The Total Cost of Light: A Predictive Model of Solid State Lighting for General Illumination

PI: Dr. Jim Sweeney   RA: Brad Powley

Introduction

The United States consumed 99.87 quadrillion BTUs of primary energy in 2006[1]. The most recent data show that an estimated 8% was dedicated to artificial illumination[2]. Meanwhile the past five years saw solid state lighting (SSL) technologies improve dramatically. In fact, experts have long predicted that SSL has the potential to double the efficacy (lumens per Watt) of the most efficient artificial illumination in the market today[3]. Renewed interest in energy efficiency focuses policy makers, utilities and technology companies on efficiency improvements to general illumination, including the dynamics of the switch from vacuum tubes to semiconductors.

Background

Much uncertainty exists surrounding this transition: the pace of technological improvement; the rate of cost reduction of key components; the future cost of electricity. All of these influence the total cost of light (TCOL), a factor that greatly influences market penetration in each of the four main sectors for general illumination: commercial, residential, industrial, and outdoor stationary. The term SSL in this research is focused on light emitting diode (LED) technology as distinguished from organic light emitting diodes (OLED), but the model framework will work equally well on an OLED analysis. As another extension, a purchaser of light such as a commercial building owner can use such a model to make lighting decisions consistent with his or her beliefs and preferences.

Other, more complex models have been built to predict the amount of energy that can be saved given different policy scenarios for federal investment in SSL development[4, 5]. These models use a simple payback approach to compute the TCOL and then combine it with demand functions for various markets in order to predict consumer choice. Five years have passed since these studies and SSL commercialization is just beginning.

Rather than take a bird's eye view and aggregate across the entire U.S. lighting market, our model seeks to "fly low" and make a detailed comparison of the TCOL for specific instantiations of SSL technology to its best competition in key lighting markets:

- 4' T-8 fluorescent lighting in the commercial sector
- Edison bulb compact fluorescent lighting (CFL) in the residential sector
- Metal Halide in the outdoor stationary sector

We choose these three technologies because 1) they stand out as the most likely competition for SSL in the years to come, and 2) they are very common in adjacent sectors. For example, if SSL

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[1] Energy Information Administration, *Annual Energy Review 2006,* June 2007, page 3.

[2] Navigant Consulting, *U.S. Lighting Market Characterization: Volume I: National Lighting Inventory and Energy Consumption Estimate*. [Prepared for the U.S. Department of Energy], September 2002, pp 36, 50.

[3] A. Romig, *Statement to U.S. Senate Committee on Energy and Natural Resources*, Albuquerque, N.M., December 2002.

[4] M. Kendall, M. Scholand, *Energy Savings Potential of Solid State Lighting in General Lighting Applications*, U.S. Department of Energy, April 2001. (Arthur D. Little, Inc.)

[5] Navigant Consulting, *Energy Savings Potential of Solid State Lighting in General Lighting Applications*, Building Technologies Program, DOE, November 2003.

can compete well in the commercial sector with T-8 fluorescents, then it is also likely to compete well among the many T-8 fixtures used by the residential and industrial sectors.

First we choose to make the comparison between SSL and 4' T-8 fluorescent lighting in the commercial sector because this market-technology combination accounts for an estimated 18% of the total U.S. commercial share of lumen-hrs (12% of electricity) and 10% of the total lumen-hrs produced[2]. It is also the most challenging of the three comparison technologies due to its low initial cost and very high efficacy. This is likely the last bastion of vacuum-tube technology in general illumination.

Research Question

Given the many uncertainties surrounding SSL, what are the key technological and cost parameters that influence the TCOL in the three key markets? Is it sensitive to discount rate, hours of operation, etcetera? When do we expect it to be more economical than the existing technology? If a manufacturer were to focus on one facet of SSL technology to quickly reduce the cost of light, what should it be?

Proposed Model

With our model, we plan to make various predictions based on industry experts' beliefs. The first is the TCOL as a function of the year of investment. Next is a sensitivity analysis. Finally, we plan to give insight about the key factors that will influence the cost of light for SSL technology in the coming years.

The TCOL breaks down into three cost categories: maintenance, electricity, and capital. The latter two categories contain uncertain components, including:

- Rate of efficacy improvement.
- Rate of lamp cost reduction.
- Rate of power supply [AC to DC converter] efficiency.
- Rate of power supply cost reduction.
- Marginal cost of electricity

We will model each of these uncertainties as probability distributions elicited from industry experts. Dependencies between various distributions, such as the rate of efficacy improvement and the rate of cost reduction, will be uncovered and included. We will test sensitivities to deterministic input parameters. Finally, the outputs of this model will be described probabilistically.