



Digging Deep: Are CFLs Really Green?

(Yes, and here are some tips to maximize their benefit)

Laurie Ramroth

Rocky Mountain Institute

March 2008

Abstract

This paper addresses the debate over compact fluorescent lamps (CFLs) and incandescent light bulbs (“incandescents”) through life-cycle analyses (LCA). It compares the environmental impacts of providing a given amount of light from incandescents and CFLs for 10,000 hours. Special attention has been paid to recently raised concerns regarding CFLs—specifically that their complex and energy-intensive manufacturing process uses so much energy that it outweighs the benefits of using CFLs, that frequently turning CFLs on and off eliminates their energy-efficiency benefits, and that they contain a large amount of mercury.

The research shows that:

- The efficiency benefits compensate for the added complexity in manufacturing,
- While rapid on-off cycling of the lamp does reduce the environmental (and payback) benefits of CFLs they remain a net “win,” and
- The mercury emitted over a CFL’s life—by power plants to power the CFL and by leakage on disposal—is still less than the mercury that can be attributed to powering the incandescent.

This document concludes with tips on how consumers can maximize the environmental benefits of CFLs by using and disposing of them properly.

Why are CFLs currently such a hot topic?

CFLs and incandescents produce light through fluorescence and incandescence, respectively. Incandescent lighting is dramatically less efficient because 90–95 percent of the energy that goes into an incandescent becomes heat. The typical CFL is four times as energy efficient as a typical incandescent. The efficiency comes with a price: CFLs currently cost three to ten times more. Fortunately, CFLs last ten times longer than incandescents, offering plenty of opportunity for payback with electricity bill savings—due to increased efficiency—over the operation life of the lamp.

CFLs have been on the market since the early 1980s, but they have only recently been touted as a key component in the fight against global warming. The benefits of CFLs have prompted the phasing out of incandescents in several countries. In America, the President recently passed the Energy Independence and Security Act of 2007; this includes a measure for phasing out incandescents.¹² The bill includes efficiency requirements for manufacturers as well as the phasing out of 100 W to 40 W lamps as part of an ongoing program that begins in 2012 and ends in 2014. Performance requirements for manufacturers of incandescents include a 25–30 percent reduction in energy use compared to today’s most common incandescent bulbs by 2014, and a 70 percent reduction by 2020.

Several claims have been made recently challenging the “green” credentials of CFLs—specifically that their complex manufacturing process uses so much energy that it outweighs the benefits, that turning CFLs on and off frequently eliminates their energy-efficiency benefits, and that they contain a large amount of mercury.

In order to address these three concerns, this study compares the greenhouse-gas emissions and toxic releases that can be attributed to lighting a room for 10,000 hours (the assumed rated life of a CFL) with 1,600 lumens of light from a CFL and, alternatively, incandescents. To calculate these emissions, we did life-cycle analyses (explained below) using the software tool SimaPro.

Life-Cycle Analysis: what’s included?

An LCA includes research into three phases of the life cycle of each product:

- The manufacturing and assembly phase
- The operation/use phase
- The disposal phase

The geographic path that the lamps take from assembly to disposal must be included in order to accurately represent the life cycle of a product. We assumed both lamps were made for General Electric (GE) in Shanghai, China and then shipped to the United States, where they were used by consumers in Denver, Colorado and ultimately ended up in a landfill in Aurora, Colorado.³⁴

Using CFLs saves 75% of greenhouse gas emissions over the entire life cycle

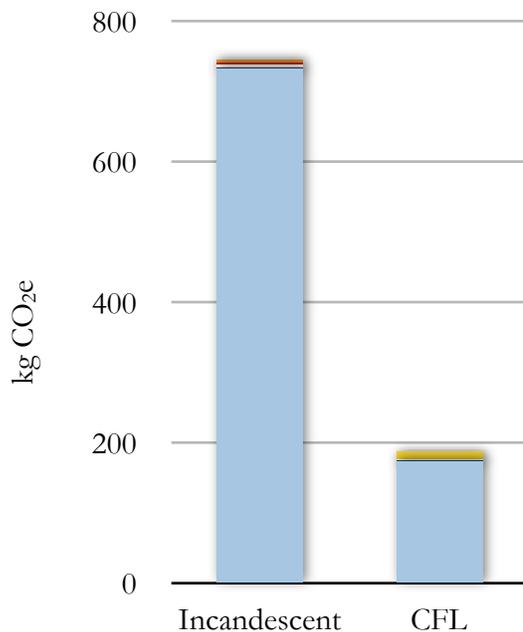
Through the LCA we determined greenhouse-gas emissions related to the creation, use, and disposal of both a CFL and an incandescent. Greenhouse-gas emissions come in several forms: the most common one is carbon dioxide (CO₂), but other gases such as CH₄ and N₂O (both products of burning gasoline and coal) contribute to climate change as well. Each of these gases is given a “Global Warming Potential” multiplier based on the impact it has on global warming over the course of 100 years when compared to the impact one atom of CO₂ has on global warming over 100 years. These units are called carbon dioxide equivalents (CO₂e).

Producing visible light via fluorescence—instead of incandescence—offers dramatic energy-efficiency benefits over the entire life cycle. During the 10,000-hour study period, the CFL would produce 25 percent (184 kg CO₂e) of the greenhouse gases that would be emitted by ten incandescent lamps over the same period (734 kg CO₂e).

Figure 1 shows how different processes in each lamp’s life cycle contribute to the total impact.

Figure 1: kg CO₂e Characterization of 100W Incandescent and 23W CFL Life Cycle

- Printed Board
- Integrated Circuit
- Container Ship
- Electricity Used on Assembly in China
- Gasoline used in Personal Vehicle
- Personal Vehicle Travel from Store to Home
- Electricity Used at the Consumer in USA



For an incandescent lamp, almost all of the greenhouse-gas emissions attributable to the lamp occur during the operation phase. Ninety-nine percent, in fact, come from generating the electricity required to power the lamp at users’ sites, while most of the other 1 percent is attributable to consumer transportation. Ninety-three percent of the CO₂e emissions from a CFL lamp occur during the operation phase, while approximately 7 percent occur during assembly.

During the 10,000-hour period, using a CFL instead of an incandescent saves 191 lbs of coal, and, if everyone in America replaced one 100 W incandescent with a 23 W CFL, 29,000,000 short tons of coal could be saved.^{5,6,7} This would account for 2.6 percent of total 2006 U.S. coal consumption.

But what about the mercury?

The greatest concern of many consumers is the mercury emissions that can occur during the

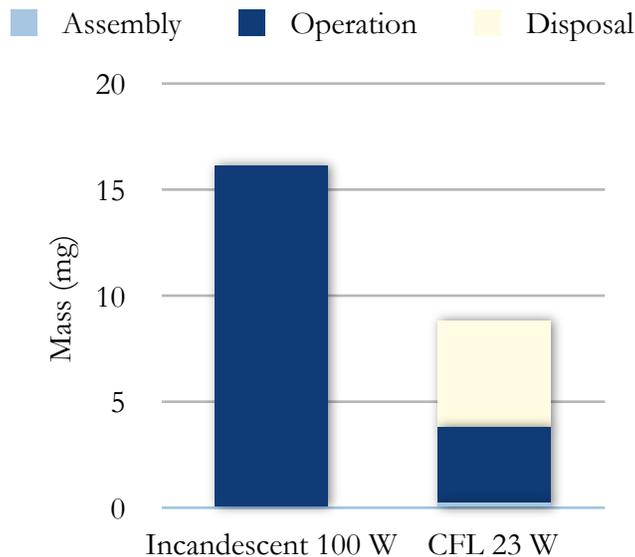
disposal of CFLs. When the gas mixture in a CFL is ionized, mercury is used to produce ultraviolet light. The average CFL contains 5 mg of mercury (an amount roughly equivalent to the volume of the tip of a ball point pen).⁵ In order to fully understand the environmental impact of mercury from CFLs compared to the impact of mercury from incandescents, one must analyze the product over all three phases of its life cycle.

Incandescent lamps are responsible for four times the mercury emissions of CFLs during the operation phase. The mercury emissions produced in the operation phase come from the generation of electricity in coal-fired plants. Coal-fired plants account for ~50 percent of the U.S. electricity mix, and for every kWh they generate, 0.016 mg of mercury is emitted.⁶

Quantifying this in the LCA for the required lumen-hours (1,600 lumens for 10,000 hours), incandescents emit 16 mg into the air during operation while CFLs only emit 4.6 mg.

Another 5 mg of mercury is added to the CFL's total if it ends up in a landfill (the worst case disposal scenario), which brings the total mercury emissions for the CFL to 9.6 mg. This is still 6.4 mg less than what is released when using an incandescent.

Figure 2: Mercury Emissions Over Life Cycle



A CFL saves a significant amount of electricity during the operation phase. Where coal-fired plants play a major role in producing electricity for a given region, the benefits of using CFLs are therefore increased proportionately.

The operating (on/off) cycle: why doesn't my CFL actually last 10,000 hours as advertised?

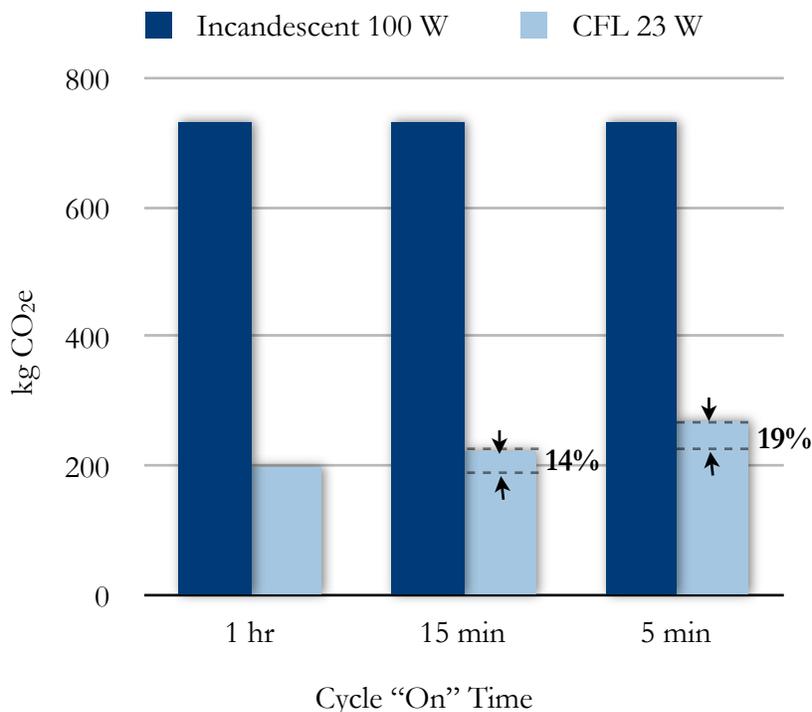
An incandescent lamp's life largely depends on operating voltage while a CFL's life depends on operating cycle.⁷ Put a different way, an incandescent lamp fails when its tungsten filament has evaporated to the point where it breaks, and thus cannot carry a current. A CFL fails due to a loss of emissive coating on the electrode. This loss of coating occurs during operation, but it is accelerated when the lamp is turned on and the electrode is bombarded with mercury ions. A sensitivity analysis was performed on the life span of the CFL to measure the influence of this parameter on the LCA results.

The shortening of a CFL's life, which can come from using them with short operating cycles, is a concern to many consumers who don't want to give up the environmental and economical benefits of using CFLs.

A study published in 1998 examined CFL performance with five different operating cycles. It found that when the length of time the lamps were on was reduced from 3 hours to 1 hour, the lamp lasted for 80 percent of its rated life. When reduced to 15 min and 5 min, the lamp lasted for 30 percent and 15 percent, respectively, of its rated life.⁸

The balance between use-phase CO₂e emissions and assembly phase CO₂e emissions is also different for CFLs and incandescents. CFLs are responsible for a larger portion of CO₂e emissions during assembly than incandescents. Incandescents, however, are responsible for a much greater amount of CO₂e during the operation phase than CFLs. When the life of the CFL is reduced through rapid cycling, the emissions associated with assembly for each additional lamp required increase the CFL's CO₂e emissions over the entire 10,000-hour study period.

Figure 3: Characterization of Lamp Life Cycle Emissions With Varying “On” Times



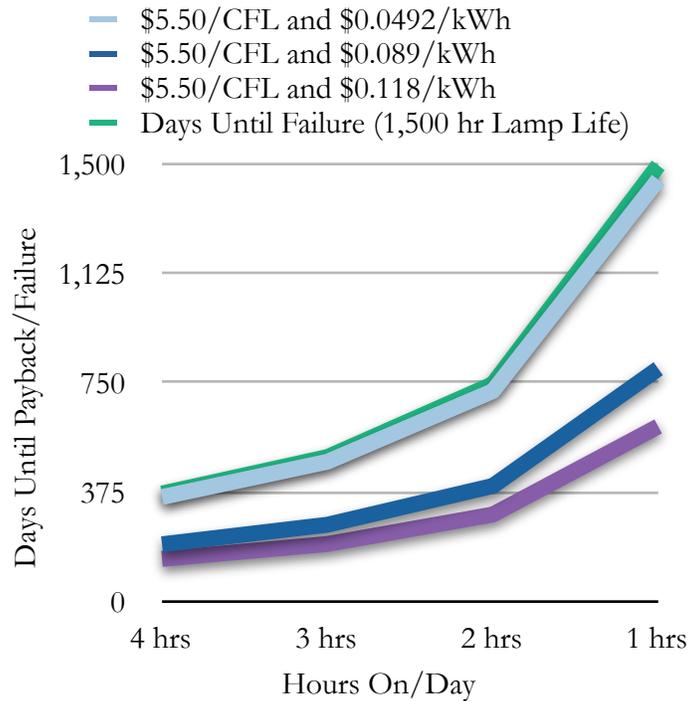
If the cycle time of the light in question is reduced from 1 hour to 15 minutes, then the amount of CO₂e emitted increases 14 percent. If the cycling time is further reduced from 15 minutes to 5 minutes, the amount of CO₂e emitted increases by 19 percent. Even with a cycle time of 5 minutes, CFLs still emit 63.4 percent less CO₂e than is emitted as a result of using incandescents. The environmental impact from CFLs is dramatically smaller than incandescents for all operating cycles.

Even though CFLs with reduced cycle times are still net winners in terms of the CO₂e impact when compared with incandescents, the reduced cycle time will have a more significant impact on the

economic savings associated with CFLs. An incandescent lamp comparable to the one used in this study currently costs \$0.55.⁹ Applying the three-to-ten cost factor, a comparable CFL (similar to the one used in this study) costs in the range of \$1.65–\$5.50. Assuming an on-time of 4 hours/day and a cost of electricity in the range of \$0.0492–0.118/kWh (average \$0.089/kWh), the lamp will always pay for itself in energy savings.¹⁰

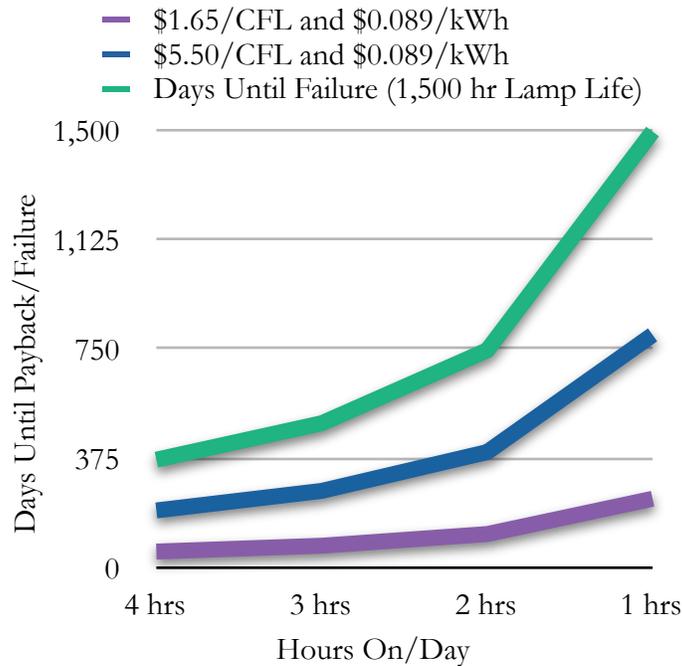
As the cost per kWh of electricity changes, so does the length of the payback period for the CFL. The following graph shows the relationship between payback and cost per kWh. As the cost of electricity decreases, the payback period gets longer. In the worst case scenario—at 1,500 hours of lamp life (assuming 5-minute on-cycles that result in 15 percent of the 10,000 hour rated lamp life) and the cheapest electricity cost—the lamp still pays for itself, but by the smallest of margins.

Figure 4: Dependency of Payback on Cost of Electricity and Failure



There is also a relationship between payback time and the capital cost of the CFL—more expensive lamps, clearly, have longer payback periods. In all scenarios the CFL pays for itself prior to lamp failure.

Figure 5: Dependency of Payback on Cost of CFL and Failure



The ability of a CFL to pay for itself through energy savings decreases as lamp life gets shorter, with low electricity costs, and with high lamp costs. Wal-Mart and Philips are working on initiatives to expand production and bring lamp costs down, which would shorten consumers' payback periods.

Conclusion and Tips

CFLs are typically greener than incandescents. To keep CFLs as green as possible consumers should consider the following tips.

1. Be aware and take advantage of any recycling programs for CFLs in your local area. One website (www.lamprecycle.org) has regulation and recycling information by state. In addition, some retailers such as IKEA offer free take-back programs in which they provide recycling bins in their stores for spent CFL disposal.
2. Be cognizant of operating cycles affect on lamp life. Understand that even if the lamp isn't lasting as long as the manufacturer claims, most likely it is still paying back in energy savings. Furthermore, in applications where the lamp is used for longer cycles (e.g., family room, and kitchen) the greenhouse-gas savings and payback benefits only improve.

Following these tips will result in an improved consumer experience with CFLs and a cleaner environment.

For more detail about this document, including more on methodology, please see our technical paper, "Comparison of Life-Cycle Analyses of Compact Fluorescent and Incandescent Lamps" at: <https://www.rmi.org/sitepages/pid173.php>.

Appendix A: Bibliography

- 1 U.S. News . 2007. "FAQ: The End of the Light Bulb as We Know It." www.usnews.com/articles/business/economy/2007/12/19/faq-the-end-of-the-light-bulb-as-we-know-it.html, January 2008.
- 2 Congress. 2007. "Energy Independence and Security Act of 2007." <http://thomas.loc.gov/cgi-bin/bdquery/z?d110:HR00006:@@D&summ2=m&>. January 2008.
- 3 The New York Times. 1993. "Company News; General Electric Lighting Unit in China Venture." <http://query.nytimes.com/gst/fullpage.html?res=9F0CE4DD133BF93AA15751C1A965958260>. February 2008.
- 4 Colorado Department of Public Health and Environment. 2007. "Colorado Active Solid Waste Facilities," www.cdph.state.co.us/HM/lflist.pdf. February 2008.
- 5 Environmental Protection Agency. 2007. "Frequently Asked Questions Information on Compact Fluorescent Light Bulbs (CFLs) and Mercury." www.energystar.gov/index.cfm?c=cfls.pr_cfls. February 2008.
- 6 Office of Solid Waste and U.S. Environmental Protection Agency. June 1997. "Mercury Emissions From the Disposal of Fluorescent Lamps: Final Report". February 2008. Page 2-8.
- 7 Bullough JD. 2000. "La vita è bella". Lighting Research Center. www.lrc.rpi.edu/programs/futures/LF-LampLife/. February 2008.
- 8 Chen W, Davis R, and Ji Y. 1998. "An Investigation of the Effect of Operating Cycles on the Life of Compact Fluorescent Lamps." IESNA Annual Conference Paper No. 35, 1998. www.lrc.rpi.edu/resources/library/fluorescent.asp. January 2008.
- 9 FOX Electric Supply Company. www.foxelectricsupply.com/content/products/ProductDetail.asp?qsCatID=25520&qsProductNo=GE100A. February 2008.
- 10 Energy Information Administration. 2007. "Electricity." www.eia.doe.gov/fuelelectric.html. February 2008.