Product Snapshot: LED Replacement Lamps
Prepared for:
U.S. Department of Energy

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Executive Summary

This LED Lighting Facts® Product Snapshot represents an analysis of the dataset from the U.S. Department of Energy’s (DOE) LED Lighting Facts product list. This document is designed to help lighting retailers, distributors, designers, utilities, energy efficiency program sponsors, and other industry stakeholders understand the current state of the LED replacement lamp market and its trajectory.

The lighting industry is experiencing major change: new federal efficacy guidelines are being phased in for many types of lamps, and manufacturers are increasingly offering LED replacements as energy- and cost-saving alternatives to traditional technologies. How do LED replacement lamps really perform? This Product Snapshot includes the following observations:

**LED A-lamp replacements:**

- All 176 LED A-lamp replacements listed meet the 2012-2014 standard efficacy levels and 97% of LED A-lamp replacements listed in 2011 or later meet the 2020 federal efficacy requirement of 45 lumens per watt.
- Excluding products listed before 2011, about 23% of LED products produce less than 450 lumens, 52% of LED A-lamp replacements produce 450 lumens or more (40-watt (W) incandescent A-lamp equivalency), 23% of LED replacements meet or exceed 800 lumens (60W incandescent A-lamp equivalency), less than 1% meet or exceed 1100 lumens (75W incandescent A-lamp equivalency), and none meet or exceed 1600 lumens (100W incandescent A-lamp equivalency).
- If current trends in light output improvement continue, 1600-lumen (100W incandescent A-lamp equivalent) LED A-lamps should be widely available in the market by late 2015 or 2016.
- About 36% of LED A-lamp replacements are warm white (below 3000K) and have a high-CRI (80 or above), while the remainder of products extend up to 6500K and down to CRI values below 70 (though low CRI values have become less common in 2011 and 2012).
- Only 30% of LED A-lamps produce a nominally omnidirectional distribution of light (with at least 5% of their total output in the 135°–180° zone)—an important concern for consumers expecting comparable performance to incandescent A-lamps.

- LED A-lamp retail prices have been falling consistently. As of March 2012, the average retail price for an 800-lumen lamp was $30. LED product costs remain well above those of compact fluorescent lamps (CFLs), but are beginning to approach them and are expected to be equivalent by 2016 in terms of cost per lumen-hour and total cost of ownership.

**LED reflector lamp replacements:**

- Of 873 LED PAR and R reflector lamps listed in the database, the highest-output LED PAR and R replacement lamps in the database can meet incandescent and halogen reflector lamp equivalency levels (based on light output alone) up to 90W PAR38, 70W PAR30, and 50W PAR20 lamps.
- Current LED PAR and R lamp products still have the potential to save 60%–80% in power consumption over improved-efficacy halogen lamps, after new federal efficacy levels are required this year.
- About 83% of LED PAR and R reflector lamps have warm white (2700K to 3000K) or bright white (3000K to 4500K) CCT levels, with CRI values above 80.
- LED MR16 replacement lamps are available at output levels up to 500 lumens (similar to 40W halogen MR16 performance), and performance continues to improve.

**LED linear lamp replacements:**

- Though LED lamps are not covered under the new federal efficacy standard, 67% of the 159 currently listed LED linear replacement lamps do not meet the minimum performance levels for medium bi-pin (T8 and T12) lamps established by the standard.
- Since 2010, the highest-output 4-foot linear LED lamps have increased from about 1800 lumens to 2200 lumens. Typical 4-foot fluorescent T8 lamps produce about 3000 lumens.
- Linear LED replacement lamps are mostly concentrated in the bright white (60%) and daylight (4500K up to 6500K; 35% of products) CCT zones, while fluorescent lamp CCTs typically fall in the bright white range.
- Most LED lamps included in this study (64%) have CRI values below 80, the typical performance level of fluorescent lamps.
About the LED Lighting Facts Product Snapshot

To answer the question of how LED replacement lamp performance is changing over time and how it compares to the performance of incumbent technologies, this Product Snapshot draws from the database of LED Lighting Facts products (available at www.lightingfacts.com/products). LED Lighting Facts is a DOE-administered truth-in-reporting program for LED products that offers informative resources to partners, including interactive product selection tools, fact sheets on solid-state lighting (SSL) technology and related standards and federal rules, and technical and market analyses based on the products in the LED Lighting Facts database. Here are some quick facts about the program:

- To have a product added to the LED Lighting Facts product list, a manufacturer must first test the product at an approved laboratory in accordance with IES LM-79-08, the industry-accepted test method for electrical and photometric measurements of SSL. The manufacturer must submit the test results and performance claims for independent verification by DOE.
- Five key performance metrics (light output in lumens (lm), input power in watts (W), efficacy in lumens per watt (lm/W), color rendering index (CRI), and correlated color temperature (CCT) in kelvin (K)) are reported on the label and the online product list. ¹
- The product list includes a variety of product types, from manufacturers large and small, lighting industry veterans and brand new companies alike.
- As of March 2012, when the data for this Product Snapshot were captured, program partners included 340 manufacturers, 243 retailers and distributors, 223 lighting professionals, and 58 energy efficiency sponsors, representing a majority of the LED industry.
- DOE’s LED Lighting Facts is the largest database of its kind. More than 4,400 products were registered as of March 2012.
- Organizations interested in partnering with the program may sign up at www.lightingfacts.com.

¹—Additional performance metrics, including lumen maintenance, electrical characteristics, light distribution, and color performance, are also listed on an optional basis by some manufacturers. This Snapshot does not include all of these optional metrics, but a thorough product performance evaluation should include as many metrics as possible.
Overview

Figures 1a and 1b show the distribution of product types registered with LED Lighting Facts as of March 2012. Of all registered products, 42% were replacement lamps and 58% were luminaires. This Product Snapshot presents analyses of A-lamps, directional replacement lamps, and linear T8/T5/T12 tube replacements.2

Figure 1a: LED Lighting Facts Listed Products
Figure 1b: LED Lighting Facts Replacement Lamps, by Type

4,472 Total Approved Products
1,878 Replacement Lamps

Note: Replacement lamp percentages do not add up to exactly 100 due to rounding.
Analysis and figure: D&R International.

2—Products in the “Other” category include outdoor area light retrofit kits, medium screw base globe lamps, non-standard products, and products that appear to fit in standard categories, but may include non-standard design features.
Figure 2 shows that directional lamps, particularly R30/PAR30s, R38/PAR38s, and MR16s, have been the fastest-growing product types since the inception of the program, with each category consistently maintaining a growth rate of about 150 new products per year. A-lamp, linear T8/T5/T12 replacement, and directional R20/PAR20 lamp categories have grown at slower rates, with each category adding approximately 80 new products per year. Decorative lamps make up the slowest-growing category, accruing approximately 50 new products per year as of 2011 (growth has been relatively constant, except for a brief stall in Q2 2011).

The faster growth rates for LED R30/PAR30, R38/PAR38, and MR16 lamps are interesting because reflector lamps constitute only about 19% of the installed base of replacement lamp types covered in this report, compared to 48% for general service A-lamps and 27% for 4-foot linear tube lamps. Because all products listed with LED Lighting Facts are designated by manufacturers as commercially available, the growth in the number of directional lamp products reflects either greater success in selling these products or anticipation of such success by manufacturers. It is also possible that the slower growth of A-lamps and linear tube lamps reflects the challenges in designing omnidirectional LED products, which result from the inherent directionality of LED sources and the optics required to redirect the light into an omnidirectional pattern. Products in both the faster- and slower-growing categories are sold in the residential and commercial markets, so the disparity does not appear to be due to a sector-based difference in price sensitivity.


Figure 2: Cumulative Products by Quarter and Product Type

Sources:
Analysis and figure: D&R International.
Performance Trends: Efficacy

DOE’s SSL Multi-Year Program Plan (MYPP) tracks improvement in light source and complete product (luminaire and replacement lamp) efficacy\(^4\); Figure 3 includes MYPP efficacy projections overlaid on efficacy trends for products in the LED Lighting Facts database. Directional replacement lamp types, including R20/PAR20, R30/PAR30, R38/PAR38, and MR16 lamps, are combined into one category because they follow similar efficacy trends (maintaining a spread between sub-types of approximately 5 lm/W).

Linear LED replacement lamps have shown the highest average efficacy of all the replacement lamp types, and their average tracks closely to the MYPP cool white luminaire projections—not a surprising trend, because most linear LED replacement lamps are designed with cool white color temperatures (see the Linear Lamps: Color Performance section for details). LED A-lamp replacements have performed at the next highest efficacy levels, and closely follow the MYPP’s warm white luminaire projections. LED directional replacement lamps have consistently performed approximately 10 lm/W below A-lamp replacements, on average.

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\(^4\)The term “efficacy” in this document refers specifically to the luminous efficacy of a lamp or luminaire, which is defined as the ratio of total light output to input power, in lm/W. The term “efficiency” is also used in this document to describe federal standard levels and product performance, though “efficacy” is a more common technical metric for lighting products.
A-Lamps

A 2012 DOE market inventory report notes that there were more than 2 billion incandescent A-lamps installed in the United States in 2010 – more than any other lamp type or technology, with the next highest category being compact fluorescent (CFL) replacements for A-lamps, of which there were approximately 1.2 billion. Halogen and LED A-lamps, the other two competing technologies for this product type, together constituted less than 1% of installed A-lamps in 2010, though that number has likely increased significantly since then.

EISA Standard

The Energy Independence and Security Act of 2007 (EISA) set minimum required efficacy levels for general service, medium screw base A-lamps beginning in January 2012. From 2012 to 2014, these new efficacy levels will apply to lamps with light output of 310–2600 lumens; they will remain in effect until December 31, 2019. Lamps with light output comparable to that generated by what are now 100W, 75W, 60W, and 40W incandescent products will be required to consume no more than 72 watts, 53 watts, 43 watts, and 29 watts, respectively. From 2012 through 2019, EISA requirements apply to the manufacture and import, but not the sale, of general service lamps. Starting January 1, 2020, lamps of all lumen values will be held to a single efficacy requirement of 45 lm/W or greater. At that point, enforcement of the legislation will shift from manufacture and import to sales. In 2014, DOE will revisit the 2020 efficacy requirement, increasing it if necessary.

EISA does not ban incandescent lamps; rather, it increases the required efficacy of all general service lamps to save U.S. consumers money on their energy bills and to encourage the availability of more efficient lighting choices in the market. Improved incandescent lamps that meet the new efficacy requirements are already widely available in the form of halogen lamps.

Table 1 shows the EISA effective dates and efficacy levels. The standard is structured to take effect incrementally, starting with higher wattage equivalency levels and progressively moving toward lower ones. No 100W-equivalent LED A-lamps were available in the market when the first provision went into effect January 1, 2012. By the end of 2011, LED lamp manufacturers had released LED replacements for the other three common incandescent lamps affected by EISA (75W, 60W, and 40W lamps), so consumers will have more choices when the relevant provisions take effect in 2013 and 2014.

Table 1. EISA A-Lamp Standards, 2012-2020

<table>
<thead>
<tr>
<th>Typical Lamp Wattage</th>
<th>Rated Lumen Ranges</th>
<th>Maximum Allowed Wattage After EISA</th>
<th>Lamp Efficacy After EISA (lm/W)</th>
<th>Effective Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>1490–2600</td>
<td>72</td>
<td>21–36</td>
<td>1/1/2012</td>
</tr>
<tr>
<td>75</td>
<td>1050–1489</td>
<td>53</td>
<td>20–28</td>
<td>1/1/2013</td>
</tr>
<tr>
<td>60</td>
<td>750–1049</td>
<td>43</td>
<td>17–24</td>
<td>1/1/2014</td>
</tr>
<tr>
<td>40</td>
<td>310–749</td>
<td>29</td>
<td>11–26</td>
<td>1/1/2014</td>
</tr>
<tr>
<td>All Lamps</td>
<td>All Lamps</td>
<td>45</td>
<td></td>
<td>1/1/2020</td>
</tr>
</tbody>
</table>
The Lighting Prize

The Bright Tomorrow Lighting Prize (L Prize) is the first government-sponsored technology competition designed to spur lighting manufacturers to develop high-quality, high-efficiency SSL products to replace the common light bulb. In August 2011, The U.S. Department of Energy announced that Philips Lighting North America had won the 60W replacement bulb category of the L Prize competition. The winning product was subsequently listed with LED Lighting Facts. Its performance in terms of light output, wattage, and efficacy is highlighted in Figure 5.

A-Lamp Performance Compared to EISA

Figure 4 shows the EISA standard light output and wattage levels for A-lamps, as well as the performance of the four commonly available A-lamp technology types: LED, CFL, halogen, and incandescent. Traditional incandescent lamps do not meet EISA’s minimum efficacy levels; halogen incandescent lamps do, though they do not meet the second-tier level set to take effect in 2020. Utilities and efficiency program sponsors should be mindful of these changes, as they will affect the baseline from which savings can be calculated. More than 90% of CFLs and LEDs on the market meet or exceed the first-tier EISA levels taking effect from 2012 to 2014.

6—Retailers will be allowed to sell any remaining non-compliant inventory, and consumers will not be restricted from using non-compliant lamps, so there will likely be a transition period after each EISA level takes effect, during which baseline lamp use includes both traditional incandescent and halogen products. In the absence of A-lamp sales data, utilities and energy efficiency program sponsors may have to assume that the EISA level is the new baseline.
Figure 4: A-lamp Performance Compared to EISA, 2012-2019

Figure 5 shows the same data as Figure 4, but zooms in on LEDs. For products listed in 2009 and 2010, 76% of LED lamps met the 2020 EISA 45 lm/W requirement; for products listed January 2011 through March 2012, this figure grew to 97%. On the basis of light output alone, before 2011, 52% of LED lamps could be considered 25W incandescent equivalents (250 lm), 27% could be considered 40W equivalents (450 lm), and 7% could be considered 60W equivalents (800 lm). For products listed in 2011 and 2012, the numbers for higher-wattage equivalency levels significantly improved, with 18%, 52%, and 23% of LED A-lamps meeting 25W, 40W, and 60W equivalence, respectively. The first 1100-lumen (75W-equivalent) LED A-lamp was listed with LED Lighting Facts in 2011, and more have trickled in since then. As of the publication of this report, several manufacturers had announced their intent to release 1600-lumen (100W-equivalent) LED A-lamps by late 2012, though none have yet been submitted to LED Lighting Facts.

Interestingly, A-lamps are not clustered tightly around conventional lamp equivalency levels; rather, they are spread throughout the regions between levels. Without correlating these data with packaging claims, it is difficult to say whether this is caused by manufacturers over-designing to exceed conventional equivalency.
levels, under-designing below those levels (whether by intention or technical limitations), or trying to create new market niches based on intermediate light output levels. Findings from numerous DOE Commercially Available LED Product Evaluation and Reporting (CALiPER) program reports (www1.eere.energy.gov/buildings/ssl/caliper.html) suggest that many LED products are marketed at conventional equivalency levels but perform below those levels.

**Figure 5: A-lamp Performance Compared to EISA, 2020**

<table>
<thead>
<tr>
<th>Light Output (lumens)</th>
<th>Wattage</th>
</tr>
</thead>
<tbody>
<tr>
<td>250 lm</td>
<td>25W-equiv.</td>
</tr>
<tr>
<td>450 lm</td>
<td>40W-equiv.</td>
</tr>
<tr>
<td>800 lm</td>
<td>60W-equiv.</td>
</tr>
<tr>
<td>1100 lm</td>
<td>75W-equiv.</td>
</tr>
</tbody>
</table>

**Sources:**
- **CFL:** D&R International review of package labels and website specifications of bulbs sold at major retailers. 60W- and 100W-equivalent products: January 2012. 40W- and 75W-equivalent products: February 2011.
- **Analysis and figure:** D&R International.
LED A-lamp Performance Trends and Projections

Figure 6 shows the minimum, maximum, and average (mean) light output of LED A-lamps listed with LED Lighting Facts by quarter, as well as a projection based on the LED Lighting Facts data, modified 2012 DOE MYPP projections, and the light output equivalency levels for 100W, 75W, 60W, and 40W incandescent lamps. The LED Lighting Facts projection is not based on individual product breakthroughs, but represents the behavior of the LED A-lamp category as a whole, including past performance and future trends of A-lamps that are widely available from multiple manufacturers. There is good agreement between the LED Lighting Facts and DOE MYPP projections that 1600-lumen (100W-equivalent) LED A-lamps will be widely available by the end of 2015.

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7—This performance projection was developed by multiplying the 2012 DOE MYPP efficacy projections for warm white luminaires (assuming efficiency correction factors from package to luminaire are similar to correction factors from package to lamp) by 13W. This estimated maximum design wattage has been increased from 12W to 13W based on an increased number of 13W LED A-lamps listed with LED Lighting Facts. The two parallel MYPP lines in the figure represent MYPP targets assumed to be achieved in Q1 (top line) and Q4 (bottom line) of each year for which projections are published.

**Figure 6: LED A-lamp Light Output Trends**

![Figure 6: LED A-lamp Light Output Trends](image)

**Sources:**
Adjusted DOE MYPP Projection: Uses warm white luminaire efficacy projections from the DOE Solid-State Lighting Research and Development Multi-Year Program Plan, April 2012, along with an estimated 13W power ceiling for LED A-lamp replacements.
Analysis and figure: D&R International.
Luminous Intensity Distribution

While light output, wattage, and efficacy are important performance attributes, distribution of light can be just as important. This is especially true for A-lamps, which may be installed in omnidirectional distribution-dependent fixtures like table lamps and wall sconces. Of 117 A-lamp product listings that included light distribution data in March 2012, only 30% directed more than 5% of their total output to the 135°–180° zone — an indication of a nominal level of omnidirectionality. That means that more than two-thirds of LED A-lamps have light distribution patterns that may not be acceptable to consumers in all fixture types, though some directional A-lamps may be acceptable in directional fixtures like downlights or track lights with directional heads.

Color Performance

The color performance of LED A-lamps listed with LED Lighting Facts is shown in Figure 7. The CRI measures the accuracy of color rendition—compared to a mathematical model of daylight—on a scale up to 100 points, and the Correlated Color Temperature (CCT) indicates how warm or cool the light appears (lower numbers indicate warmer light, higher numbers indicate cooler light). There was a wide range of LED performance in March 2012, with CRI values ranging from the 50s to the 90s, and CCT values ranging from below 2700K to 6500K. Figure 7 overlays several common performance zones, including the LED Lighting Facts program’s distinctions among warm white, bright white, and daylight CCTs, as well as a CRI level of 80—the typical performance of fluorescent products.

Approximately 36% of LED A-lamps perform in the high-CRI, warm white zone, close to the performance of traditional incandescent lamps. Products in the bright white and daylight categories may fill other market niches where higher CCT values are sometimes more acceptable, such as office areas, but partners should ask for verified performance information to ensure that manufacturers are not claiming a different CCT than the product really delivers.

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8—The 135°–180° zone is 25% of the space surrounding the lamp and corresponds to light emitted in a downward direction for a base-down A-lamp (for example, an A-lamp installed in a table lamp fixture). We use the term “nominal omnidirectionality” because a thorough review of omnidirectionality would also include distribution uniformity across the range of angles.

9—Descriptions of a product’s CCT are not standardized and vary among manufacturers and retailers. The descriptions used by the program are intended to serve as guides and not definitive standards.

10—Based on benchmark testing by Pacific Northwest National Laboratory (PNNL) on behalf of the DOE SSL Program.
Figure 7: Color Performance of LED A-lamps

![Graph showing CRI and CCT for LED A-lamps with data points for Pre-2011, 2011-2012, and Typical Fluorescent Performance.]
**Cost**

Figure 8 shows the total cost of ownership (TCO) for a consumer (including lamp cost and energy cost) per 1,000 kilolumen-hours (klm-hrs), for 60W-equivalent versions of the four common A-lamp technologies: incandescent, halogen, CFL, and LED lamps. One kilolumen (1,000 lumens) is 25% more light than a typical 60W incandescent A-lamp produces, and 1,000 hours is the approximate annual usage of a lamp in the residential sector, so this metric essentially measures the cost of consuming slightly more light than that produced by a 60W A-lamp over a year’s time.

While LED lamps had considerably higher average prices at retail stores when these data were collected ($30/lamp) than incandescent, halogen, and CFL lamps ($0.55, $1.90, and $1.80, respectively), their TCO is considerably less than that of incandescent and halogen lamps, due to energy savings. LED cost continues to decrease, and combined with slight increases in CFL lamp prices (which may be caused in part by increasing costs of rare-earth elements that are required for CFL phosphors), DOE’s MYPP cost projections indicate that LED TCO may be competitive with CFL TCO by 2016.

**Figure 8: Total Cost of Ownership of A-lamps per 1,000 Kilolumen-hours**

![Figure 8: Total Cost of Ownership of A-lamps per 1,000 Kilolumen-hours](image)

**Sources:**

Electricity rate: $0.1188/kWh. Source: U.S. Energy Information Administration; Electric Power Monthly, January 2012 (data from Nov. 2011); average residential retail price of electricity in the U.S.

Lamp purchase prices: Represents average per-lamp multi-pack prices when available and average lamp prices otherwise.

Lamp lifetime: 1,500 hours, 1,000 hours, 10,000 hours, and 25,000 hours, based on the average reported lifetime for incandescent, halogen, CFL, and LED lamps, respectively.

Wattage: 60W, 43W, 13W, and 12.5W, based on the average reported wattage for incandescent, halogen, CFL, and LED lamps, respectively.

Light output: Average lamp light output for 60W-equivalent A-lamps.


Analysis and figure: D&R International.
Table 2. DOE Energy Conservation Standards, Incandescent Reflector Lamps

<table>
<thead>
<tr>
<th>Lamp Spectrum Type</th>
<th>Lamp Diameter</th>
<th>Lamp Voltage</th>
<th>ANSI*</th>
<th>Inches</th>
<th>≥125 V</th>
<th>≥125 V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard Spectrum</td>
<td>&gt;20</td>
<td>&gt;2.5</td>
<td>5.9*P(0.27)</td>
<td>6.8*P(0.27)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>≤20</td>
<td>≤2.5</td>
<td>5.0*P(0.27)</td>
<td>5.7*P(0.27)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Modified Spectrum</td>
<td>&gt;20</td>
<td>&gt;2.5</td>
<td>5.0*P(0.27)</td>
<td>5.8*P(0.27)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>≤20</td>
<td>≤2.5</td>
<td>4.2*P(0.27)</td>
<td>4.9*P(0.27)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: Efficacy requirements apply to all incandescent lamps with wattages ≥ 40 W and ≤ 205 W.

*ANSI (American National Standards Institute) diameter is expressed in 1/8 inches.

Reflector Lamp Performance

Figures 9a, 9b, and 9c show the DOE Energy Conservation Standard efficacy requirements for reflector lamps compared to a sample of incandescent, CFL, and halogen reflector lamps and LED replacement lamps registered with LED Lighting Facts.

Products listed in 2011 and 2012 are highlighted to show contrast with older products. This contrast demonstrates that products in all reflector lamp categories have been improving in light output. LED Lighting Facts now includes products that produce up to 90W PAR38, 70W PAR30, and 50W PAR20 halogen light output levels—none of which had been attained when the previous Product Snapshot on replacement lamps was published in May 2011. According to a 2011 review of major lamp retail outlets, the only commonly available reflector lamps whose light output has not yet been matched by LEDs are 100W, 120W, and 150W halogen PAR38 lamps.

Higher-performing halogen reflector lamps that meet the new standard levels are widely available. Similar to EISA, the DOE Energy Conservation Standard for incandescent reflector lamps will increase the baseline from which savings can be measured. LEDs will still offer substantial savings over halogen reflector lamps—approximately 60%–80%, based on power levels. The potential savings will increase over time as LED product efficacy increases.

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12—Center beam candlepower and beam angle are more commonly used to measure reflector lamp performance. However, for this edition of the Product Snapshot, light output is used as a proxy for those metrics pending the collection of more data.

Sources:
- **Incandescent, Halogen**: D&R International review of package labels and website specifications of bulbs sold at major retailers, February 2011.
- **CFL**: D&R International review of package labels and website specifications of bulbs sold at major retailers, February 2011.

**Analysis and figure**: D&R International.

Figure does not include the performance of BR30 lamps, which are widely available and exempt from the DOE standard.
Figure 9b: Performance of Incandescent Reflector and LED Replacement Lamps, R30/PAR30

[Graph showing light output vs. wattage for LED (Pre-2011), LED (2011-2012), CFL, and Halogen lamps.]

Sources:
*Analysis and figure*: D&R International.

Figure does not include the performance of BR30 lamps, which are widely available and exempt from the DOE standard.
**Figure 9c: Performance of Incandescent Reflector and LED Replacement Lamps, R20/PAR20**

<table>
<thead>
<tr>
<th>Light Output (lumens)</th>
<th>Wattage</th>
</tr>
</thead>
<tbody>
<tr>
<td>LED (Pre-2011)</td>
<td>50W</td>
</tr>
<tr>
<td>LED (2011-2012)</td>
<td>45W</td>
</tr>
<tr>
<td>CFL</td>
<td>40W</td>
</tr>
<tr>
<td>Halogen</td>
<td>75W</td>
</tr>
<tr>
<td>Exempt (R20 lamps rated at 45W or less)</td>
<td>40W</td>
</tr>
</tbody>
</table>

**Sources:**
- **Incandescent, Halogen:** D&R International review of package labels and website specifications of bulbs sold at major retailers. 60W and 100W-equivalent products: January 2012. 40W and 75W-equivalent products: February 2011. DOE CALiPER Program, May 2009.
- **CFL:** D&R International review of package labels and website specifications of bulbs sold at major retailers, February 2011.
- **Analysis and figure:** D&R International.
MR16 lamp performance is shown in Figure 10. MR16 lamps are not covered by the DOE standard discussed earlier. The LED MR16 product category has improved in light output levels from 2009 to 2012; before 2011, only five products produced more than 400 lumens, but by March 2012, when the data for this report were captured, 28 products performed at that output level. However, very few LED products could meet the light output levels of nominally 40W halogen MR16 lamps (500–600 lumens), based on CALiPER benchmark testing.

Figure 10: Performance of Halogen and LED MR-16 Lamps

Sources:
Halogen: DOE CALiPER Program, August 2010.
Analysis and figure: D&R International.
Color Performance

The color performance of LED reflector lamps (PAR and R lamps only) is shown in Figure 11. Similar to A-lamps, there is a high concentration of lamps with low CCT and high CRI (83% had a CRI of 80 or above and were in the warm white or bright white CCT ranges), though there is a higher concentration of LED reflector lamps with bright white CCT (62%). This may partially account for the lower average efficacy of the LED reflector lamp category as a whole (as discussed in the Performance Trends: Efficacy section, above), compared to other replacement lamp types.

Figure 11: Color Performance of LED Reflector Lamps

Sources:
Analysis and figure: D&R International.
Linear Lamps

DOE Energy Conservation Standard

Table 3 shows an overview of the DOE Energy Conservation Standard requirements for general service fluorescent lamps. Lamp efficacy for general service fluorescent lamps depends on the lamp type and CCT. This report focuses on 4-foot medium bi-pin (T8 and T12) and mini bi-pin (T5) fluorescent lamps because of the proliferation of LED replacements for these product types. However, the DOE Energy Conservation Standard does not affect LED replacement lamps; it pertains only to the fluorescent lamp types shown in Table 3.

Table 3. DOE Energy Conservation Standard for General Service Fluorescent Lamps

<table>
<thead>
<tr>
<th>Lamp Type</th>
<th>Minimum Lamp Efficacy (lm/W)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CCT≤4500K</td>
<td>4500K&lt;CCT≤7000K</td>
<td></td>
</tr>
<tr>
<td>2-Foot U-Shaped</td>
<td>84</td>
<td>81</td>
<td></td>
</tr>
<tr>
<td>4-Foot Medium Bi-Pin Based</td>
<td>89</td>
<td>88</td>
<td></td>
</tr>
<tr>
<td>4-Foot Mini Bi-Pin Based</td>
<td>86</td>
<td>81</td>
<td></td>
</tr>
<tr>
<td>Standard Output</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4-Foot Mini Bi-Pin Based</td>
<td>76</td>
<td>72</td>
<td></td>
</tr>
<tr>
<td>High Output</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8-Foot Slimline</td>
<td>97</td>
<td>93</td>
<td></td>
</tr>
<tr>
<td>8-Foot High Output</td>
<td>92</td>
<td>88</td>
<td></td>
</tr>
</tbody>
</table>

4-Foot Linear Lamp Performance

Figure 12 shows the DOE Energy Conservation Standard compared to T5, T8, and T12 fluorescent products and LED replacement lamps. Products listed with LED Lighting Facts in 2011 and 2012 are highlighted to show contrast with older products. Most fluorescent T8 and T5 products meet the new efficiency standard, while most T12 lamps do not. Though LED lamps are not covered under the new standard, it is useful to compare them for reference; most LED lamps (67%) do not meet the minimum performance levels for medium bi-pin (T8 and T12) lamps established by the standard.

Unlike the LED reflector lamp category, which showed a marked improvement as a whole, only the top few products in the 4-foot linear LED replacement category showed an improvement in light output since the last Snapshot on replacement lamps in May 2011 (from around 1800 lumens in 2010 to 2200 lumens in 2012), while the average and minimum stayed about the same (approximately 1500 lumens and 500 lumens, respectively). By contrast, 4-foot linear fluorescent lamps generally produce more than 2500 lumens per lamp, with levels greater than 3000 lumens per lamp common for 4-foot T8 lamps.

Performance should not be evaluated on the basis of light output and efficacy alone. A 2011 DOE GATEWAY study showed that linear replacement lamp performance is highly dependent on application, with parabolic, louvered, and basket-type troffers leading to significant differences in work plane intensity. A complete performance review should include evaluation of lamp performance while operating in the target fixture, including measurement of light intensity on the work surface.


Figure 12: Performance of 4-Foot Linear Fluorescent and LED Replacement Lamps

![Graph showing performance comparison between LED and fluorescent lamps.](image)

**Sources:**
- **LED:** DOE LED Lighting Facts Products List, March 2012, [www.lightingfacts.com/products](http://www.lightingfacts.com/products)
- **Analysis and figure:** D&R International.
Color Performance

In terms of color performance, linear LED replacement lamps as a whole perform quite differently from LED A-lamp and reflector lamp replacements. Figure 13 shows that linear LED replacement lamps are mostly concentrated in the bright white (60%) and daylight (35%) zones. Fluorescent lamp CCT varies, but typically falls in the bright white range, so the similar performance of replacement products is not surprising. However, it is notable that most LED lamps included in this study (64%) had CRI values below 80, the typical performance level of fluorescent lamps. While high CRI values are a potential advantage of LED technology, many linear LED replacement lamp manufacturers appear to be designing for different performance attributes. This may be cause for concern for product buyers and specifiers in applications where color quality is important.

Figure 13: Color Performance of Linear LED Replacement Lamps

Sources:
Analysis and figure: D&R International.
Summary of Results

On the whole, LED replacement lamp performance has improved since 2009, when products first began to be submitted to LED Lighting Facts. Light output, in particular, has steadily increased for top-performing products in all categories, and LED products are now available at incandescent light output levels equivalent to 75W A-lamps, 90W PAR lamps, and 40W MR-16 lamps. Four-foot linear LED replacement lamps do not yet produce light levels comparable to fluorescent lamps, though light output alone does not necessarily indicate product viability in that category.

LED replacement lamp efficacy is following similar trends; all categories have improved consistently, and on the basis of lamp performance alone, all categories offer considerable efficacy gains over incandescent and halogen lamp technologies, where applicable. The top-performing LED products in all categories meet or slightly exceed fluorescent efficacy, though many LED A-lamps and linear replacement lamps in the market do not.

One of the top challenges for buyers and specifiers of LED replacement lamps continues to be a high degree of variability in performance among products. All performance metrics for all product categories covered in this report were highly variable, so industry partners should continue to exercise caution when evaluating products. Additional challenges exposed in this report include high initial product cost (though prices continue to decrease) and in many products, color rendering, color temperature, and light distribution that do not match traditional lamp performance.

LED Lighting Facts is the largest database of independently verified performance data for LED products, and this Snapshot covers more than 1,800 LED replacement lamps, representing a broad swath of the industry. Partners are encouraged to take advantage of LED Lighting Facts as a valuable source of information as the lighting industry progresses. Program resources and updates can be found at www.lightingfacts.com.
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