



Best-in-Class LED Reflector Lamps Summary Report

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INSTITUTE FOR
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INTRODUCTION

With the implementation of new lighting standards, providing guidance to consumers about which lamps (i.e., bulbs) are both energy efficient and aesthetically pleasing is essential. The purpose of this study was to jumpstart that guidance by identifying a list of the “best-in-class” LED reflector lamps that are both energy efficient and aesthetically pleasing to consumers. This is just a start and we hope that this guidance about lighting will spread to other categories.

LED REFLECTOR LAMPS: OVERVIEW

As compared to general purpose light lamps which produce omni-directional light, a reflector lamp is a cone-shaped bulb that creates a directional beam of light. Reflectors are typically used in recessed can, track and outdoor lighting fixtures, and are designed to either provide ambient lighting or illuminate a floor, workspace or wall. Incandescent reflector lamps come in a variety of types (e.g. blown or parabolic aluminized reflector) shapes (e.g. PAR, R, BR and MR) and sizes (e.g. PAR38, PAR30, PAR20).

Figure 1. Examples of common uses for reflector lamps



Source: ENERGY STAR

Reflector lamps are intended for applications where you want to shine light in a particular direction, and provide either a narrow cone of concentrated light (spot lighting) or a broader cone of more diffuse light (flood lighting). When the light source must be located some distance away to illuminate surfaces such as walls or countertops, from high ceilings or for outdoor security lighting, reflector lamps are often the best choice to produce the relatively narrow beams required. Historically, most residential reflector lamps have utilized conventional incandescent lighting technology. After the passage of federal energy efficiency standards, many of these

incandescent lamps began using a halogen fill gas to reduce energy use, increase lamp lifetime and make the light appear slightly whiter, or cooler in color.

More recently, compact fluorescent or CFL reflector lamps have come to market, offering energy savings and longer lifetimes than typical halogen reflector lamps. However, many CFL reflector lamps are not dimmable or do not dim in the same way as halogen reflector lamps. Similarly, although the CFL reflector lamps can provide a broad cone of diffuse light for a flood lamp application, they do not focus light in a more concentrated way like halogen lamps, making them appear dimmer to many users.

LED reflector replacement lamps are now entering the market that offer many of the aesthetic and performance advantages of halogen lamps, while providing even higher energy efficiency levels and longer lifetimes than CFL reflector lamps. Some LEDs now last for 30,000 hours or more – about 30 years of typical use. They also produce very little heat and are quite durable. Because LEDs themselves are inherently directional and readily dimmable, they are a great fit for reflector lamp applications. However, LED reflector lamps can still be expensive to purchase relative to other options and can vary widely in their visual performance. For these reasons, we chose to evaluate currently available LED PAR replacement lamps to provide consumers with advice on selecting those lamps with the highest customer satisfaction and the greatest value for the money.

HOW WE EVALUATE

The overall evaluation consisted of two phases:

- **Phase I** — select the most promising ENERGY STAR lamps to purchase for testing
- **Phase II** — from that smaller group, select the ten best-in-class performers

PHASE I: EVALUATION OF PRODUCTS TO TEST

Lamps meeting the following criteria were considered for purchase:

- Meets ENERGY STAR Program Requirements for Integral LED Lamps, version 1.4, and present on the [ENERGY STAR Qualified Products List](#) on or before 2 December 2011
- LED technology; CFLs were not evaluated
- Within one of three size and shape combinations: PAR38, PAR30 or PAR20¹
- Product attributes (e.g. CRI, CCT) are publicly available
- Available for purchase, either online or through a bricks-and-mortar retailer
- Within the “warmer” CCT range of 2700-3000K

Following the selection process, the lamps were sorted by manufacturer-reported wattage. We then selected lamps with the highest efficiencies.

We attempted to screen a wide variety of lamps across an array of manufacturers, aesthetic qualities, technologies and optical designs. However, if we simply chose the top 30 entries on the sorted ENERGY STAR qualified products list there would have been multiple duplicates. These duplicated lamps carried largely identical performance characteristics, but might be sold in varying beam angles, manufactured under another brand name, or arrive from a different retailer and in different packaging. To avoid multiple listings of essentially the same product, we combined all such models into a single “family” of products and selected only the most readily available representative product for purchase.

¹ Lamps on the ENERGY STAR list included the designations ER/PAR/R. These letters refer to the shape of the reflector for traditional incandescent/halogen technologies, and by extension, they indicate a different type of light beam produced by that type of lamp. However, LED lamps are not dependent on the form of a reflector envelope to produce their light pattern. Instead, the “PAR” designation for an LED reflector replacement lamp describes the shape of the traditional light bulb it is intended to replace. Compared to other reflector shapes, traditional PAR lamps are designed to produce controlled, intense, narrow beams of light. This study is specific to LED lamps that produce relatively narrow, intense beams, which focuses this ranking on the PAR category.

Applying the evaluation criteria described above on lamps listed in the ENERGY STAR Qualified Product List (QPL) reduced the possible lamp candidates as follows:

- PAR38 lamps — 97 lamps listed on ENERGY STAR QPL → 67 final candidates
- PAR30 lamps — 90 lamps listed on ENERGY STAR QPL → 49 final candidates
- PAR20 lamps — 29 lamps listed on ENERGY STAR QPL → 17 final candidates

PHASE II: TEST SCORING CRITERIA

The next phase of the ranking assessment included an in-depth evaluation of product performance. More and more consumers now purchase efficient light bulbs to save energy and money. However, if the quality of the light produced is not as acceptable as what they are used to, many people will revert back to more familiar, but less efficient options, sometimes discounting all future models of that type due to a single bad experience.² *For this reason, we departed from a standard methodology of selecting the ten most energy efficient products of a given category, to develop a list of LED reflector lamps that not only save energy, but also are likely to meet or exceed consumer expectations in their overall performance. In the case of lighting, this means excelling in both energy and visual parameters.* By reviewing manufacturer-reported lamp specifications as well as conducting independent laboratory and qualitative evaluations, we ranked LED reflector lamps on a relative scale from 1 to 100 based on the criteria identified in Table 1. These criteria are a mix of both quantitative and qualitative measures, designed to identify LED lamps that go “above and beyond” minimum ENERGY STAR requirements. Therefore, customers can choose these lamps with confidence, knowing they are buying energy efficient lamps that also produce useful, aesthetically pleasing light.

² http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/cfl_lessons_learned_web.pdf

Table 1. Relative weighting of lamp performance criteria

Scoring Categories	Weighting (Points)
Energy	15
Efficacy exceeds ENERGY STAR requirements (%)	4
Beam efficacy	8
Power factor	3
Economics	20
Simple payback	8
Lifetime cost of light	12
Photometrics (measured light performance)	20
SPD variance (spectral power distribution)	10
CRI variance (color rendering index)	6
DUV (delta UV)	4
Light appearance (qualitative light performance)	45
Human qualitative evaluation	20
Beam imagery	10
Dimming behavior	15
Highest possible score	100

Below we explain each of the ranking criteria in turn.

- **Energy.** We focused on three energy efficiency metrics to rank overall lamp energy efficiency. Lamps could earn up to fifteen (15) points in this category. We chose to make energy performance criteria only one-fifth of the total score because the products evaluated were all ENERGY STAR-qualified, and therefore more energy efficient than typical reflector lamps used in homes. Some of the products we tested narrowly met the ENERGY STAR specification, while others had approximately twice the efficiency needed to make the ENERGY STAR list.
 - **Percentage more efficient than ENERGY STAR criteria.** One of the criteria on which ENERGY STAR evaluates lamps is luminous efficacy, or the amount light (lumens) produced per watt of power consumed. Products earn points in this category based on the percentage that they *exceed* ENERGY STAR requirements. Lamps that are considerably more efficient than ENERGY STAR program requirements earn the maximum score of four (4) points.
 - **Beam efficacy.** Beam efficacy is a less known, but very important metric to help compare reflector lamp performance. Overall luminous efficacy—lumens per watt—

measures the total light output of a product, which is perfectly appropriate for lamps that shine in all directions, like general service A-lamps. Beam efficacy is a measure of the useful light within a reflector lamp's stated beam angle, divided by the total lamp power. Beam efficacy rewards directional lamps for placing the light where you want it and minimizing the electrical power needed to do so. The brighter the beam, the more light is contained within the beam angle. Two ENERGY STAR lamps with comparable luminous efficacy may deliver very different amounts of light to a surface. Therefore, we added beam efficacy to its evaluation criteria. Lamps that effectively produce and direct light while using minimal power are awarded a maximum of eight (8) points.

- **Power factor (PF).** Products with a power factor nearest to 1 cause fewer distribution losses in building wiring. ENERGY STAR lamps that draw 5 or more watts are required to have a minimum $PF \geq 0.70$. Products are awarded points for the extent to which they exceed ENERGY STAR power factor requirements, and can earn a maximum of three (3) points for a $PF = 1$. Currently, no LED PAR replacement lamp on the ENERGY STAR list achieves a $PF = 1$, the highest observed being $PF = 0.986$.
- **Economics.** ENERGY STAR does not evaluate lamp cost-effectiveness per se. We recognize that price is a top consideration for customers, and some lamps present a better value proposition either because they cost less to purchase, provide more energy savings, or both. Therefore, we included two economic criteria—simple payback and cost of light—into our overall lamp assessment. Lamps that pay back the fastest, and provide light least expensively can earn up to twenty (20) points in this category.
 - **Simple payback.** Lamps with the shortest payback period relative to a halogen reflector lamp are awarded a maximum of eight (8) points.
 - **Cost of Light.** We arrive at the cost of light by combining the retail and energy costs over a lamp's expected useful life. The cost of light incorporates the purchase price of the product, the amount of light it produces and the cost of the energy drawn by the lamp over its lifetime. We awarded a maximum of twelve (12) points to lamps with the lowest cost of light.
- **Photometrics.** In this section, we compare laboratory measurements on the color of the light produced. ENERGY STAR sets an acceptable range for correlated color temperature (CCT) and a minimum for color rendering index (CRI). Hundreds of LED reflector lamps now on the market meet these two specifications. To select the ten best lamps, we employ a narrower set of requirements that quantify subtleties in color that mimic the halogen incandescent bulbs with which consumers are familiar. Lamps with the most halogen-like photometry may achieve the highest overall score of twenty (20) points for this category.
 - **Spectral Power Distribution (SPD) Variance.** We measure the difference between the SPD of LED and typical halogen incandescent reflector lamps. We do this by quantifying the product's radiative power by wavelength across the visible spectrum, weighting by the photopic sensitivity of the human eye and then measuring the correlation between the spectral plots. Those with zero variance in SPD from incandescent halogen would be awarded a maximum of ten (10) points.

- **Color Rendering Index (CRI) Variance.** ENERGY STAR qualified lamps must have a CRI of 80 or greater. ENERGY STAR requires that manufacturers follow the industry standard practice of deriving CRI based on tests of nine (9) color swatches (out of a standard set of 14). To test the color rendering accuracy of our products, We used a method including all 14 standard color swatches (8 pastels, and 6 other important colors, such as vegetation and skin tones). LED lamps could earn a maximum of six (6) points for rendering all 14 colors with the least deviation from a halogen incandescent light source. See Figure 2.

Figure 2. Identical CRI reference colors under different light sources



Source: Ecova

- **Delta Ultra Violet (DUV).** Color measurement metrics attempt to reduce color qualities down to a single number. Because of this, two lamps can still have a different color appearance even though they may have same CCT, due to other subtleties about their color that CCT doesn't measure. DUV is a metric for capturing the subtleties more specific to LEDs. These lamps tend to shift from greenish to pinkish in their degree of "whiteness." LEDs are rewarded for having minimal DUV, and appearing most similar to halogens in color. Lamps earned a maximum of four (4) points by displaying minimal DUV.
- **Light appearance.** Although the quantitative photometric characteristics mentioned above are reasonable indications of a light's appearance, the human eye is the ultimate judge. In fact, all photometric quantities are derived from studies of how people perceive and interact with light. We gave this category the most weight relative to other criteria, with an overall score of forty-five (45) possible points. Lamps that earned the highest scores in this category had the most pleasing light color, consistent beam spread and smoothest dimming.
 - **Human Qualitative Evaluation.** For this test, we set up each of the LED reflector lamps, asking subjects to compare the light quality of each to a halogen PAR reference lamp. Participants were asked to score the LEDs on a preference scale of 1 to 5, judging on light pattern, color, and how the light quality compared to an incandescent. Lamps could earn a maximum of twenty (20) points in this category.

Lamps with smooth beam patterns, pleasing color and incandescent-like qualities earned the greatest number of points.

- **Beam Imagery.** We recorded two images of the beam from each test lamp. One image recorded the circular beam pattern by aiming the lamp perpendicular onto a diffuse white screen. Next, the lamp was positioned parallel to the screen, yielding an image of the beam in profile along the lamp's central axis. These reference images were also compared in side-by-side fashion and rated on an absolute scale of quality. This evaluation was combined with a live viewing situation above. Lamps earned up to ten (10) points for producing beams with smoothly tapering edges, no dark spots, streaks, unexpected patterns or color variations and little to no irregularities. See Figure 3. (Note: Bright, smooth centers reflect high center beam candlepower (CBCP), which translates to more of the energy being channeled into the working beam of the lamp, as opposed to uncontrolled light spilling off into the periphery. See beam efficacy, above.)

Figure 3. LED lamp beam pattern (left) and profile (right)



Source: Ecova

- **Dimming Behavior.** We operated all lamps on both conventional (600W Incandescent rotary) and ELV (electronic low voltage) dimmers, evaluating the behavior of lamps that claimed to be dimmable. In addition, each lamp was operated in line with a 100W halogen lamp, controlling both with an incandescent rotary dimmer (i.e. mixed technology dimming). During these tests, we scored on smoothness, color change, instances of flicker, any audible hum and other notable issues of LED dimming (such as the ratio of drop-off and re-strike levels). In an integrating sphere, dimming was measured at 100%, 75%, 50% (rated by light output) and minimum flicker-free re-strike level (representing the bottom of the dimmable range). Our goal was to identify lamps with smooth incandescent-like dimming qualities. A maximum of fifteen (15) points was available in this category. Non-dimmable lamps received zero (0) points.

MARKET SEGMENTATION

We broke down the LED reflector market into three main categories based on lamp size:

- **PAR38**
- **PAR30**
- **PAR20**

To ensure adequate representation of the reflector market, the list of “best-in-class” lamps contains five (5) PAR38, four (4) PAR30 and one (1) PAR20 lamps, roughly the same market segmentation as the ENERGY STAR qualified products list (Table 2). We list the best performing lamps within each of the size categories, instead of just the ten highest scoring lamps regardless of size.

Table 2: Reflector lamp market segmentation

	PAR38	PAR30	PAR20
Number of selected models	5	4	1

LABORATORY PRODUCT TESTING

We used the following test methods for measuring light and electrical performance characteristics:

- **LED Electrical and Photometric Measurements.** IES LM-79-08: IES Approved Method for the Electrical and Photometric Measurements of Solid-State Lighting Products. Published by the Illuminating Engineering Society, New York, New York. ISBN # 978-0-87995-226-6. For more information see <http://www.ies.org/store/product/approved-method-electrical-and-photometric-measurements-of-solidstate-lighting-products-1095.cfm>.
- **Dimming.** A standardized test procedure for LED reflector dimming was not available at the time of this study. We adapted a test procedure specifically for this product category.

RESULTS: “BEST-IN-CLASS” LED REFLECTOR LAMPS

PAR38

Rank: #1

Manufacturer: Technical Consumer Products

Description: This is a 17-watt LED flood light. It replaces a 90-watt halogen flood.

Payback period with typical use: 4.1 years

Lifetime cost savings vs. halogen, including lamp cost: \$200

Lifetime energy savings: 1,817 kilowatt hours



Rank: #2

Manufacturer: Osram Sylvania

Description: This is an 18-watt LED flood light. It replaces a 75-watt halogen flood.

Payback period with typical use: 7.7 years

Lifetime cost savings vs. halogen, including lamp cost: \$158

Lifetime energy savings: 1,434 kilowatt hours



Rank: #3

Manufacturer: Philips EnduraLED

Description: This is a 17-watt LED flood light. It replaces a 75-watt halogen flood.

Payback period with typical use: 7.6 years

Lifetime cost savings vs. halogen, including lamp cost: \$161

Lifetime energy savings: 1,466 kilowatt hours



Rank: #4

Manufacturer: EcoSmart, The Home Depot

Description: This is an 18-watt LED flood light. It replaces a 75-watt halogen flood.

Payback period with typical use: 4.5 years

Lifetime cost savings vs. halogen, including lamp cost: \$155

Lifetime energy savings: 1,411 kilowatt hours



Rank: #5

Manufacturer: Samsung LED Company

Description: This is an 18-watt LED flood light. It replaces a 75-watt halogen flood.

Payback period with typical use: 7.7 years

Lifetime cost savings vs. halogen, including lamp cost: \$159

Lifetime energy savings: 1,444 kilowatt hours



PAR30

Rank: #1

Manufacturer: Technical Consumer Products

Description: This is a 14-watt LED flood light. It replaces a 75-watt halogen flood.

Payback period with typical use: 5.3 years

Lifetime cost savings vs. halogen, including lamp cost: \$167

Lifetime energy savings: 1,515 kilowatt hours



Rank: #2

Manufacturer: EcoSmart, The Home Depot

Description: This is a 15-watt LED flood light. It replaces a 65-watt halogen flood.

Payback period with typical use: 5.2 years

Lifetime cost savings vs. halogen, including lamp cost: \$137

Lifetime energy savings: 1,250 kilowatt hours



Rank: #3

Manufacturer: Duracell, CMG Energy Solutions

Description: This is a 12-watt LED flood light. It replaces a 50-watt halogen flood.

Payback period with typical use: 17 years

Lifetime cost savings vs. halogen, including lamp cost: \$107

Lifetime energy savings: 977 kilowatt hours



Rank: #4

Manufacturer: Samsung

Description: This is a 15-watt LED flood light. It replaces a 75-watt halogen flood.

Payback period with typical use: 6 years

Lifetime cost savings vs. halogen, including lamp cost: \$107

Lifetime energy savings: 1,517kilowatt hours



PAR20

Rank: #1

Manufacturer: Osram Sylvania

Description: This is an 8-watt LED flood light. It replaces a 35-watt halogen flood.

Payback period with typical use: 6.4 years

Lifetime cost savings vs. halogen, including lamp cost: \$72

Lifetime energy savings: 659 kilowatt hours



GLOSSARY OF TERMS

Average rated life: A rating that indicates when 50% of a large group of lamps has failed.

Beam angle. The rated beam angle for a PAR lamp is defined by ANSI as the angle where the light output is 50% as intense as the center of its beam (center along the lamp axis). This 2:1 ratio of center-to-edge output is undetectable to the eye, so the beam of the PAR lamp will actually appear much wider than published.

Beam efficacy. The measure of the useful light delivered within a reflector lamp's stated beam angle, divided by the total lamp power.

Beam lumens. The total luminous flux (light) found within the declared beam angle. See "light," "lumen," luminous flux."

Blackbody. An ideal light source that absorbs all radiation falling upon it, and reflecting none. It emits radiation equally across all wavelengths. In concept, a blackbody is black when cold, and begins to emit light when it is heated, such as would a piece of metal. An incandescent filament can be considered a blackbody radiator. See "correlated color temperature."

Blackbody locus. The series of points plotted on a color diagram representing the chromaticities (color coordinates) of blackbodies having various color temperatures. See "correlated color temperature."

Candela (cd). The SI unit of luminous intensity. See "luminous intensity."

Candlepower (cp). Luminous intensity expressed in candelas.

Center beam candlepower (CBCP). The intensity of light at the center of a reflector lamp beam.

Color rendering index (CRI). A measure of how well a light source renders a set of standard colors relative to the same colors illuminated by a reference source having the same CCT as the light source of interest. For lights with a CCT below 5000°K, the reference is incandescent. Above 5000°K, it is daylight. CRI is a psychological measurement of appearance. See "Kelvin."

Compact fluorescent (CFL). A self-contained fluorescent lamp of small diameter tubing folded into a compact shape, typically containing an integrated ballast and screw base.

Correlated color temperature (CCT). The temperature of a blackbody radiator at the point it matches the color of the light source of interest. This is called the "color temperature" (CT), measured in degrees Kelvin. Exact matches cannot be obtained, so the closest match is called the "correlated color temperature" (CCT). This indicates that the light does not exactly match a color in a defined series of standard colors. CCT is a physically defined measurement.

Dimmer. An electrical control device used to modify the intensity of light emitted by a light source by modifying the voltage or current available to it. ELV (electronic low voltage) dimmers are solid-state devices for controlling electronic low voltage transformers and dimmable LED power supplies.

Downlight. A lighting fixture that directs light predominantly downward, usually ceiling-mounted, and can be recessed, surface-mounted or suspended.

Efficacy. The luminous efficiency of a light source expressed as lumen output per watt of power. The total luminous flux emitted by a lamp, divided by the lamp's total power input.

Efficiency. The luminous efficiency of a luminaire expressed as the percentage of lumen output of a luminaire relative to the lumen output of the lamp(s) alone.

Incandescent lamp. A lamp in which light is produced by a tungsten filament heated to incandescence by an electric current.

Kelvin (°K). The unit of temperature used to designate the color temperature of a light source. See "correlated color temperature." The Kelvin scale is a temperature scale, where each degree is the same dimension as a Celsius degree (°C), however, $0\text{ °K} = 273\text{ °C}$.

Light. The narrow band of the electromagnetic spectrum to which the human visual system is most sensitive. Luminous flux. See "luminous flux."

Light emitting diode (LED). A solid-state semiconducting device that produces visible light by passing current through a p-n diode junction.

Lumen (lm). The fundamental unit of luminous flux. A lumen is the SI unit of luminous flux. See "luminous flux."

Luminous flux (lm). Radiant flux that has the capacity to produce a visual sensation. Luminous flux quantifies the total lumen output of a light source in all directions. It is the radiant flux of a source multiplied by the relative spectral sensitivity of the human visual system.

Luminous intensity (cd). A unit quantifying the total lumen output of a source in a given direction.

Power factor. Represents the ratio of "real" AC power consumed by an electrical load to the amount of "apparent" power that travels on the grid. An ideal device has a power factor of 1, where the device draws the same amount of apparent power as real power.

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