Errata: Refrigerated Display Case Energy Savings Estimates

October 2008

The Department of Energy would like to correct certain values and figures given in the September 2008 version of "Energy Savings Estimates of Light Emitting Diodes in Niche Lighting Applications." Specifically, the installed base of refrigerated display case fluorescent lighting systems in the U.S. was given in linear feet of display cases instead of, as labeled in the report, the number of refrigerated display cases. In addition, calculations in the September 2008 report estimating the electricity consumption and annual energy savings of refrigerated display cases assumed that the installed base of refrigerated fluorescent display cases given in Table 3-7 was the number of refrigerated display cases (rather than assuming correctly that it is the total linear feet of display cases). As there are approximately twelve linear feet per refrigerated display case, annual electricity consumption estimates and potential energy savings estimates are overestimated in the September 2008 report by a factor of twelve.

This document highlights the corrections to the report issued on September 2008 by page number.

Page xii: Corrected text
Page xiii: Corrected figure
Page xiv: Corrected table and text
Page xv: Corrected table
Page 5: Corrected text
Page 30: Corrected text
Page 35: Corrected text
Page 37: Corrected table and text
Page 38: Corrected text
Page 39: Corrected table
Page 66: Corrected text
Page 68: Corrected figure
Page 69: Corrected table and text
Page 70: Corrected table and text

designed LED products can save energy, and provide equivalent or better lighting quality, compared to conventional lighting technologies. In addition, the potential for very long service life of LED products, and greatly reduced lighting maintenance costs, is an important factor in light source selection for many applications. These and other ancillary benefits of using LEDs are discussed in Table 1-2.

This report presents the findings of analysis on these twelve LED niche applications, 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 colored-light, indoor and outdoor white-lighting 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, assuming the average national generation fuel mix in the U.S.[1] To put these figures into perspective, energy savings are also presented in terms of the output of an equivalent number of large (1000 MW) coal power plants and the annual electricity consumption of thousands or millions of typical U.S. households.

Figure ES.1 summarizes the electricity savings (at the site) from the top two colored-light, indoor white-light, and outdoor white-light niche applications with the greatest electricity savings in 2007 or if no savings have yet occurred in that type of application, the greatest electricity savings potential. Also displayed is the corresponding number of coal power plants that could be avoided due to these potential electricity savings.

[1] Primary energy savings are calculated by multiplying electricity savings by the 2007 source-to-site conversion factor (EIA 2008). Power plant and household numbers are estimated by dividing electricity savings by the annual output of a 1000 MW coal power plant with an average capacity factor of 72.6% (EIA 2007b) and by the average residential household electricity consumption (DOE 2007a), respectively.

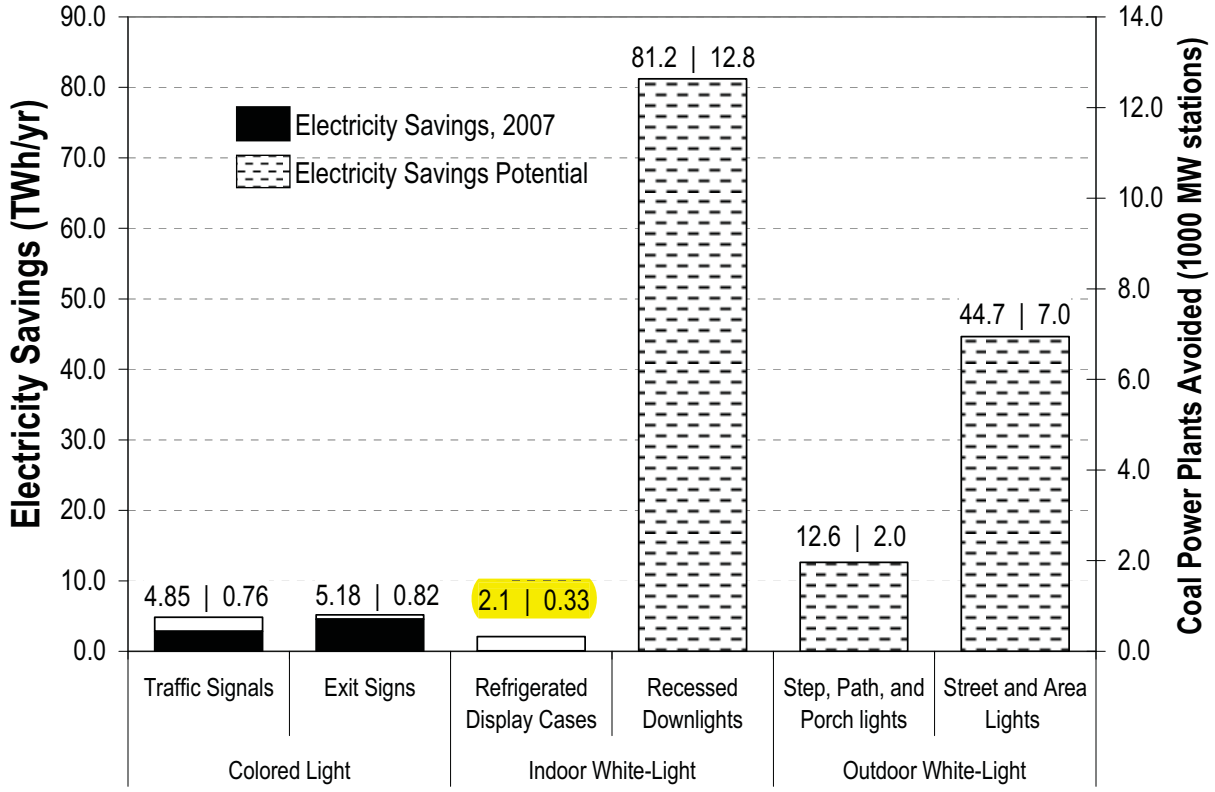

Figure ES.1 Electricity Saved and Potential Savings of Selected Niche Applications

In 2007, the current penetration of LEDs in the twelve niche applications analyzed in this report resulted in a realized electricity savings of 8.7 TWh per year. To put this figure 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 (DOE, 2002a).

Table ES.1 provides a detailed summary including both electricity consumption and primary energy consumption. Some sectors have estimates of zero percent LED penetration, thus contribute no savings to the total of 8.7 TWh. In general, the average luminaire efficacy of the LED for all twelve applications was assumed to be between 22.5 lm/W and 60.9 lm/W. More detailed information on this and other assumptions for all of the applications can be found in the body of the report.

Table ES.1 Energy Consumption and Savings in 2007 of Applications Evaluated

Application	Annual Electricity Consumption (TWh)	LED Market Penetration	Electricity Savings 2007 (TWh)	Primary Energy Savings 2007 (TBtu)
Colored Light Applications				
Traffic Signals	2.38	52%	2.82	30.4
Decorative Holiday Lights	6.63	5.2%	0.33	3.53
Exit Signs	2.50	88%	4.56	49.2
Electric Signage	11.6	6.1%	0.95	10.3
Indoor White-Light Applications				
Recessed Downlights	103.1	0.0%	0.0	0.0
Refrigerated Display Cases	13.4	3.6%	0.08	0.81
Retail Display	32.0	0.0%	0.0	0.0
Task Lighting	18.8	0.0%	0.0	0.0
Kitchen Under-Cabinet Lighting	2.84	0.0%	0.0	0.0
Office Undershelf Lighting	3.43	0.0%	0.0	0.0
Outdoor White-Light Applications				
Street and Area Lights	178.3	0.0%	0.0	0.0
Step, Path, and Porch lights	22.0	0.0%	0.0	0.0
Total	**397 TWh**	--	**8.7 TWh**	**94 TBtu**

As shown in Table ES.1, the electricity savings in 2007 attributable to LEDs are dominated by exit signs, where they have achieved an estimated 88% market penetration. This niche market represents 52% of the total energy savings attributable to LEDs in 2007. The second most significant energy saving niche market in 2007 was traffic signal heads. In this application, approximately 52% of the signals are estimated to incorporate LED technology, representing approximately 32% of the total energy savings from LEDs in 2007. From negligible penetration in 2002, LEDs have reached 6.1% of the electric signage market and 5.2% of the decorative holiday lights market, contributing to 11% and 4% of the total energy savings from LEDs in 2007, respectively. LEDs have also begun to penetrate the refrigerated display case market, reaching 3.6% penetration in 2007. Other applications such as recessed downlights, retail display, task lighting, street and area lights, and step, path, and porch lights were estimated to have insignificant market penetration of LEDs. Commercial LED products are available in these markets; however significant market 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 theoretical maximum energy savings (i.e., the sum of 2007 electricity [or primary energy] savings and potential electricity [or primary energy] savings) attributable to LEDs for each market for a complete conversion to LED relative to the conventional lighting technology. For applications with no market penetration of LEDs and no energy savings in 2007, energy savings potential equals theoretical maximum energy savings.

Table ES.2 Potential and Theoretical Maximum Energy Savings of Applications Evaluated

Application	Electricity Savings Potential (TWh)	Primary Energy Savings Potential (TBtu)	Theoretical Maximum Electricity Savings (TWh)	Theoretical Maximum Primary Energy Savings (TBtu)
Colored Light Applications				
Traffic Signals	2.03	21.9	4.85	52.3
Decorative Holiday Lights	5.97	64.4	6.30	67.9
Exit Signs	0.63	6.78	5.18	55.9
Electric Signage	6.58	71.0	7.53	81.3
Indoor White-Light Applications				
Recessed Downlights	81.2	876.6	81.2	876.6
Refrigerated Display Cases	2.0	21.6	2.1	22.4
Retail Display	7.87	84.9	7.87	84.9
Task Lighting	13.0	140.1	13.0	140.1
Kitchen Under-Cabinet Lighting	2.22	24.0	2.22	24.0
Office Undershelf Lighting	1.37	14.8	1.37	14.8
Outdoor White-Light Applications				
Street and Area Lights	44.7	482.0	44.7	482.0
Step, Path, and Porch lights	12.6	136.3	12.6	136.3
Total	**180 TWh**	**1944 TBtu**	**189 TWh**	**2039 TBtu**

Of the applications analyzed in this report, recessed downlights, street and area lights, refrigerated display cases, task lights and outdoor step, path, and porch lighting represent the top five applications with the greatest future savings potential for LEDs. Of these, recessed downlights appear to be the most promising, with 81.2 TWh of potential savings.

The potential for greater energy efficiency with LED sources is an important consideration, along with other attributes that might induce lighting users to adopt this technology over conventional light sources. In several applications, well-designed LED products and luminaires can offer the following benefits, relative to conventional lighting products:

- 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 8W LED red signal head replaces a 135W reflector lamp – a 94% reduction in energy consumption - while complying with the same safety standards. And as SSL 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 electric signage, street and area lights, and retail display lighting. Presently, LED technology offers operating lives that are

the estimates for energy consumption and savings potential from LEDs presented in this report represent a brief snapshot of the state of the twelve analyzed lighting applications in 2007.

1.4. Technology Benefits in Addition to Energy Savings

There are several benefits outside of energy savings that are driving the adoption of LED technology in the twelve applications analyzed in this report. In addition to yielding more than 94 TBtu per year of primary energy savings, and potentially a further 2039 TBtu per year when the market reaches saturation, LED products offer other advantages over conventional products. These advantages as well as the niche market where these advantages are applicable are listed in Table 1-2.

Table 1-2: LED Benefits in Addition to Energy Savings

Benefit	Applicable Niche Markets
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 electric signage, street and area lights, and retail display lighting. Presently, LED technology offers operating lives that are approximately twenty-five times longer than those of incandescent sources.[9] Researchers indicate that operating life will continue to improve as the technology develops.	Traffic Signals and Pedestrian Crossings; Decorative Holiday Lights; Exit Signs; Electric Signs; Recessed Downlights; Refrigerated Display Cases; Retail Display; Task Lights; Office Undershelf; Kitchen Undercabinet; Street and Area Lights; Step, Path and Porch Lights
Lower Maintenance and Life-Cycle Costs - The longer life of LEDs translates into less frequent relamping and lower maintenance costs. Although several LED products cost more than conventional products, the lower energy consumption and extended operating life (and associated maintenance savings) equate to lower life-cycle costs. For example, the cost of ownership, including energy and maintenance costs, of one intersection of LED traffic signals is about ninety percent less than that of an intersection of incandescent traffic signals (ENERGY STAR, 2006, 2008a).	Traffic Signals and Pedestrian Crossings; Decorative Holiday Lights; Exit Signs; Electric Signs; Recessed Downlights; Refrigerated Display Cases; Retail Display; Task Lights; Office Undershelf; Kitchen Undercabinet; Street and Area Lights; Step, Path and Porch Lights

[9] We assume that manufacturers' claims of 50,000-hour LED lifetimes can be substantiated. However, these claims have not been independently verified by DOE.

3. Indoor White-Light Applications

In addition to colored-light applications, LED sources have begun to penetrate white-light applications during the past few years. Improved light output and efficiencies of monochromatic blue LEDs have enabled the manufacture of high-brightness white LEDs, produced by combining a blue LED with a yellow phosphor or by mixing red, green, and blue LEDs. Warm white LEDs, which are more pleasing to the U.S. consumer, can be produced by using different different phosphors in the LED, or by combining white LEDs with monochromatic red or amber LEDs. LED penetration in indoor white-light applications has the potential to save substantial amounts of energy if LEDs can achieve the stringent color quality and color-rendering requirements that consumers demand in general lighting applications. As with colored-light applications, electricity is saved in white-light applications where LED sources are used to replace incandescent, halogen, and in some cases, CFL and certain types of fluorescents..

This report evaluates six indoor white-light niche market applications: recessed downlights, refrigerated display case lighting, retail display, task lighting, office undershelf lighting and kitchen undercabinet lighting. LED products for these indoor white-light applications are currently being manufactured, although the market has not yet adopted them in large numbers.

- LED recessed lights have the greatest energy savings potential of all the applications studied in this report.
- LED refrigerated display case lighting is a promising niche application because LEDs perform better in cold temperatures compared to room temperature, and they can provide more uniform lighting of the display area than the incumbent fluorescent lamp systems, due to the directional light output of LEDs. Wal-Mart has recently converted to LED refrigerated display case lighting in 500 of its U.S. stores, which may influence other storeowners to shift toward LEDs as well (LEDs Magazine, 2007).
- LED retail display lighting is beneficial in several respects: LEDs' small size allows them to be integrated unobtrusively into display cases; LED directionality allows precise targeting of products to be illuminated; LEDs do not damage heat or UV-sensitive merchandize, and, for products like jewelry and crystal, the multiple diodes of the LED lamp lead to more reflections and increased sparkle.
- LED task lighting such as portable desk lamps, office undershelf lighting, and kitchen undercabinet lights have the potential to provide brighter, more directed illumination for work spaces than the incandescent and fluorescent products they replace.

If LEDs become standard technology in these six indoor white-light niche market applications, 108 TWh per year of electricity savings could be possible, equal to 1.1% of total annual primary energy consumption and 13% of electrical energy consumption for lighting in the U.S. in 2007.

3.1. Recessed Downlights

The energy savings potential of LEDs for recessed downlights is significant, more than the energy savings potential of any other niche application described in this report. We estimate that there is no market penetration of LEDs in recessed downlight applications as of 2007 because LED recessed downlight products only recently have become available in the market. However, we estimate that if all recessed downlights in the U.S. were converted to LEDs, 877 TBtu of

is 877 TBtu/yr at the power plant, equivalent to the annual consumption of 12.8 large (1000 MW) electric power plants and representing the annual electricity consumption of 6.7 million households.

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 potentially 877 TBtu/yr of primary energy when the market reaches saturation, LED recessed downlights offer other advantages over traditional recessed downlights. These include:

1. Longer Operating Life
2. Lower Maintenance and Life-Cycle Costs
3. Reduced Radiated Heat
4. Minimal Light Loss
5. Dimmability and Controllability
6. Directional Illumination

For more information about these ancillary benefits of LEDs, refer to Table 1-2.

3.2. Refrigerated Display Cases

While in its nascent stage of development in the first half of this decade, LED refrigerated display case lighting systems did not provide any energy savings. However, during the past five years, technical advances in white LEDs have enabled LED refrigerated display case lighting systems to offer energy savings when replacing fluorescent systems in 2007. These LED systems have just recently entered the market, and we estimate that less than one percent of the market has switched to LED refrigerated display case systems, amounting to a small 0.08 TWh in electricity savings in 2007.

In contrast, if 100% of the market switched to LED systems there is the potential to save 2.1 TWh of electricity. This corresponds to a primary energy savings of 22.4 TBtu, equivalent to the annual consumption of one third of a (1000 MW) coal power plant or the annual electricity consumption of over one hundred and sixty thousand households.

3.2.1. Introduction

The common supermarket is the main source of produce and household goods for the majority of the U.S. population. Supermarkets are major energy consumers, requiring high-quality lighting throughout the store to illuminate merchandise and ample space heating and cooling to keep produce fresh and customers comfortable. Almost half of the annual electricity costs for a supermarket are used to operate refrigerated display cases (EPA, 2006), a term which includes both refrigerators and freezers. Lighting to illuminate food items contributes about 15% of the total electricity consumed by refrigerated display cases (DOE, 2007a). Lighting also adds to the

Table 3-6: Critical Inputs for Refrigerated Display Case Lighting Energy Consumption and Savings Potential Estimates

Critical Input	Notes and Sources
Installed Base of Lamps	Number of Refrigerated Display Cases: Commercial Refrigerated Equipment Advanced Notice of Proposed Rulemaking National Energy Savings spreadsheets.
Annual Operating Hours	Refrigerated display cases operate continuously, amounting to 8,760 hours/year.
Lamp Wattages	Commercial Refrigerated Equipment Notice of Proposed Rulemaking Engineering Analysis spreadsheets.
Lighting Technology Mix	Number of Stores with LED Cases: LEDs Magazine, 2006. Average Number of Case-Doors per Store: GE, 2007. Average Number of Doors per Case: Commercial Refrigerated Equipment Notice of Proposed Rulemaking Engineering Analysis spreadsheets.

3.2.2. Refrigerated Display Cases Installed Base

Industry manufactures at least 48 different refrigerated display case systems. However, the majority of refrigerated display cases in the market consists of four system types: vertical without doors, remote condensing, medium temperature (38 ^{o}F) systems [VOP.RC.M]; semi-vertical without doors, remote condensing, medium temperature systems [SVO.RC.M]; vertical with transparent doors, remote condensing, medium temperature systems [VCT.RC.M]; and vertical with transparent doors, remote condensing, low temperature (0 ^{o}F) systems [VCT.RC.L]. This analysis only considers the four main system types in the installed base calculation.

The installed bases for the four main types of refrigerated display cases systems were obtained from the National Energy Savings spreadsheets from DOE's Energy Conservation Standard Advanced Notice of Proposed Rulemaking on Commercial Refrigerated Equipment, and are shown in Table 3-7.

Table 3-7: Installed Base of Refrigerated Display Case Lighting Systems in the U.S, 2007

Light Source	Percent of Stock	SVO.RC.M Stock	VOP.RC.M Stock	VCT.RC.M Stock	VCT.RC.L Stock	Total Stock
Fluorescent	96.4%	229,430	300,780	21,480	298,760	850,450
LED	3.6%	8,600	11,300	850	11,250	32,000
Total	**100.0%**	**238,030**	**312,080**	**22,330**	**310,010**	**882,450**

With Wal-Mart's recent installation of LED refrigerated display cases in 500 of its U.S. stores, we estimate that 32,000 LED refrigerated display cases are installed in the U.S. (LEDs Magazine 2007). The total number of LED refrigerated display cases was developed by multiplying the number of stores with LED cases and the average number of case-doors per store, and dividing by the average number of doors per case. The percent LED penetration in the refrigerated display case market was determined by dividing the total number of LED cases by the installed base of refrigerated display cases in the U.S., which equals 3.6%. The remaining 96.4% of refrigerated display cases are assumed to be fluorescent, the standard technology in this application.

3.2.3. Refrigerated Display Cases Operating Hours

For this analysis, refrigerated display cases lighting systems for both conventional and LED systems are assumed to operate 24 hours per day year-round, amounting to an annual operating cycle of 8,760 hours. However, it should be noted that additional energy savings can be achieved through the use LED refrigerated display cases with lighting controls. LEDs can be dimmed more efficiently than fluorescents because rapid and frequent on/off cycles do not affect the life of the LED, enabling the use of movement-triggered controls. These controls can reduce the annual operating hours of the LED system and lead to even greater energy savings calculated in this report.

3.2.4. Refrigerated Display Cases Lamp and Ballast/Driver Average Wattages

The average lamp and ballast or driver wattages were determined from the Engineering Analysis spreadsheets for the DOE's Energy Conservation Standard Notice of Proposed Rulemaking for Commercial Refrigerated Equipment. The lighting system wattages for each of the four main types of systems were weighted by the 2007 installed base of each of those refrigerated display case lighting systems to obtain the total average wattage for fluorescent and LED refrigerated display case lighting systems. Each 16-watt LED strip was modeled to replace a single four-foot, 76 CRI, 85 lm/W, nominally 32-watt, T8 lamp powered by a standard two-lamp electronic ballast.

Table 3-8: Average System Wattages for Refrigerated Display Case Lighting Systems

Light Source	SVO.RC.M Average Wattage	VOP.RC.M Average Wattage	VCT.RC.M Average Wattage	VCT.RC.L Average Wattage	Total Average Wattage
Fluorescent	458	642	348	348	482
LED	244	342	224	224	271

3.2.5. Refrigerated Display Cases Energy Saving Potential

The annual electricity consumption of the over ten million refrigerated display cases in the U.S. was 3.7 TWh per year of lighting electricity use and 9.7 TWh per year of compressor electricity use for a total of 13.5 TWh/yr with the potential for reduction through the use of LEDs with an average luminaire efficacy of 30.4 lm/W. Almost four percent of the national installed base of refrigerated display case lighting systems consists of LEDs, saving 0.08 TWh/yr of electricity in 2007 through reductions in lighting (0.06 TWh/yr) and compressor (0.02 TWh/yr) electricity use. However, the potential to save an additional 2.0 TWh/yr of electricity exists if the commercial refrigerated display case market completely switched to LED systems, through reductions of 1.6 TWh/yr of lighting electricity use and 0.4 TWh/yr of compressor electricity use. This corresponds to 21.6 TBtu/yr of primary energy savings at the power plant, the energy consumption of one third of a 1000 MW coal power plant or equivalent electricity consumption of one hundred and sixty thousand households.

Table 3-9: Refrigerated Display Case Lighting and Compressor Energy Consumption and Savings Estimate, 2007

Niche Application	Annual Electricity Consumption 2007 (TWh)	Electricity Savings 2007 (TWh)	Potential Electricity Savings (TWh)	Theoretical Maximum Electricity Savings (TWh)
Refrigerated Display Cases	13.4	0.08	2.00	2.1

3.2.6. Technology Benefits in Addition to Energy Savings

White LED lamps offer several advantages that will make them suitable to this niche application. LED light sources for commercial refrigerated display cases offer several benefits and features to storeowners that set them apart from fluorescent. These features can help improve the marketing and enhance the sales of products displayed. These benefits include:

1. Longer operating life
2. Lower Maintenance and Life Cycle Costs
3. Reduced Radiated Heat
4. Minimal Light Loss
5. Dimmability and Controllability
6. Directional Illumination
7. Durability
8. Smaller Package Size
9. Uniform Illumination
10. Adjustable Color
11. Increased product shelf life

These features, both financial and aesthetic, make LED light sources a compelling alternative to fluorescent. For more information about individual ancillary benefits, refer to Table 1-2.

3.3. Retail Display

LED retail display products have recently been introduced on the market and have reached efficiencies high enough to displace incandescent, halogen, CFL and certain types of fluorescent spot-, flood-, and track-lights used to display merchandise in retail stores. LED retail display lights have the potential to save 7.87 TWh/yr if 100% of the market shifted to LEDs, equal to 84.9 TBtu/ yr of primary energy consumption. This amounts to the annual consumption of one large (1000 MW) electric power plant or the annual electricity consumption of seven hundred thousand U.S. households. We estimate that there is no penetration of LEDs in retail display applications as of 2007 because products have only recently entered the market.

3.3.1. Introduction

Shopping centers rely on bright, high-quality lighting to highlight merchandise and attract customers into stores. Lighting can help indicate to customers the quality of products inside, the

5. Conclusion

In the last few years, LEDs have emerged as a competitive lighting technology, capturing market share in several niche applications from incandescent, halogen, neon, high intensity discharge, and certain types of fluorescent light sources. Most cost-effective in colored-light applications, LEDs have proven to be an economically viable replacement in applications such as exit signs, where they are the least cost option, and traffic signal heads, where the initial LED light source can be more than 20 times as expensive as the incandescent light source it replaces while the lifetime costs are lower (ENERGY STAR, 2006). 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 colored-light, indoor and outdoor white-light installations. In the colored-light sector, LED technology is being used in traffic signal heads, decorative holiday lights, exit signs, and electric signage. In all of these applications, LEDs are replacing incandescent, fluorescent or neon 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 2.82 TWh of electricity are saved every year because of the LED traffic signals that have replaced incandescent technology. LED exit signs save even more electricity, 4.56 TWh per year, since they have become the technology of choice in this application. Substantial energy savings have also been realized through LED holiday lights and electric signage, saving 0.33 TWh and 0.95 TWh per year, respectively. If these four colored-light applications switched entirely to LEDs, a potential of 15.2 TWh per year of electricity could be saved, equivalent to the annual output of approximately two large coal power plants or the annual electricity consumption of approximately one million typical U.S. households.

In the indoor white-light installations, LED products are available for recessed downlights, refrigerated display cases, retail display lighting, task lighting, office undershelf, and kitchen undercabinet lighting fixtures. In all of these applications, LED products have only recently become available in the marketplace and we assume that there is no significant market penetration of LEDs as of 2007. In all of these applications, luminaire designers are taking advantage of the directional light output of LEDs to design highly efficient fixtures that have the potential to save substantial amounts of electricity. Indoor white-light applications have the greatest potential of all the applications studied in this report to save substantial amounts of energy. If the six indoor white-light applications switched entirely to LEDs, a potential of 108 TWh per year of electricity could be saved, equivalent to the annual output of approximately seventeen large (1000 MW) electric power plants or the annual electricity consumption of nine million typical U.S. households.

Finally, in the outdoor white-light applications, street and area lights represent the most significant niche market opportunity for LEDs. Designers can take advantage of the enhanced visibility of LEDs at night, due to their high blue content relative to high or low pressure sodium lamps. LEDs in outdoor white-light applications are the focus of major marketing programs such as *LED Cities*, DOE's *Gateway* demonstration program, as well as the DOE ENERGY STAR® program for solid state lighting. A few pioneering cities have installed LED street and area lights and are reporting significant energy and cost savings, as well as better nighttime

Figure 5-2 apportions the electricity savings if 100% of these twelve niche markets convert to LED technology. This total represents the combined 2007 energy savings and future potential energy savings if the remainder of each market converts to LED luminaires with efficacies between 22.5 and 60.9 lm/W. 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 devices, which today are significantly more efficacious than an incandescent, but are outperformed by the best T8 fluorescent and high-intensity discharge lamps. White-light LED technology is presently the focus of many research initiatives around the United States and the world, and continued advancements in efficacy, lumen output, operating life, and other critical performance metrics are anticipated.

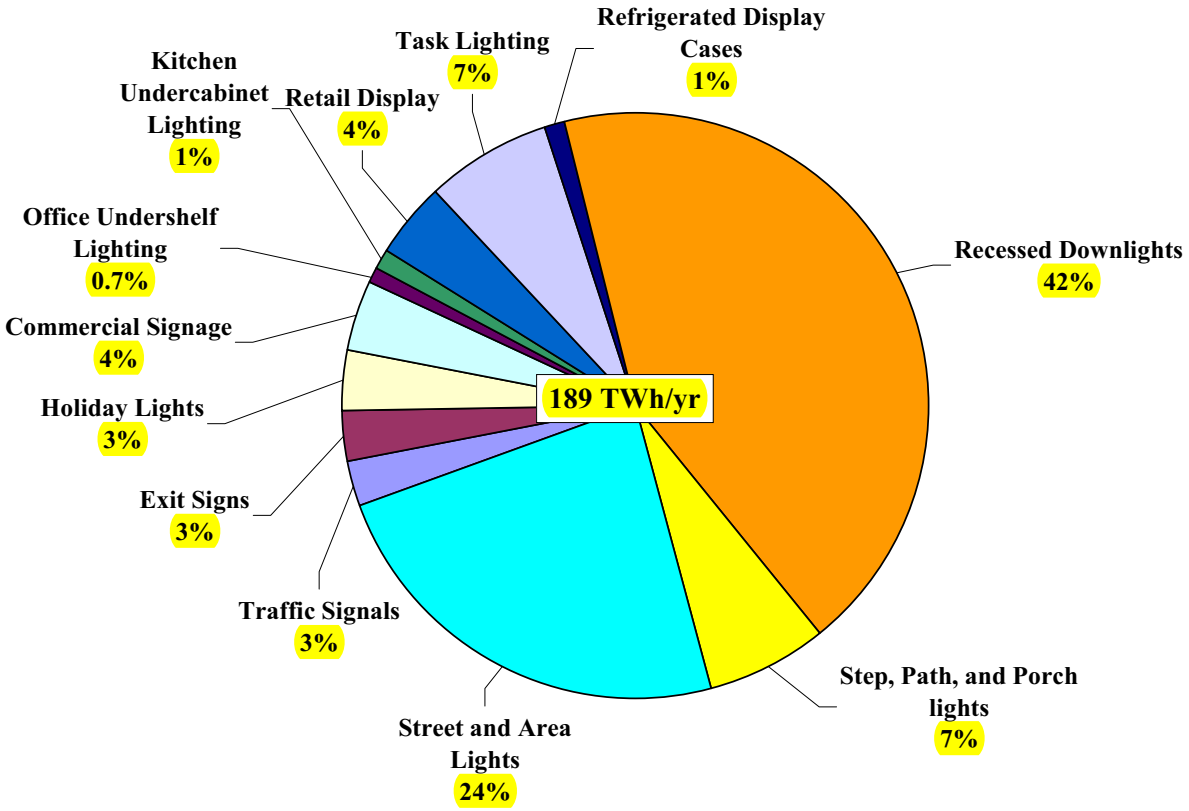

Figure 5-2: Maximum Site Electricity Savings With 100% LED Market Penetration

Table 5-1 summarizes the current energy savings of the analysis in detail, both electricity consumption and primary energy consumption. Some sectors have estimates of zero percent LED penetration, thus contribute no savings to the total of 8.7 TWh. Energy savings estimates were not prepared for seven applications analyzed: recessed downlights, retail display, task

lighting, office undershelf, kitchen undercabinet, street and area lights, and step path and porch lights. This was because significant adoption of LEDs has yet to occur.

Table 5-1. Energy Consumption and Savings in 2007 of Applications Evaluated

Application	Annual Electricity Consumption (TWh)	LED Market Penetration	Electricity Savings 2007 (TWh)	Primary Energy Savings 2007 (TBtu)
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Task Lighting	18.8	0.0%	0.0	0.0
Kitchen Under-Cabinet Lighting	2.84	0.0%	0.0	0.0
Office Undershelf Lighting	3.43	0.0%	0.0	0.0
Outdoor White-Light Applications				
Street and Area Lights	178.3	0.0%	0.0	0.0
Step, Path, and Porch lights	22.0	0.0%	0.0	0.0
Total	**397 TWh**	**--**	**8.7 TWh**	**94 TBtu**

In 2007, electricity savings attributable to LEDs are dominated by exit signs, where LEDs have an estimated 88% market penetration. This niche market represents 52% of the total energy savings attributable to LEDs in 2007. The second most significant energy saving niche market in 2007 was traffic signal heads. In this application, approximately 52% of the signals are estimated to be LED, representing approximately 32% of the total energy savings from LEDs in 2007. From negligible penetration in 2002, LEDs have reached 6.1% of the electric signage market and 5.2% of the decorative holiday lights market, contributing to 11% and 4% of the total energy savings from LEDs in 2007, respectively. LEDs have also gained marketshare in the refrigerated display case market, achieving almost 4% penetration in 2007. Other applications, such as recessed downlights, retail display, task lighting, street and area lighting, and step, path and porch lighting 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 2007 and the additional energy savings from the conversion of each market to 100% LED.

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

Application	Electricity Savings Potential (TWh)	Primary Energy Savings Potential (TBtu)	Theoretical Maximum Electricity Savings (TWh)	Theoretical Maximum Primary Energy Savings (TBtu)
Colored Light Applications				
Traffic Signals	2.03	21.9	4.85	52.3
Decorative Holiday Lights	5.97	64.4	6.30	67.9
Exit Signs	0.63	6.78	5.18	55.9
Electric Signage	6.58	71.1	7.53	81.3
Indoor White-Light Applications				
Recessed Downlights	81.2	876.6	81.2	876.6
Refrigerated Display Cases	2.0	21.6	2.1	22.4
Retail Display	7.87	84.9	7.87	84.9
Task Lighting	13.0	140.1	13.0	140.1
Kitchen Under-Cabinet Lighting	2.22	24.0	2.22	24.0
Office Undershelf Lighting	1.37	14.8	1.37	14.8
Outdoor White-Light Applications				
Street and Area Lights	44.7	482.0	44.7	482.0
Step, Path, and Porch lights	12.6	136.3	12.6	136.3
Total	**180 TWh**	**1944 TBtu**	**189 TWh**	**2039 TBtu**

Across the niche markets analyzed, there are significant opportunities for energy savings in the colored-light applications as well as the indoor and outdoor white-light applications. A total of 15.2 TWh per year of potential site electricity savings are available in commercial advertising signs, traffic signals, holiday lights, exit signs and the other applications that are grid-connected. Similarly, 107.7 TWh per year of site electricity savings are available if the installed base of recessed downlights, refrigerated display cases, retail display lights, task lights, office undershelf, and kitchen undercabinet lights switched to LEDs. In the outdoor white-light market, 57.3 TWh per year of site electricity savings are available in the street and area light and outdoor step, porch, and walkway applications. If these opportunities are fully realized, combined with the savings already captured to day, approximately 2039 TBtu of national energy consumption could be avoided. This represents 2.0 quadrillion Btus, "quads", or approximately two percent of total national energy consumption in 2007.

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. Each niche market analyzed in this report covers the particular LED benefits that are most relevant to a given application. Benefits impacting multiple applications are summarized here:

- 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 8W LED red signal head replaces a 135W reflector lamp – a 94%