLOUD	STC	10,000
MN	THIEFRIVERFALLS	TVF	6,503
MO	CAPEGIRARDEAU	CGI	10,495
MO	COLUMBIA	COU	10,902
MO	FORTLEONARDWOOD	TBN	5,512
MO	JEFFERSONCITY	JEF	9,402
MO	JOPLIN	JLN	16,606
MO	KAISERLAKEOZARK	AIZ	6,497
MO	KANSASCITY	MKC	11,353
MO	KANSASCITY	MCI	29,801

State	City	Airport Code	Runway Length (ft.)
MO	KIRKSVILLE	IRK	7,398
MO	SPRINGFIELD	SGF	15,003
MO	STJOSEPH	STJ	12,856
MO	STLOUIS	STL	27,435
MO	STLOUIS	SUS	12,004
MS	BAYSTLOUIS	HSA	8,500
MS	BILOXI	BIX	6,632
MS	COLUMBUS	CBM	26,300
MS	COLUMBUS/WPOINT/STARKVILL	GTR	6,497
MS	GREENVILLE	GLH	19,584
MS	GULFPORT	GPT	13,937
MS	HATTIESBURG/LAUREL	PIB	6,501
MS	JACKSON	JAN	17,000
MS	MERIDIAN	MEI	9,004
MS	NATCHEZ	HEZ	11,500
MS	OXFORD	UOX	4,700
MS	PASCAGOULA	PQL	6,500
MS	TUPELO	TUP	6,500
MT	BILLINGS	BIL	19,820
MT	BOZEMAN	BZN	11,653
MT	BUTTE	BTM	14,101
MT	GREATFALLS	GTF	21,153
MT	HELENA	HLN	16,633
MT	KALISPELL	FCA	11,524
MT	MISSOULA	MSO	14,113
MT	WESTYELLOWSTONE	WYS	8,399
NC	ASHEVILLE	AVL	8,001
NC	CHARLOTTE	CLT	26,176
NC	CHERRYPOINT	NKT	32,255
NC	FAYETTEVILLE	FAY	11,807
NC	FAYETTEVILLE	POB	10,501
NC	GOLDSBORO	GSB	11,758
NC	GREENSBORO	GSO	16,380
NC	GREENVILLE	PGV	13,834
NC	HICKORY	HKY	10,800
NC	JACKSONVILLE	OAJ	7,100
NC	KINSTON	ISO	11,500
NC	NEWBERN	EWN	10,004
NC	PINEHURST/SOUTHERNPINES	SOP	7,503
NC	RALEIGH/DURHAM	RDU	21,070
NC	ROCKYMOUNT	RWI	7,100
NC	WILMINGTON	ILM	15,004
NC	WINSTONSALEM	INT	10,593
ND	BISMARCK	BIS	15,394
ND	DEVILSLAKE	DVL	8,982
ND	FARGO	FAR	19,247
ND	GRANDFORKS	GFK	15,455
ND	JAMESTOWN	JMS	12,249
ND	MINOT	MIB	13,200
ND	MINOT	MOT	14,050
ND	WILLISTON	ISN	10,103
NE	ALLIANCE	AIA	21,713
NE	GRANDISLAND	GRI	19,124

State	City	Airport Code	Runway Length (ft.)
NE	HASTINGS	HSI	10,002
NE	KEARNEY	EAR	11,592
NE	LINCOLN	LNK	26,480
NE	MCCOOK	MCK	11,049
NE	NORFOLK	OFK	11,243
NE	NORTHPLATTE	LBF	12,135
NE	OMAHA	OMA	24,675
NE	SCOTTSBLUFF	BFF	16,281
NH	MANCHESTER	MHT	16,100
NH	PORTSMOUTH	PSM	11,321
NJ	ATLANTICCITY	ACY	16,143
NJ	NEWARK	EWR	24,272
NJ	TETERBORO	TEB	12,243
NJ	TRENTON	TTN	10,806
NJ	WRIGHTSTOWN	WRI	17,125
NM	ALAMOGORDO	HMN	35,506
NM	ALBUQUERQUE	ABQ	39,793
NM	CARLSBAD	CNM	22,640
NM	FARMINGTON	FMN	15,675
NM	HOBBS	HOB	21,910
NM	LASCRUCES	LRU	21,067
NM	ROSWELL	ROW	30,425
NM	RUIDOSO	SRR	14,599
NV	ELKO	EKO	9,290
NV	ELY	ELY	10,832
NV	LASVEGAS	LAS	41,521
NV	LASVEGAS	LSV	20,178
NV	RENO	RNO	25,111
NY	ALBANY	ALB	13,200
NY	BINGHAMTON	BGM	12,102
NY	BUFFALO	BUF	13,478
NY	ELMIRA/CORNING	ELM	14,034
NY	FARMINGDALE	FRG	11,554
NY	FORTDRUM	GTB	19,481
NY	GLENSFALLS	GFL	9,000
NY	ISLIP	ISP	20,436
NY	ITHACA	ITH	8,619
NY	JAMESTOWN	JHW	9,799
NY	MASSENA	MSS	8,998
NY	MONTICELLO	MSV	6,000
NY	NEWYORK	JFK	37,279
NY	NEWYORK	LGA	14,000
NY	NEWBURGH	SWF	15,834
NY	NIAGARAFALLS	IAG	18,986
NY	OGDENSBURG	OGS	5,200
NY	PLATTSBURGH	PLB	9,365
NY	POUGHKEEPSIE	POU	9,110
NY	ROCHESTER	ROC	17,501
NY	SYRACUSE	SYR	16,503
NY	UTICA	UCA	11,002
NY	WATERTOWN	ART	10,000
NY	WHITEPLAINS	HPN	9,712
OH	AKRON	CAK	20,796

State	City	Airport Code	Runway Length (ft.)
OH	CINCINNATI	LUK	15,031
OH	CLEVELAND	BKL	11,395
OH	CLEVELAND	CLE	28,642
OH	CLEVELAND	CGF	5,102
OH	COLUMBUS	OSU	14,991
OH	COLUMBUS	CMH	18,251
OH	COLUMBUS	LCK	23,036
OH	DAYTON	DAY	26,403
OH	LORAIN/ELYRIA	LPR	5,002
OH	MANSFIELD	MFD	15,796
OH	SPRINGFIELD	SGH	14,508
OH	TOLEDO	TOL	16,199
OH	WILMINGTON	ILN	19,701
OH	YOUNGSTOWN/WARREN	YNG	14,005
OK	ALTUS	LTS	25,954
OK	ENID	END	33,395
OK	FORTSILL	FSI	5,000
OK	LAWTON	LAW	8,599
OK	OKLAHOMACITY	TIK	21,100
OK	OKLAHOMACITY	OKC	30,481
OK	STILLWATER	SWO	11,004
OK	TULSA	TUL	23,476
OR	ASTORIA	AST	10,078
OR	CORVALLIS	CVO	9,055
OR	EUGENE	EUG	13,237
OR	KLAMATHFALLS	LMT	15,047
OR	MCMINNVILLE	MMV	10,096
OR	MEDFORD	MFR	11,953
OR	NEWPORT	ONP	8,099
OR	NORTHBEND	OTH	12,227
OR	PENDLETON	PDT	15,767
OR	PORTLAND	PDX	25,321
OR	REDMOND	RDM	14,046
OR	SALEM	SLE	10,956
PA	ALLENTOWN	ABE	12,897
PA	ALTOONA	AOO	9,134
PA	BRADFORD	BFD	10,999
PA	DUBOIS	DUJ	5,504
PA	ERIE	ERI	9,211
PA	FRANKLIN	FKL	8,898
PA	HARRISBURG	MDT	9,007
PA	JOHNSTOWN	JST	15,210
PA	LANCASTER	LNS	9,500
PA	LATROBE	LBE	10,597
PA	PHILADELPHIA	PHL	30,458
PA	PITTSBURGH	AGC	12,873
PA	PITTSBURGH	PIT	39,811
PA	READING	RDG	11,501
PA	STATECOLLEGE	UNV	9,050
PA	WILKES-BARRE/SCRANTON	AVP	11,801
PA	WILLIAMSPORT	IPT	10,754
RI	PROVIDENCE	PVD	13,247
SC	ANDERSON	AND	9,997

State	City	Airport Code	Runway Length (ft.)
SC	BEAUFORT	NBC	24,144
SC	CHARLESTON	CHS	16,005
SC	COLUMBIA	CAE	15,602
SC	EASTOVER	MMT	15,537
SC	FLORENCE	FLO	12,498
SC	GREENVILLE	GYH	8,000
SC	GREER	GSP	11,000
SC	HILTONHEADISLAND	HXD	4,000
SC	MYRTLEBEACH	MYR	9,503
SC	SUMTER	SSC	18,010
SD	ABERDEEN	ABR	12,401
SD	BROOKINGS	BKX	8,830
SD	HURON	HON	12,201
SD	PIERRE	PIR	13,778
SD	RAPIDCITY	RCA	13,497
SD	RAPIDCITY	RAP	12,302
SD	SIOUXFALLS	FSD	20,151
SD	WATERTOWN	ATY	13,495
SD	YANKTON	YKN	9,480
TN	BRISTOL/JOHNSON/KINGSPORT	TRI	12,447
TN	CHATTANOOGA	CHA	12,401
TN	JACKSON	MKL	9,544
TN	KNOXVILLE	TYS	17,605
TN	MEMPHIS	MEM	38,386
TN	MILLINGTON	NQA	8,000
TN	NASHVILLE	BNA	33,991
TN	SMYRNA	MQY	13,582
TX	ABILENE	ABI	18,078
TX	ABILENE	DYS	17,000
TX	AMARILLO	AMA	21,403
TX	ANGLETON/LAKEJACKSON	LBX	7,000
TX	AUSTIN	AUS	21,248
TX	BEAUMONT/PORTARTHUR	BPT	11,820
TX	BROWNSVILLE	BRO	16,400
TX	COLLEGESTATION	CLL	17,308
TX	CORPUSCHRISTI	CRP	13,588
TX	DALLAS	DAL	22,699
TX	DALLAS-FORTWORTH	DFW	78,390
TX	ELPASO	ELP	26,528
TX	FORTBLISS/ELPASO/	BIF	13,572
TX	FORTHOOD/KILLEEN	GRK	10,000
TX	FORTWORTH	AFW	17,219
TX	FORTWORTH	FTW	15,184
TX	FORTWORTH	NFW	12,002
TX	HARLINGEN	HRL	27,062
TX	HOUSTON	EFD	21,611
TX	HOUSTON	IAH	50,402
TX	HOUSTON	HOU	26,152
TX	KILLEEN	ILE	5,495
TX	LAREDO	LRD	21,995
TX	LONGVIEW	GGG	16,109
TX	AMARILLO	AMA	21,403
TX	ANGLETON/LAKEJACKSON	LBX	7,000

State	City	Airport Code	Runway Length (ft.)
TX	AUSTIN	AUS	21,248
TX	BEAUMONT/PORTARTHUR	BPT	11,820
TX	BROWNSVILLE	BRO	16,400
TX	COLLEGESTATION	CLL	17,308
TX	CORPUSCHRISTI	CRP	13,588
TX	DALLAS	DAL	22,699
TX	DALLAS-FORTWORTH	DFW	9,000
TX	ELPASO	ELP	26,528
TX	FORTBLISS/ELPASO/	BIF	13,572
TX	FORTHOOD/KILLEEN	GRK	10,000
TX	FORTWORTH	FTW	15,184
TX	FORTWORTH	NFW	12,002
TX	HARLINGEN	HRL	27,062
TX	HOUSTON	EFD	21,611
TX	HOUSTON	IAH	50,402
TX	HOUSTON	HOU	26,152
TX	KILLEEN	ILE	5,495
TX	LAREDO	LRD	21,995
TX	LONGVIEW	GGG	16,109
TX	LUBBOCK	LBB	22,392
TX	MCALLEN	MFE	9,758
TX	MIDLAND	MAF	26,055
TX	PARIS	PRX	15,250
TX	SANANGELO	SJT	18,390
TX	SANANTONIO	SKF	11,550
TX	SANANTONIO	SAT	21,526
TX	TEMPLE	TPL	11,041
TX	TYLER	TYR	17,250
TX	VICTORIA	VCT	22,292
TX	WACO	ACT	12,492
TX	WICHITAFALLS	SPS	36,125
UT	CEDARCITY	CDC	13,475
UT	OGDEN	HIF	13,508
UT	OGDEN	OGD	17,887
UT	PROVO	PVU	15,213
UT	SALTLAKECITY	SLC	38,168
UT	STGEORGE	SGU	6,606
UT	WENDOVER	ENV	16,000
VA	CHARLOTTESVILLE	CHO	6,001
VA	DANVILLE	DAN	9,620
VA	HAMPTON	LFI	10,000
VA	LYNCHBURG	LYH	9,186
VA	NEWPORTNEWS	PHF	14,529
VA	NORFOLK	ORF	13,876
VA	NORFOLK	NGU	7,374
VA	RICHMOND	RIC	20,936
VA	ROANOKE	ROA	11,820
VA	STAUNTON/WAYNESBORO/HARRIS	SHD	6,002
VA	VIRGINIABEACH	NTU	35,977
VT	BURLINGTON	BTV	11,431
VT	RUTLAND	RUT	8,170
WA	BELLINGHAM	BLI	6,701
WA	EVERETT	PAE	16,514

State	City	Airport Code	Runway Length (ft.)
WA	FORTLEWIS/TACOMA	GRF	6,125
WA	MOSESLAKE	MWH	24,247
WA	OLYMPIA	OLM	9,576
WA	PASCO	PSC	19,034
WA	PORTANGELES	CLM	8,248
WA	PULLMAN/MOSCOW,ID	PUW	5,929
WA	SEATTLE	BFI	12,546
WA	SEATTLE	SEA	21,327
WA	SPOKANE	SKA	13,901
WA	SPOKANE	GEG	17,199
WA	WALLAWALLA	ALW	16,977
WA	WENATCHEE	EAT	9,961
WA	YAKIMA	YKM	11,438
WI	APPLETON	ATW	13,502
WI	CAMPDOUGLAS	VOK	9,000
WI	EAUCLAIRE	EAU	11,300
WI	GREENBAY	GRB	15,899
WI	JANESVILLE	JVL	19,001
WI	KENOSHA	ENW	13,239
WV	BECKLEY	BKW	11,750
WV	CHARLESTON	CRW	11,053
WV	CLARKSBURG	CKB	7,000
WV	HUNTINGTON	HTS	9,524
WV	LEWISBURG	LWB	7,004
WV	MORGANTOWN	MGW	7,968
WV	PARKERSBURG	PKB	10,781
WY	CASPER	CPR	32,529
WY	CHEYENNE	CYS	14,707
WY	CODY	COD	14,707
WY	GILLETTE	GCC	13,303
WY	JACKSON	JAC	6,300
WY	LARAMIE	LAR	14,800
WY	RIVERTON	RIW	13,003
WY	ROCKSPRINGS	RKS	15,223
WY	SHERIDAN	SHR	13,339
WY	WORLAND	WRL	11,747
	TOTAL		**8,703,542**

Sources: FAA, 2003b. Fltplan.com, 2003.

Appendix D. Solid State Exit Signs. Department of Labor, Occupational Safety and Health Administration Final Rule

Department of Labor, Occupational Safety and Health Administration Final Rule: Exit Routes, Emergency Action Plans, and Fire Prevention Plans; Final Rule. Federal Register Volume 67 pages 67949-67965; November 7, 2002. Amending 29 CFR Part 1910. The relevant parts of section 1910.37 are provided below for convenience:

§ 1910.37 Maintenance, safeguards, and operational features for exit routes.

(b) Lighting and marking must be adequate and appropriate.

(2) Each exit must be clearly visible and marked by a sign reading "Exit."

(6) Each exit sign must be illuminated to a surface value of at least five foot-candles (54 lux) by a reliable light source and be distinctive in color. Self-luminous or electroluminescent signs that have a minimum luminance surface value of at least .06 footlamberts (0.21 cd/m2) are permitted.

(7) Each exit sign must have the word "Exit" in plainly legible letters not less than six inches (15.2 cm) high, with the principal strokes of the letters in the word "Exit" not less than three-fourths of an inch (1.9 cm) wide.