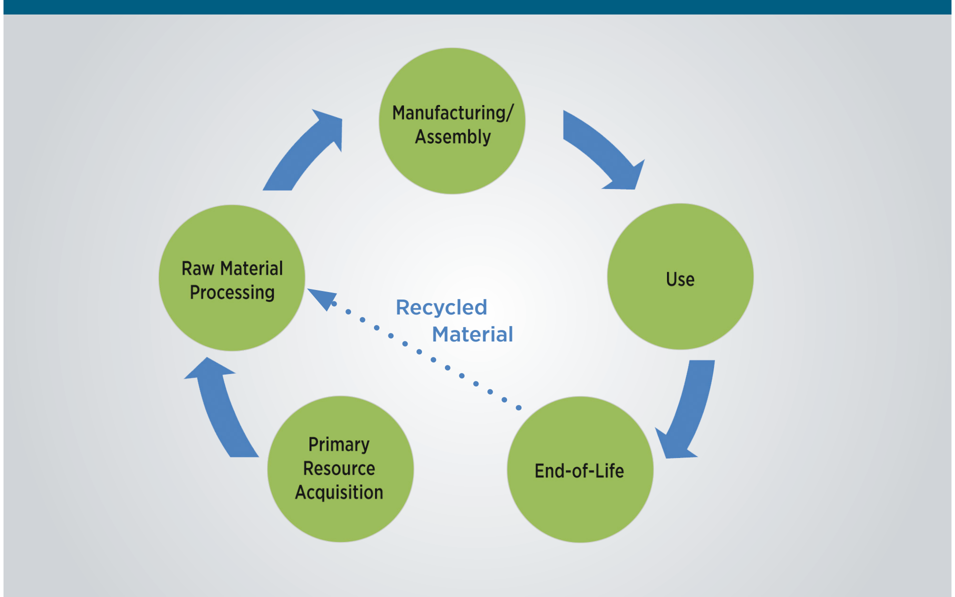
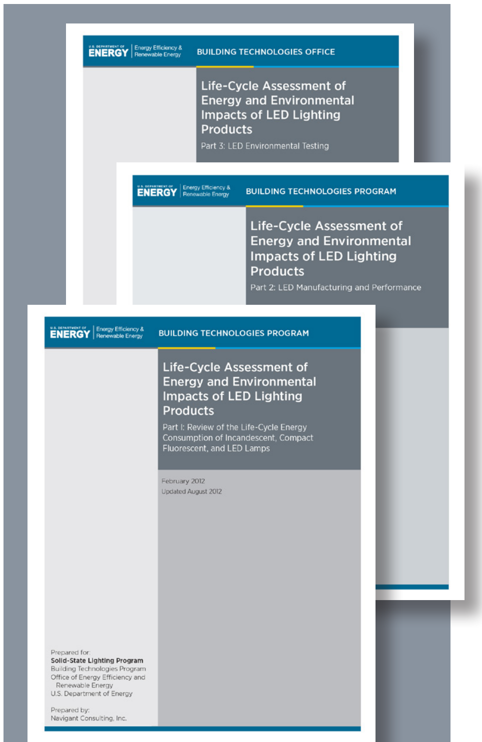
Life-Cycle Assessment of Energy and Environmental Impacts of LED Lighting Products

Light-emitting diode (LED) products for general illumination have the potential to save energy and improve lighting quality and performance in comparison to many conventional lighting technologies. However, in order to accurately gauge the full energy and environmental impacts of any lighting product, its materials and energy resources must be evaluated over its entire life-cycle.

The U.S. Department of Energy (DOE) conducted a three-part study to assess the total life-cycle impact of LED screw-based replacement lamps in relation to two comparable lighting technologies traditionally used in residential homes: incandescent lamps and compact fluorescent lamps (CFLs). This life-cycle assessment (LCA) study considers not only use, but also manufacturing, transport, and disposal, and is the most comprehensive study of its kind for LED products, breaking new ground in our understanding of how lighting affects the environment. The full reports for all three parts of the study are available online at www.ssl.energy.gov/tech_reports.html.

General Life-Cycle Stages of a Product or System (Part 1 report)





Part 1: Review of the Life-Cycle Energy Consumption of Incandescent, Compact Fluorescent, and LED Lamps (February 2012)
Compared the total life-cycle energy consumed by these products, based on existing LCA literature.

Part 2: LED Manufacturing and Performance (June 2012)
New LCA that provided more detail on the LED manufacturing process and evaluated a variety of environmental impacts in addition to energy use.

Part 3: LED Environmental Testing (March 2013)
Disassembled and chemically tested product samples to determine whether potentially toxic elements are present in concentrations that exceed regulatory thresholds for hazardous waste.

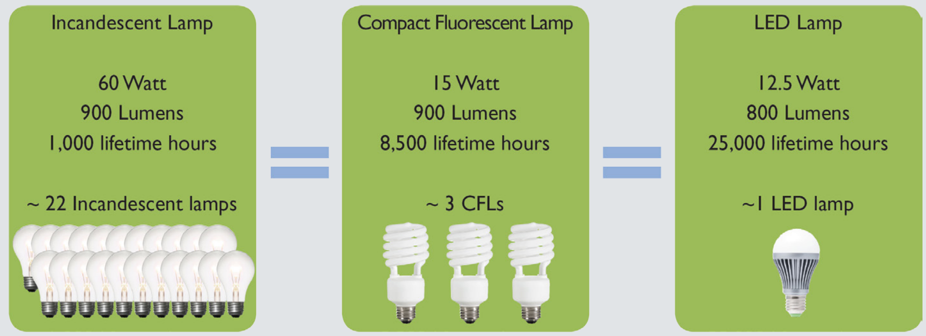
PART 1: Review of the Life-Cycle Energy Consumption of Incandescent, Compact Fluorescent, and LED Lamps

This study was based on 10 existing lighting-product LCAs that included academic publications as well as manufacturer and independent-research reports. It examined three life-cycle phases—manufacturing, transportation (from factory to retailer), and use—comparing the energy consumed and considering how that consumption might change in the future for LED lamps.

Key Findings

- The average life-cycle energy consumption of LED lamps and CFLs was similar, and was about one-fourth the consumption of incandescent lamps.
- If LED lamps meet their performance targets by 2015, their life-cycle energy is expected to decrease by approximately one-half, whereas CFLs are not likely to improve nearly as much.
- The "use" phase of all three types of lamps accounted for 90 percent of total life-cycle energy, on average, followed by manufacturing and transport. Most of the uncertainty in the life-cycle energy consumption of an LED lamp was found to center on the manufacturing of the LED package. Various sources estimated this at anywhere from 0.1 percent to 27 percent of life-cycle energy use.

Number of Lamps Needed to Reach Equivalence to 20 Million Lumen-Hours (Part 1 report)



The three lamp types considered in Part 1 are not equivalent in terms of their lumen output and lifetime. So in order to compare apples with apples, 20 million lumen-hours of lighting service was used as a functional unit, with life-cycle energy estimates multiplied by the number of lamps needed to reach this value.

PART 2: LED Manufacturing and Performance

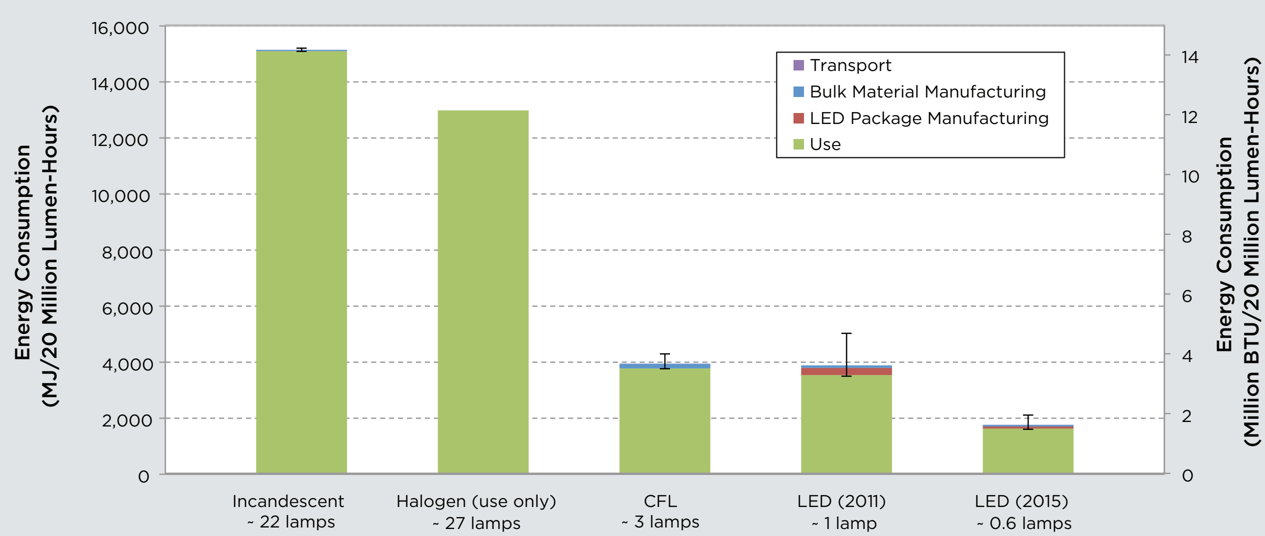
This new LCA study compared the environmental impact of an LED lamp, an incandescent bulb, and a CFL from the beginning to the end of their life-cycles—including manufacturing, shipping, operation, and disposal. In addition, it was the first public study to consider the LED manufacturing process in depth.

The comparison looked at the LED lamp as it was in 2012 and also projected what it might be in 2017, taking into account some of the anticipated improvements in LED manufacturing, performance, and driver electronics.

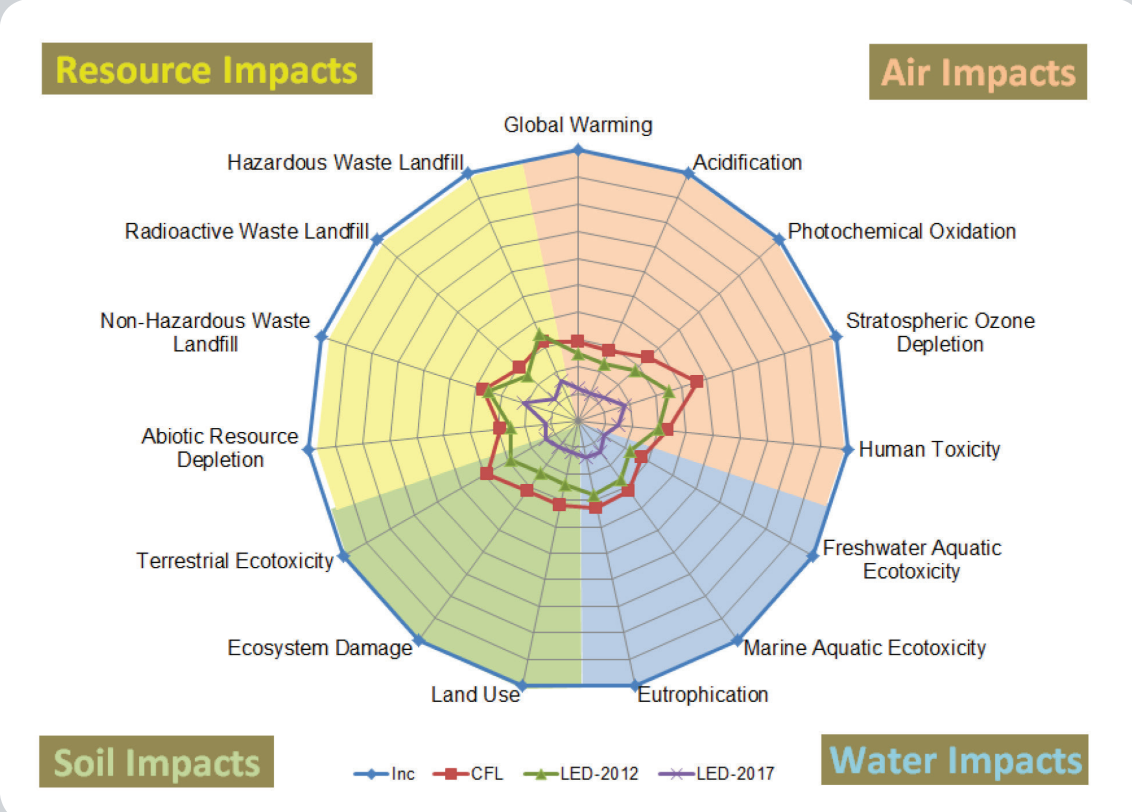
Key Findings

- The energy these three lamp types consumed in the use phase constituted their dominant environmental impact.

Life-Cycle Energy Consumption of Incandescent CFL and LED Lamps (Part 1 report)



Life-Cycle Assessment Impacts of the Lamps Analyzed (Part 2 report)



In order to evaluate the 15 impact measures of interest across the four lamps considered, "spider" graphs were prepared. Each category is represented by a spoke in the web, and the relative impacts of each lamp type are plotted on the graph. The lamp type having the greatest impact of the set analyzed (incandescent, in this case) defines the scale, represented by the outer circle at the greatest distance from the center of the web. The other products are then normalized to that impact, so the distance from the center denotes the severity of the impact relative to the incandescent lamp.

- Because of its low efficacy, the incandescent lamp was found to be the most environmentally harmful of the three types of products, across all 15 impacts examined in the study.
- The LED lamp had a significantly lower environmental impact than the incandescent, and a slight edge over the CFL.
- The CFL was found to be slightly more harmful than today's LED lamp on all impact measures except hazardous waste landfill, because of the LED lamp's large aluminum heat sink. As the efficacy of LED lamps continues to increase, aluminum heat sinks are expected to shrink in size—and recycling efforts could reduce their impact even further.
- The light source that performed the best was the LED lamp projected for 2017, whose impacts are expected to be about 50 percent lower than the 2012 LED lamp and 70 percent lower than the CFL.

PART 3: LED Environmental Testing

This study focused on end-of-life disposal and involved the disassembly of lamps, using standard testing procedures from the U.S. Environmental Protection Agency and the State of California to see whether any of 17 potentially toxic elements were present in concentrations exceeding regulatory thresholds for hazardous waste. A total of 22 samples, representing 11 different models, were tested.

Because the lamps examined in the study were ground up as part of standard test procedures, thereby exposing encapsulated materials, the results represent a worst-case scenario for the elements in question leaching into groundwater from these lamps.

Key Findings

- The selected models were generally found to be below restrictions for Federally regulated elements.
- Nearly all of the lamps (regardless of technology) exceeded at least one California restriction—typically for copper, zinc, antimony, or nickel.
- Examination of the components in the lamps that exceeded these thresholds revealed that the greatest contributors

were the screw bases, drivers, ballasts, and wires or filaments.

- Concentrations in the LED lamps were comparable to concentrations in cell phones and other types of electronic devices, and usually came from components other than the LEDs themselves.

CONCLUSIONS

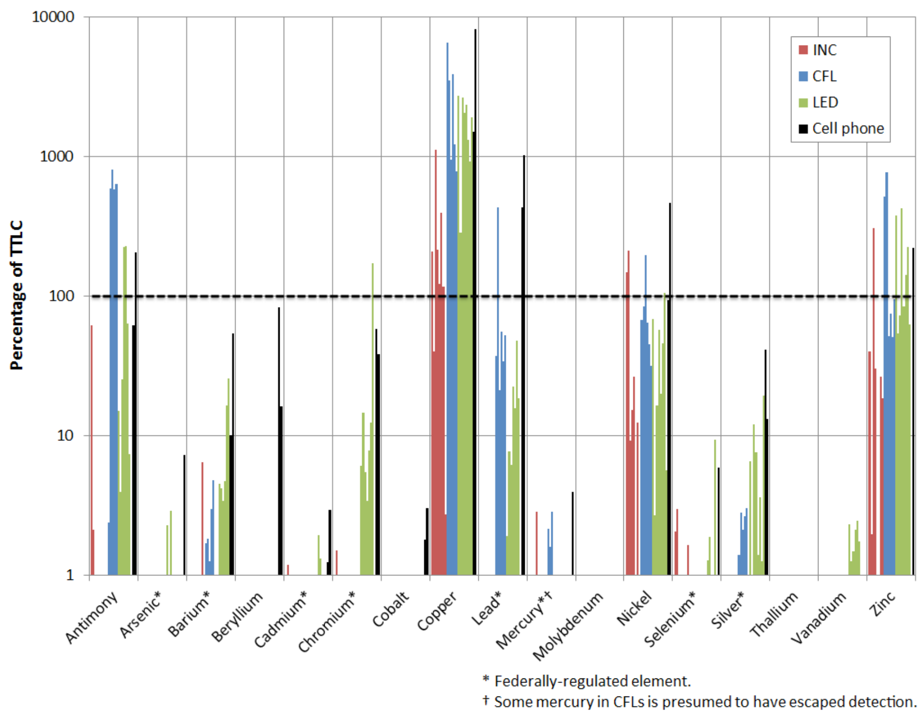
The energy that incandescent, compact fluorescent, and LED products consume while in use dominates not only the total energy consumed over their entire life-cycle, but also their total environmental impact. Because of this, continued focus on LED efficacy targets and market acceptance is appropriate.

The greatest environmental impact after energy-in-use for the LED sources comes from manufacturing the aluminum heat sink, which would be reduced in size as the efficacy increases and more of the input wattage is converted to useful light (instead of wasted as heat). The heat sink is the main reason the LED currently exceeds the CFL in the category of hazardous waste to landfill, which is driven by the upstream energy and environmental impacts from manufacturing the aluminum from raw materials. Recycling efforts could further reduce the adverse impact of manufacturing the aluminum heat sink.

Far more important than the minor relative differences between the current LED lamp and the CFL is the significant reduction in environmental impacts that would result from replacing an incandescent lamp with a more efficient product. Reductions on the order of 3 to 10 times are possible across the indicators by transitioning the market to new, more efficacious light sources.

Even though the impact of LED lamps over their entire life-cycle compares favorably to CFLs and incandescent lamps, recycling will likely gain importance as consumer adoption increases. Part 2 of the study conservatively assumed minimal recycling and indicated that the recycling of aluminum would be particularly effective in reducing the life-cycle impact of LED lighting products, many of which contain aluminum heat sinks. For many such products, the value of the recovered aluminum might even offset the cost of recycling. The Part 3 findings provide further impetus for lamp recycling, to ensure compliance with stringent regulations for the disposal of hazardous waste.

Percentage of CA Total Threshold Limit Concentration (Part 3 report)



For More Information

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