Residential Lighting Efficiency at a Crossroads: Why Next-Generation Technologies and Programs Are more Important than Ever

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ABSTRACT

The nation's leading utilities have been operating compact fluorescent lamp (CFL) programs for more than 18 years, and during that time CFLs have improved dramatically in size, price, performance and availability. So, has the market been transformed? Are residential lighting programs obsolete? Are the new federal standards all we need? The truth is that CFL sales are plummeting, four out of five sockets still contain inefficient lamps, and EISA (the Energy Independence and Security Act of 2007, which aims to make everyday screw-based lamps use about 30 percent less power) is weaker and slower than most people think. The landscape of residential lighting technology and policy is changing rapidly, and utilities are now facing a critical opportunity to secure additional savings.

This paper argues that residential lighting programs must continue and explains how and why they require strategic re-design. To that end, the author provides an overview of recent state and federal policy changes, evaluate continuing potential for CFLs, present data from incandescent lamps that already meet the EISA standards, highlight emerging opportunities for new breeds of efficient incandescents, explore the feasibility of LEDs in residential settings in the coming years, and discuss the increasing need for consumer education.

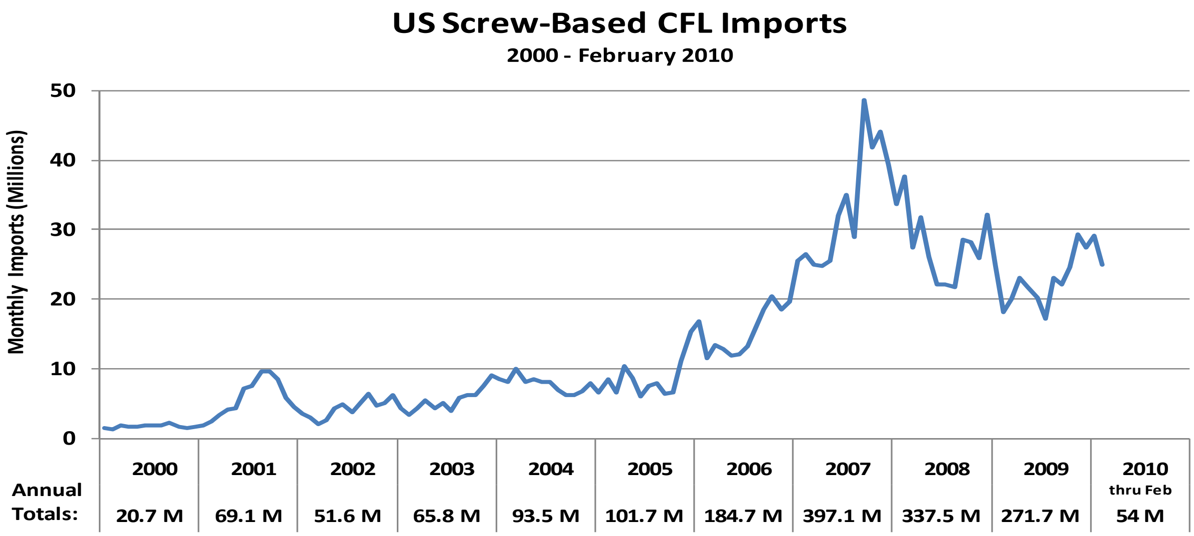
Findings will provide guiding principles for innovative, effective, next-generation lighting programs.

Introduction

The landscape of residential lighting technology and policy is changing rapidly, and utilities are now facing critical decisions about what to do with their lighting programs. Over the past few years, many utilities have had to reduce the percentage of savings they claim from compact fluorescent lamp (CFL) programs due to the premise that some consumers would buy CFLs even if they weren't rebated by their utility. This is because during the nearly 20 years that utilities have been running CFL rebate programs, CFLs have improved dramatically in size, price, performance and availability, and many consumers are now familiar with the concept that CFLs save energy. Furthermore, some people believe that the general purpose lamps standards from the Energy Independence and Security Act of 2007 (EISA) will ban incandescents entirely leaving CFLs as the only option for screw-based residential lighting. It is easy to see why electric utilities and other members of the efficiency community are wondering if there is a future for residential lighting programs.

The reality is that without utility programs, the energy savings they have achieved could erode, future savings will be lost, and manufacturers will not be incentivized to develop new, state-of-the-art, high efficiency replacement lamps. CFL programs have curbed the growth of residential lighting energy use significantly and helped to place CFLs in nearly 70% of U.S. homes; however, the fact remains that four out of five sockets in US households still contain inefficient incandescent lamps (DOE 2009) and CFL sales have declined by more than 30 percent since a 2007 peak (USA Trade® Online May 2010).

Figure 1. U.S. Imports of Screw-Based CFLs. Graph Source: USA Trade® Online May 2010 Data Graphed by Ecos



On its own, EISA will not force future incandescent sales to be replaced with CFLs. The standard is a step in the right direction, but is less stringent and slower than most people think.

EISA: What, When and How?

After lengthy negotiations in 2007, a group of politicians, lighting manufacturers and efficiency advocates developed a set of general purpose lamp efficiency standards. These standards became federal law in December of 2007 as part of the Energy Independence and Security Act of 2007 (EISA). Contrary to much of the hype around these lamp standards, EISA does not ban incandescent lamps. EISA sets minimum efficacy standards that most incandescent lamps do not meet; however, the standard does not ban any technology that meets the requirements. Its minimum efficacy requirements will be phased in from 2012 to 2014; 60 W lamps will not be affected until 2014. Lamps that use improved incandescent technology can pass these standards; some of these products have been available since 2008.

The general purpose lamp standards in EISA apply to common screw-base household light bulbs. There are numerous exceptions for specialty lamps, but today's 40 W, 60 W, 75 W and 100 W lamps will be affected. EISA is one of many general purpose lamp standards. California passed the world's first general purpose lamp standards in 2005; this rule, now in its Tier 2 phase, requires incandescent lamps to use 5% less power than standard incandescent lamps. In June of 2007, Nevada passed what is today's most stringent general purpose lamp efficacy law that will require all general purpose lamps sold after 2012 to have efficacies of 25 lm/W or greater. Because Nevada and California had existing lighting laws in place when EISA was passed, EISA provided these states an option to make these standards begin in 2011 (EISA H.R. 6-94). California elected to do this while thus far Nevada is keeping its 25 lm/W rule in place. In 2008, Canada passed general purpose lighting efficiency laws that are similar in stringency to EISA but differently structured. Overseas, Australia and the European Union passed general purpose lighting legislation in 2008 and 2009. In short, the US is not alone in raising the bar for residential light bulb efficiency—manufacturers are responding to changing requirements around the world.

Starting on January 1, 2012, EISA will require lamps sold in the U.S that produce between 1490 and 2600 lumens to use a maximum of 72 watts. Today's 100 W bulbs fall in that lumen range producing about 1690 lumens; therefore, EISA will require 100 W equivalent lamps to use about 30% less power (from 100 W to 72 W). However, since the power level requirement is the same over a range of light output levels, a 72 W lamp in 2010 could be up to 200 lumens dimmer than today's 100 W lamp (1490 lumens instead of 1690 lumens) resulting in only a 22% efficacy improvement. Similar wattage caps apply for today's 75 W lamps in 2013, and today's 60 W and 40 W lamps in 2014. A wattage limit over a range of lumens results in a range of allowable efficacies for each category. Table 1 shows the EISA requirements (EISA H.R. 6-86) with comparisons to the lamps intended for replacement.

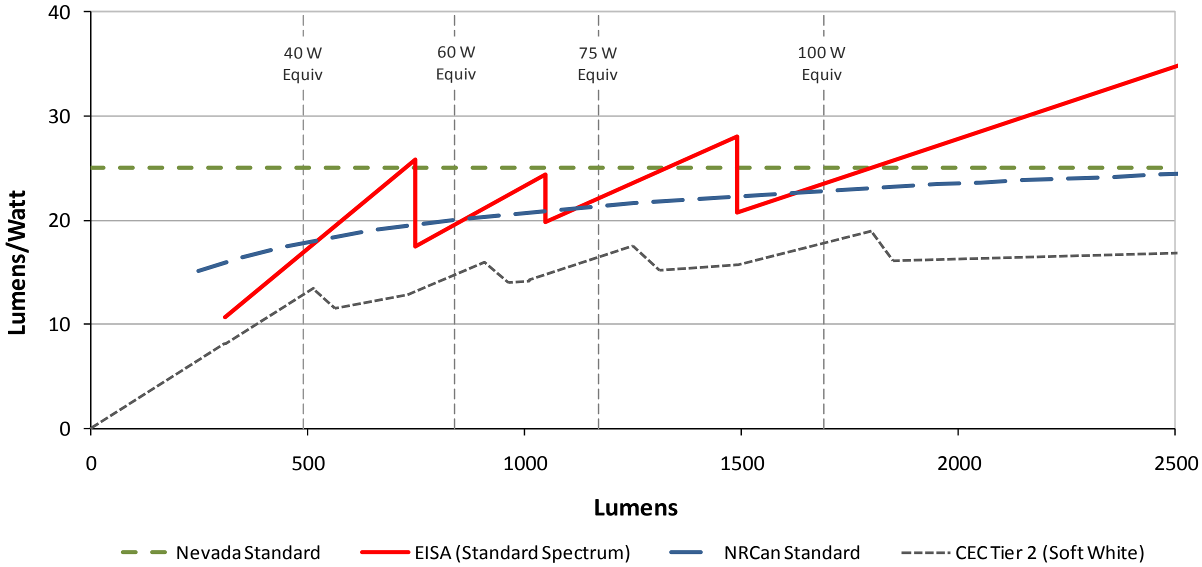
Table 1. EISA Requirements with Comparisons to Today's Incandescent Technology[1]

EISA Effective Dates	Typical Incand. Replaced	Typical Incand. Lumens	Typical Incand. Efficacy	EISA Replace-ment	EISA Lumen Ranges	EISA Min Efficacy Ranges	Minimum Efficacy Increase
1/1/2012	100 W	1690	17 lm/W	72 W	1490 - 2600	21 – 36 lm/W	23% (4 lm/W)
1/1/2013	75 W	1170	16 lm/W	53 W	1050 - 1489	20 – 28 lm/W	27% (4 lm/W)
1/1/2014	60 W	840	14 lm/W	43 W	750 - 1049	17 – 24 lm/W	25% (3 lm/W)
1/1/2014	40 W	490	12 lm/W	29 W	310 - 749	11 – 26 lm/W	-13% (-2 lm/W)

When graphed to compare light output to efficacy, EISA forms a jagged "peak and valley" pattern similar to California's Tier 2 standard. For comparison, the Nevada standard forms a straight line at 25 lm/W across all lumen output levels. The Canadian standard is similar in stringency to EISA but has a smooth curve shape which requires lamps to become progressively more efficient as their light output increases (which is the way incandescent technology behaves). See Figure 2. Light output in lumens is on the horizontal axis; lamp efficacy in lm/W is on the vertical axis. To comply, a lamp's coordinates for light output and efficacy must fall above the standard's line. Note that the California CEC Tier 2 line is the standard that is in effect in California today. In 2011, California will phase in the EISA standard.

[1] All table figures rounded to nearest whole number.

Figure 2. North American General Purpose Lamp Standards (Graph source: Ecos)



EISA's valleys are easiest places for manufacturers to comply because these allow the lowest efficacy minimums for each lumen output range. For example, note how a typical 100 W equivalent lamp emits about 1700 lumens (vertical dashed gray line). EISA allows a minimum efficacy of just over 20 lm/W at about 1500 lumens. A likely outcome is that new incandescent lamps will comply with EISA in the valleys that fall to the left of today's typical lumen output. This means that lamps intended to replace today's 40 W, 60 W, 75 W and 100 W lamps are likely to be dimmer than consumers expect.

Furthermore, EISA (and the Canadian standard) allow incandescent modified spectrum lamps to be 25% less efficient than standard incandescent lamps. Modified spectrum lamps are inherently less efficient than standard spectrum lamps because not all of the produced light leaves the lamp. They have the same filaments as standard incandescent lamps, but then have neodymium or other light blue-purple tinting in the bulb's glass cover. This tint filters out the yellow/green and red sections of the visible spectrum to produce a color temperature that is slightly cooler than standard incandescents. Modified spectrum lamps provide a subtle color difference that is described in marketing materials as "clean, beautiful light™" (GE 2010) or "similar to natural daylight" (Philips 2010) and are promoted for use in most residential lighting applications.

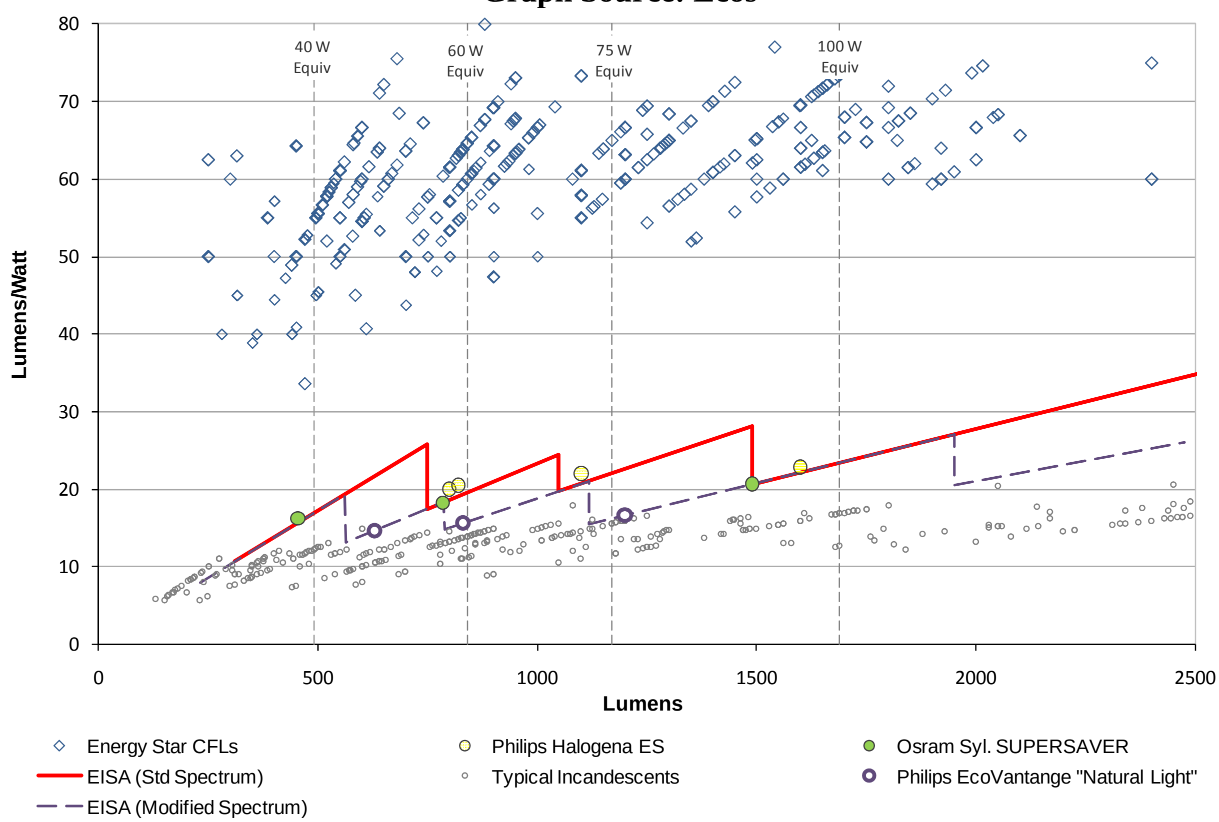
Post-EISA baseline

EISA is likely to form the new baseline for general purpose lamp efficacy. EISA's efficacy requirements are only slightly higher than today's incandescent efficacy levels, which form the baseline against which today's residential lighting programs are measured, and well below those of CFLs. For example, a typical 60 W incandescent lamp (840 lumens) has an efficacy of approximately 14 lm/W. A 60 W equivalent CFL (800 – 900 lumens) is approximately 60 lm/W. In 2014, EISA will require true a 60 W equivalent lamp (840 lumens) to have an efficacy of about 20 lm/W. However, because the EISA 60 W equivalent lumen bin range begins at 750 lumens, a lamp that complies with the standard at its minimum requirement could be 90 lumens dimmer than today's 60 W lamps, and have an efficacy of just over 17 lm/W, only 3 lm/W above today's 60 W incandescent efficacy.

Since 2008, incandescent lamps that comply with EISA have been available to consumers at Home Depot and online. This improved incandescent technology uses an infrared reflective (IR) coating and is currently available in the U.S. in several medium screw-based products. Lamps' filaments are housed inside small spherical or ovoidal halogen-filled capsules that are covered with a very thin metallic IR coating. This coating lets visible light out but reflects non-visible infrared light back onto the filament to reheat it. (Note that the coating alone is abbreviated as IR; an IR-coated halogen capsule is abbreviated as HIR for halogen infrared reflective). Recycling the filament's own heat in this way means that less electricity is required to heat the filament. While HIR technology is a huge leap forward for incandescents, the general purpose HIR lamps currently available cluster in EISA's valleys. Clustering of products in the weakest parts of the standard is a logical manufacturer response to standards and not new to EISA. Lamps introduced to pass the 2008 California Tier 2 standard followed a similar trend.

The graph below depicts EISA standard spectrum (solid line), the reduced stringency EISA modified spectrum (dashed line) and the lamps available to date that pass each of the standards. Energy Star CFLs and typical incandescents are also plotted for comparison. Note how the lamps that pass the modified spectrum standard are no more efficient than some of today's incandescent lamps.

Figure 3. Lamp Compliance with EISA's Standard and Modified Spectrum Standards. Graph Source: Ecos



Residential Opportunities for Next Generation Lighting Technologies

By now there is no doubt that LEDs will join CFLs to play a key role in next generation residential lighting. As predicted, efficacies are improving and prices are dropping (DOE 2010). Because LEDs are directional light sources, they are ideal for applications like downlights and reflector lamps which aim light at a particular surface (typically a wall, floor, or work surface). LED downlights are currently available that have CFL-like efficacies and smoothly dim down to 20% of the rated light output. Their directional nature means that they require diffusers or and/or careful arranging for omni-directional applications like A-lamp replacements. Thus far, the LED A-lamp replacement lamps on the market are 40 W equivalents at most and less efficient than CFLs. Competitions like the DOE's L-Prize are spurring developments in LED A-lamp replacement products, but a immediate residential opportunity for LED replacement lamps is in downlights and reflector lamps. Today's homes have an average of 40 – 90 downlights depending on home size, and CFLs have historically experienced poor customer acceptance in downlight applications for a variety of reasons including early failure (from high operating temperatures) and need for dimmability (NLPIP 2008). LEDs present a viable energy-savings opportunity in downlights, and several high-quality products are already available to consumers. High purchase prices are the key barrier for these lamps at this time. LEDs however will not be limited to replacement lamps in residential applications. In fact, their performance is maximized when they are incorporated into luminaires designed for their directional properties and heat dissipation needs. ENERGY STAR provides specifications for many LED luminaires suited for residential applications, including undercabinet fixtures, portable task lights, outdoor step, path and porch lights, and ceiling mounted luminaires (ENERGY STAR 2007).

Incandescent lamps are widely known as inefficient light sources since at least 90% of the energy used is converted to heat; only 10% leaves the lamp as visible light (Rea 2000). The technology has been relatively stable over the past 100 years with few large improvements in efficacy. Today, in large part due to EISA, certain incandescent technologies are undergoing innovations that could double their efficacy. Building off their existing IR technology, researchers at Deposition Sciences, Inc. (DSI), a subsidiary of Advanced Lighting Technologies (ADLT), have developed a more advanced IR coating. Prototype 120 V HIR capsules with the advanced coating tested in Ecos' lab in 2008 showed efficacies of up to 40 lm/W (similar to some covered CFLs) at high light output levels. DSI estimates an HIR capsule using this same advanced coating designed for a 60 W replacement lamps would yield about 30 lm/W (27 watts at 800 lumens). Ecos is currently evaluating a new 12 V HIR capsule developed by ADLT. The manufacturer claims the 50 W capsule has an efficacy of 27 lm/W (not counting power supply losses) and is expected to last for 5,000 hours (Stockdale 2010).

Other new lighting technologies may also be introduced that will pass EISA. Electron stimulated luminescence (ESL) is being developed by the U.S. start-up Vu1. Similar to CRT televisions, ESL lamps project electrons onto a phosphor-coated surface; the phosphors then emit visible light. Vu1 has working prototypes of a 30 lm/W reflector lamp that emit 600 lumens. The lamp is dimmable and Vu1 claims that it is compatible with motion sensors and timers. The company has not yet announced when they expect to have production ready for distribution. Vu1 plans to eventually expand their product offerings to A-lamps and fluorescent tubes. (Vu1 2010).

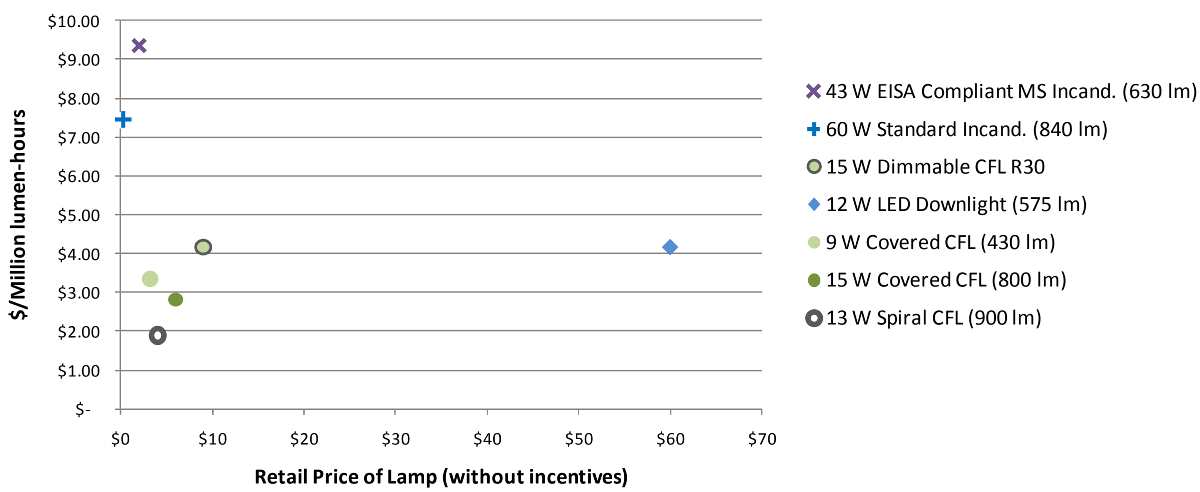
The new technology mix, with claimed product lifetimes varying from a minimum of 1,000 hours to up to 50,000 hours combined with a wide range of retail prices, makes it difficult to quickly determine which lamps provide light most cost-effectively. The graph below illustrates the total cost of light of seven example replacement lamps on a dollars per million lumen-hour basis. Lamp purchase price and total cost of energy to operate the lamp over its entire lifetime is compared to the total light emitted during the lamp's rated lifetime. The IESNA 9^{th} ed. Handbook (p. 25-1) provides a formula for this calculation:

$$U = \frac{10}{Q}\left(\frac{P+h}{L} + WR\right)$$

Where
*U = unit cost of light for a lamps (dollars/106 lm*h*
Q = mean lamp flux (lumens)
P = lamp price (cents)
h = labor cost to replace one lamp (cents)
L = average rated lamp life (thousands of hours)
W = mean input power per lamp (lamp and losses) (watts)
R = energy cost (cents/kilowatt-hour)

This visual is intended to illustrate example costs of particular lamps and is in no way intended to illustrate general costs of light by technology. Interestingly, the LED downlight (dimmable), which is the most expensive lamp analyzed, has a $/Mlm-h cost that is identical to that of the dimmable R30 CFL. The EISA-compliant modified spectrum incandescent has the highest $/Mlm-h cost due to its poor efficacy and retail price that is similar to a CFL. The standard 60 W is the least expensive lamp to purchase (about $0.25) but has the second highest $/Mlm-h cost. The calculations for the lamps below do not include any labor since they are residential products and most households do not pay labor costs to replace lamps. Retail prices for lamps can vary widely; the prices used in these calculations were advertised online prices that were not reduced by utility rebates. Other lamp data is manufacturer data.

Figure 4. Total Cost of Light Comparison. Graph source: Ecos

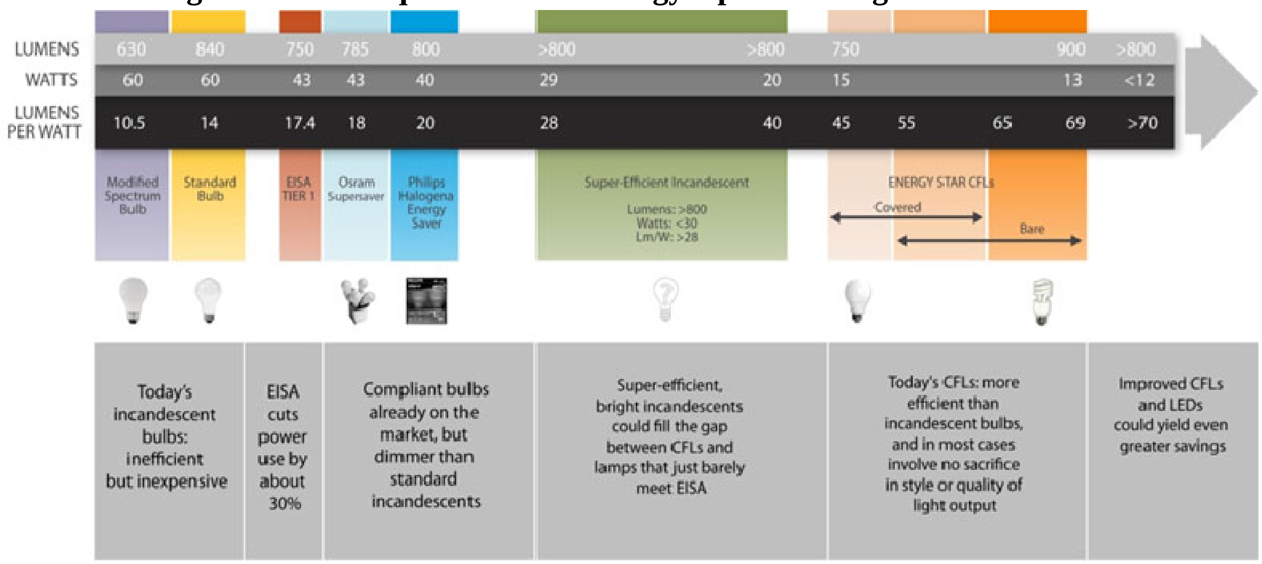


What this means for next generation residential lighting programs is that savings from lamps with widely varying lifetimes should be compared on a lifetime basis instead of first year savings. If programs are required to evaluate cost-effectiveness and savings only on first year savings, LEDs—with higher upfront costs and longer rated lives than CFLs—will not fare well.

Why Programs Must Continue and What They Should Look Like

Next generation lighting programs must continue to push the limits of residential lighting efficiency. These programs cannot be simple extensions of today's CFL rebate programs. To be effective and relevant, they must be re-designed to account for EISA and increasing CFL free-ridership levels in some areas, but also to maximize savings for as many technology options as possible. Multiple technology choices and technology neutral specifications will be key in future programs. CFLs have significantly reduced lighting energy use and will continue to do so, but other technologies can fill unmet needs for dimming, directional lighting, and certain color characteristics. The visual below illustrates a continuum of 60 W equivalent products (approximately 800 lumens) for perspectives on how future lighting programs can incorporate various technologies, how these technologies compare to each other, and where the EISA baseline falls. Lamps become more efficient from left to right.

Figure 5. 60 W Equivalent Technology Options. Image source: Ecos



On the most basic level, next generation lighting programs should continue to fill more of the remaining 80% of residential sockets with CFLs. To do so, utilities will need comprehensive, up-to-date research to better understand why their customers buy or don't buy CFLs, CFL performance (for example: are CFLs lasting as long, or longer, than claimed, and why?), and what percentage of their customers would purchase CFLs in the absence of any utility promotions. Targeted marketing campaigns can then be accurately tailored to different demographics, informational materials can be developed to address areas of consumer confusion, and utilities can have updated information on free-ridership figures. However, no matter how much promotion, marketing and education occur, some customers will choose not to use CFLs in some or all of the sockets in their homes. There are multiple reasons for this, including dislike of CFL light properties, desire for low-level dimming, use of occupancy sensors and motion detectors, renters who do not pay utilities and may not want to invest in long-term efficiency measures, desire for visual effect of a point source light, and fears about negative health impacts and mercury. For those customers (and sockets), next generation lighting programs will need to offer a range of efficient choices, and to keep in mind that program offerings beyond typical CFLs will not be subject to the same free-ridership considerations as CFLs.

New, high-quality advanced lighting technologies such as LEDs and highly efficient incandescents will diversify residential lighting options. If programs do not rebate these products and steer customers to the most efficient non-CFLs, many are likely to default to the least expensive lamps that pass EISA at its lowest levels. Alternatively, customers could choose the least expensive LED replacement lamps. If utilities are not actively promoting the highest quality LEDs, customers could end up with poor quality products with misleading claims and become disenchanted with LEDs in general. The DOE and EPA are leading the way in setting quality and efficiency specifications for LEDs, but it is the utilities that move these efficient products into sockets. With the right rebates in place, programs can also challenge manufacturers to continue product innovation and quality improvements. Incandescent efficiency doesn't need to stop at EISA's minimum requirements. If incandescent lamps could be developed with efficacies that double today's levels, this technology could fill a significant gap by providing consumers an efficient, low-cost option for dimmable or point source illuminations needs. If there were markets for such products, manufacturers would likely seek to fill them. With the right incentives in place, super efficient incandescents and high-quality LEDs could join CFLs as common household products and would not be subject to free ridership penalties.

Utilities could also consider expanding or beginning promotion of both CFL and LED ENERGY STAR fixtures and residential lighting controls such as timers. The viability of such offerings would vary from utility to utility depending on factors such as the amount of new construction and maturity of the market.

One of the most important roles for future utility programs will be education—consumers are going to need guidance to navigate the all the changing technologies and standards. The existing Federal Trade Commission (FTC) labeling requirements for lamp packages include the phrase: "To save energy, find the bulbs with the light output you need, then find the one with the lowest watts" (FTC 1996). These are adequate instructions but there is one important problem. Most consumers have no idea what light output (in lumens) they need. In recent history, lamps have been marketed and grouped according to the power they need to operate, not the light that they provide. This was not always the case; many early incandescents were marked with a candlepower rating. Now, however, consumers are used to buying lamps with the familiar wattages of 40, 60, 75 and 100 and yet are almost entirely unfamiliar with the rated lumen outputs of the lamps they regularly use. It is critical that future utility programs allocate budget to educate consumers about the service lamps provide—light measured in lumens—rather than the outdated comparison of how much power, in watts, a lamp requires. As the familiar incandescent wattages are phased out with EISA and efficient technologies besides CFLs become available, consumers will be confused and likely frustrated when shopping for new lamps. In addition, some of the savings intended by EISA could be lost.

Consider this: starting in 2012, EISA will require today's 100 W incandescent lamps to shift to 72 W lamps. In 2013, 75 W lamps will shift to 53 W lamps. If a consumer goes to the store in 2013 looking to replace a burned out 75 watt lamp, the choices will be 72 W and 53 W incandescent lamps. That consumer is likely to choose the 72 W lamp (intended as a 100 W replacement) if he or she does not know how to shop by lumens. Moving from a 75 W lamp (pre-EISA) to a 72 W lamp (post-EISA) does not save energy and erodes the intension of EISA.

New FTC labeling requirements will take effect in the same timeframe as EISA, and these are likely to standardize wattage equivalency claims and emphasize lumen output. Updated labeling requirements are a step in the right direction, but utility programs can fill an urgent need now by giving consumers the tools to purchase the most efficient lamps with the light output they need.

Conclusion

Next generation lighting programs have an important role to play in shaping the future of residential lighting. EISA will raise the baseline efficiency by which these programs' savings are measured by a few lumens/watt, but what will happen beyond that remains to be determined. Due to increasing free-ridership percentages and the slightly higher post-EISA baseline, program costs are likely to increase above today's 1¢/kWh levels, but savings from residential lighting programs will still be among the least expensive program measures and far less than 4-5¢/kWh for new generation. In the absence of rebates for the best and most efficient CFLs, LEDs, and potentially high-efficiency incandescents and ESLs, consumers could migrate to the least efficient EISA-compliant products which are no more efficient than today's incandescent lamps. To meet consumers' lighting needs and keep them incentivized to purchase efficient lighting technologies, programs will need to offer consumers choices and then educate them to make good choices. Not all lumens are created equal but they should all be created efficiently. Innovative next generation utility programs will play a critical role in ensuring that this happens.

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