

How Many Steps Does it Take to Change a Light Bulb?
Integrating Higher Efficiency Lamps into the American Consciousness

Environmental Studies Integrative Exercise

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General lighting services (GLS) constitute 19 percent of U.S. electrical consumption. Integration of high-efficiency lighting technologies presents an opportunity to significantly decrease U.S. electricity requirements. This, in turn, will improve energy stability in the face of rising fuel costs and increased shortages. A decreased reliance on coal (and other fossil fuels) in electricity production will also appreciably mitigate emissions associated with climate change, acid rain, and compromised air quality. Seeking to reduce demand in volatile energy markets, Congress passed the Energy Independence and Security Act of 2007 (EISA 2007), which introduced increased efficiency standards for energy use. Title III, Section B of the law initiated a phase-out of low efficiency light bulbs. In the next five years, partisan ideology, misinformation, premature market launch, increased prices, consumer tastes, and an artificially low cost of electricity coalesced into public outcry over ‘banned’ incandescents, delay and debilitated enforcement of the phase-out itself, and limited public acceptance of higher efficiency lamps. Building on marketing case study methodology, this study evaluates methods of incentivizing widespread integration of efficient lighting technology. We then assess barriers revealed by poor market implementation of compact fluorescent lamps (CFLs) as well as resistance to EISA 2007. Our analysis concludes with recommendations for improvements private firms, industry, and policy makers should consider in future policies and programs intended to enhance energy efficiency.

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1. Introduction:

Lighting the 21st Century

Over eight billion lamps illuminated the American indoors in 2010, an increase of more than one billion lamps since 2001 (Navigant Consulting, Inc. 2012a). In the same decade, annual electrical consumption increased by over 325,000 million kilowatt hours (kwh) (EIA 2012a). Interior lighting accounts for approximately 19 percent of electricity consumed in the United States (Navigant Consulting, Inc. 2012a). An additional four to five percent is expended to offset waste heat generated by those same lamps (ENERGYSTAR 2006). General lighting service (GLS)¹ lamps comprise the largest installation base of any kind of lamp in the United States, numbering more three billion in 2010 (Navigant Consulting, Inc. 2012a). General use lighting through incandescent bulbs persists as quite likely the most inefficient use of electricity in the 21st century; 80-95 percent of power consumed by each lamp produces not light, but heat.² These dismal numbers come as no surprise given that Americans today cling to a product that remains essentially unchanged from the first lamp and filament model introduced into the marketplace by Thomas Edison in 1879. Advances since then more effectively improved production and accessibility of bulbs than their actual light output, which remains in the realm of 12 lumens per watt (lm/W) on average (Navigant Consulting, Inc. 2012a). Regardless, the incandescent bulb evolved into the standard at the center of a tremendous global lighting infrastructure. In contrast to its infamy in contemporary energy discussions, in its early history the incandescent light bulb symbolized innovation, equity, and improved quality of life. It endures as the lamp that brought illumination to the masses, affordable light to every household.

Higher efficiency alternatives exist, and have for the better part of a century. Fluorescent lighting emerged in the 1930s and proved successful in commercial and industrial spaces. The unwieldy lamp and its specialized pin fixtures, however, did not suit the market for GLS. In 1980, light bulb manufacturer Philips introduced the smaller, more viable, compact fluorescent lamp (CFL) to the market. CFLs, which are up to 85 percent more efficient than standard incandescent bulbs and last eight to nine times as long, offer marked energy savings, and yet continue to fail to capture the GLS market. A 2010 Energy Information Administration (EIA) assessment of U.S. lighting installations revealed that incandescents held a dominant 72 percent share of the GLS market by volume, and CFL installations accounted for just 27 percent of the

¹ GLS lamps are defined as medium screw-based lamps that are compatible with fixtures traditionally occupied by general use, A-shaped incandescent bulbs (Navigant Consulting, Inc. 2012b).

² Folks in the industry joke that incandescents serve better as heaters than as lamps. Depending on climate, incandescent lamps *can* in fact lessen energy load for heating. However, the cost and impact analyses of cooling buildings against warming them still favor strategies to reduce concomitant heat generation (Lefèvre et al. 2006).

GLS market in the same year (Navigant Consulting, Inc. 2012b). Energy efficiency becomes especially relevant in anticipation of U.S. growth. EIA's "Annual Energy Outlook" predicts a modest but consistent rise in electrical consumption through 2035 in every scenario of economic growth (EIA 2012a). As higher demand inflates fuel prices, the repercussions of a perpetually expanding electrical load will prove increasingly costly. Moreover, electricity production is the single greatest contributor to U.S. emissions, exceeding even the quantity produced by motor vehicles (Environmental Defense 2002). Approximately 70 percent of electricity production relies on burning non-renewable fossil fuels. Electricity consumption in 2010 required 84 million tons of coal, 12 million barrels of petroleum, and 525 million Mcf of natural gas *beyond* what was used in 2001 (EIA 2012). Burning these fuels contributed emissions of an additional 430 million metric tons of carbon dioxide (CO₂), nearly 700,000 metric tons of sulfur dioxide (SO₂), and 282,000 metric tons of nitrogen oxides (NO_x). Byproducts of fossil fuel use not only play a significant role in climate change, they also contaminate air and water sources, producing illness and thousands of premature deaths each year. Coal plants, in particular, release fine particulate matter that produce smog and exacerbate respiratory conditions. They also emit toxic heavy metals such as mercury, cadmium, and trace amounts of uranium, as well as carcinogens like arsenic and volatile organic compounds (VOCs) (UCS 2012). Furthermore, emissions from all plants - and their impacts - are rarely constrained to the location in which they were produced.

Concerns about air and water pollution present significant risks to human health. However, the damage pales in comparison to that associated with climate change. After the 2005 landfall of Hurricane Katrina, the costliest and most destructive hurricane in U.S. history, Americans turned to their government to acknowledge what the United Nations-sanctioned Intergovernmental Panel on Climate Change (IPCC) had concluded a full decade before: that a causal link existed between anthropogenic emissions of greenhouse gas (GHG) and climate change (IPCC AR3 1995). Climate models from the IPCC, Union of Concerned Scientists (UCS), and American Meteorological Association (AMA) predict fewer storm occurrences, but greater likelihood of more extreme wind, precipitation, and storm events arising as a direct result of GHG accumulation. Warming temperatures also portend rising sea levels and storm surges that are likely to cause flooding along the coastal counties (including Great Lakes region) in the United States, within which a reported 53 percent of Americans reside (Glaeser 2011; U.S. Census Bureau 2011). Events of moderate precipitation become rarer and rarer with atmospheric warming, leading to increased risk of fire, drought, and erosion of dry earth. Occasions of precipitation are therefore likely to be more intense and harder to manage (Perera et al. 2012). Hurricane Katrina demonstrated that such storms could happen any year and that combating climate change is an urgent issue.

As energy costs fluctuated wildly in the wake of Hurricane Katrina, George W. Bush signed the Energy Independence and Security Act of 2007 (EISA 2007) into law, sanctioning energy efficiency standards for home appliances, motor vehicles, and buildings, as well as

investments in GHG capture and renewable fuels. EISA 2007 includes a provision for the phase-out of low-efficiency light bulbs over the next ten years. The advantages are clear. Higher efficiency lighting technologies not only reduce overall lighting costs for the average consumer, they also present an opportunity to significantly mitigate growth in electricity demand in the United States, which in turn limits the adverse consequences associated with its production. The EIA's projections regarding future electricity consumption rely heavily, in fact, on the assumption that major strides will be made to improve electrical efficiency; if not, growth in demand will rise at the same rate as GDP (EIA 2012a). American convictions were continuously reinvigorated as populations nationwide experienced climate catastrophes such as those described above. The most damning evidence of all hit the Northeast in the form of Hurricane Sandy, the second most destructive storm in American history, barely seven years after Hurricane Katrina. A Civil Society Institute survey conducted two months after the storm found that 71 percent of respondents representing a national sample agreed or strongly agreed that climate change was to blame for the destructive power of Hurricane Sandy, and that government should take immediate action to address it (Civil Society Institute/Environmental Working Group: Energy, Water and Clean Energy Survey. Dec 2012).

EISA 2007 represents the first comprehensive government policy to affect energy consumption across several sectors. Our study focuses on measures that specifically target GLS efficiency. The policy's current 2016 standards will effectively eliminate existing incandescent technologies from the market. CFLs, even as they exist today, meet final government output standards, and are undeniably the most cost-effective general use lamp on the market (Navigant Consulting, Inc. 2012b). Ostensibly, they ought to have already naturally supplanted incandescent bulbs. They represent the most sensible lighting option even if reduced electricity bills are a consumer's *only* consideration. The American consumer's priorities, however, extend beyond just the cost of lighting to include concerns surrounding GHG emissions, pollution, health, and climate change, all of which can be improved through higher efficiency lighting installations. The feeble market penetration of CFLs therefore exposes an incongruous distribution in American consumption patterns. Somehow, free market signals are failing to root out the inferior product.

Several barriers contribute to problematic market trends. Imperfect information, lags in technology, consumer tastes, sticker shock, and plain old inertia account partially for the resistance encountered by CFLs and the bulb phaseout. Prices that belie the true costs or benefits of goods and services also distort supplier and consumer decision-making. For instance, electricity prices that do not incorporate health implications due to emissions or research and development (R&D) budgets that do not capture public benefits from innovation both undermine the desirability of CFLs. The difference between the true social value and actual market value of a good is termed an externality. Consumer behaviors in such cases do not accurately reflect their

desires. A June 2007 Fox News opinion poll asked a sample of U.S. voters if they thought the money saved personally in electricity bills and the benefits to the environment justified paying at least twice as much for a CFL compared to a traditional incandescent. Even before EISA 2007, 59 percent of respondents said yes, a belief that is not reflected within the market consumption shares even three years later. Continued demand for incandescent lamps in spite of availability of superior substitutes reveals an inefficient use of energy sustained by what economists call an inefficient market allocation. The story of CFL integration is therefore an ideal case study for understanding how to align market behaviors in order to maximize social benefits. We seek to understand what barriers confronted CFLs to limit their market penetration in the United States and what can we learn from their story in order to recommend strategies to incentivize transitions to higher efficiency lighting technology in the future?

The struggle to understand global climate change is ongoing, but today we know enough to say that comprehensive regulation and other programs that will mitigate emissions will be necessary to prevent catastrophic changes in the Earth's climate and related systems (IPCC 2007). The United States is in a critical position to mitigate these global changes and their consequences. America has a carbon-based economy; our systems of transportation, our agricultural regimes, our lines of industrial production, and our electrical grid all rely on the burning of fossil fuels. While a shift to renewable sources of energy is desirable, it is not possible to replace these carbon-powered systems with renewable ones fast enough to prevent highly damaging and costly climate change. The United State has higher CO₂ emissions per person ratio than every large country in the world except Australia.

Fine particles, especially those released by burning coal, have been linked to aggravated asthma, chronic bronchitis, and premature death. Ozone, produced by nitrous oxide emissions, can increase susceptibility to bronchitis and pneumonia, and inflame lung tissue (Trimble and Rusco 2012). Dockery et al. found statistically significant and robust associations between air pollution and mortality, even after adjusting for smoking and other risk factors (1993). Deaths due to lung cancer and cardiopulmonary disease were positively correlated with air pollution, especially fine particulates, including sulfates (Dockery et al. 1993, Samet et al. 2000).

Government Involvement

The rate at which the atmosphere is polluted with greenhouse gasses is determined in part by the levels of human electrical consumption. Unlike other sectors of electricity use, such as appliances or electronics, lighting technology is fairly uniform and overall efficiency of the lighting sector can be affected by relatively small changes in technology. Efficiency solutions are considered by experts to be a "low-hanging fruit" for reducing emissions, in that the economics of reducing emissions strongly favor improving new technology rather than the wholesale replacement of contemporary systems and technology (Vandenberg et al. 2008) For example, replacing gasoline powered cars with electric ones requires an overhaul of the fuel system-gas

stations and the operations that supply them. Changing the nation's lighting regime requires the entrance of a different kind of bulb that can fit into common sockets into the marketplace, a considerably easier and simple change.

The 2012 *Annual Energy Outlook* is optimistic that efficiency will improve and will help control electrical demand as the U.S. population and economy grow. Efficiency in the lighting sector improves most drastically. The EIA anticipates electrical consumption will decrease by 47 percent between 2010 and 2035 (EIA 2012a). These projections operate under the assumption that the provisions of EISA 2007 are met.

The pressing necessity of emissions reductions to mitigate the damage that will ensue with global climate change is one of the reasons government involvement in electrical efficiency is desirable. In theory, as newer, more efficient technologies develop and surpass old technologies (such as the incandescent bulb) they would push the old technologies out of the market. But as people worldwide are already feeling the effects of global climate change, coordination between government and industry will be needed to stave off catastrophe.

A different type of efficiency engages economists. In examining markets, pareto efficiency denotes the optimal allocation of resources, such that no alternative allocations can make an individual better off without causing others to be worse off. Efficient markets are those that maximize benefits of all transaction participants, and pareto optimal outcomes are the most desirable from a sociopolitical perspective. Ideally, markets arrive at optimal allocations without interference, but most neoclassical economists admit that this is often not the case. Inefficient allocations, or market failures, exist for several reasons: lack of information, externalities, and/or imperfect competition.

Traditional economic theory predicts four outcomes, weighing resource consumption against quality of life. In the first scenario, quality of life improves initially with increased consumption, peaks, and overuse results in societal collapse. In the second, quality of life increases alongside consumption, but reaches a point at which increasing consumption is no longer possible. In this scenario, austerity measures result in a decrease in quality of life, and consumption continues at this lower standard. The third case begins as do the previous two, but rather than embracing austerity measures, quality of life measures peak and then plateau at a top limit. Quality of life and resource consumption remains constant. In the final scenario, quality of life and consumption continue to increase. Technological and structural innovation allows us to continue to increase our consumption and quality of life indefinitely. The only sustainable paths of resource consumption require either very tight management and limitations of resource use and/or major advances in technology. Innovation has long been seen as the protector of our quality of life. When population growth or consumption increases begin to put pressure on our resources, technology is often the solution. It allows us to do more with less, or do so using alternatives. Many energy action policies depend on significant technological improvements that will make energy efficient lighting cheaper, more aesthetically pleasing, and longer lasting. And

it is only with these developments that we can hope to be able to successfully deal with increases in consumption in the face of growing scarcity.

Like many environmental issues, policies and initiatives aimed at improving lighting efficiency have been undermined by politics, economic considerations, and public resistance. This was also true for EISA 2007. Although the policy passed with industry enthusiasm and bipartisan support, the enforcement mechanism was defunded by Tea Party-backed Republican Congressional representatives in 2011. Despite this setback, the policy still went into effect and has contributed to an increasing market share for higher efficiency compact fluorescent light bulbs (CFL) as compared to the lower efficiency incandescent bulbs. Because these bulbs contain mercury and are less efficient than the new LED (Light Emitting Diode) bulbs, experts foresee another transition in the future toward the latter improved technology. The Department of Energy (DOE) has created a program titled the Next Generation Lighting Initiative to incentivize and facilitate the transition to LED lights. In this paper, we detail the history of artificial lighting, emphasizing the social and economic importance of the light bulb to American life. We then explain how major American energy legislations impacted the development and adoption of efficient lighting. We assess the story of the phase-out, focusing on the political drama and the public resistance to CFLs. Based on our evaluation of American social attachment to artificial light, strategies for market implementation, education initiatives, and incentives for the development and application of higher efficiency lamps, we assess the success and failure of CFL market integration, and propose improved strategies for the likely next transition in the lighting market to LEDs.

Methodology

We combine methods taken from the fields of political science, economics, sociology, and psychology to create an approach similar to a marketing case study. We build on methodology taken from Chad Perry's "Processes of a Case Study Methodology for Postgraduate Research in Marketing" (1998). According to Perry, this "methodology usually investigates a contemporary phenomenon within its real-life context when the boundaries between phenomenon and context are not clearly evident" (ibid). Because the ultimate purpose of this study is to discover the elements behind efficient lighting adoption in the face of complex and conflicting factors, we felt a case study marketing approach of EISA would be the most appropriate.

In order to better study the 2007 EISA, we outline the emergence of CFL and LED bulbs and explain the reasons for incandescent resilience. We seek to understand the pressures to conserve energy in the last 40 years in the light of previous major policies and emerging technologies so that we can evaluate the environment that is necessary for the passage of future policies. In addition to describing the technology and development of alternative lighting regimes, this section will focus on federal policy rather than local or state policy. This is due to

our focus on the phase-out of incandescent light bulbs, which can only be effectively implemented on a federal level because there are no customs regulations across state lines and conflicting state laws undermines the efficacy of a phase-out. Our overview of the political history of the energy market leads us to a technical and historical overview of CFL and LED bulbs. We then generate a list of historically used methods created to lead to the adoption of CFLs and evaluate each for their effectiveness, ease of implementation, and cost. From this list, we select the methods that were the most effective or show the most promise with minor alterations for our final suggestion.

We arrive at our conclusion inductively, meaning that our “theory emerges from the data” (ibid). We delve into the case study of the EISA with a focus on the main obstacles faced. The case of the EISA incandescent phase-out was chosen because we believe this case should predict similar results for future phase-outs for predictable reasons. Once we isolate the main shortcomings of EISA, we can use our previously generated list of methods for the CFL adoption to resolve those issues. Unlike Perry’s model, we conclude with more than a marketing recommendation, but with a basic framework for the comprehensive adoption of all similar technologies.

2. The Spark that Came After the Fire:

The Social History of Artificial Lighting

*Early to bed and early to rise,
makes a man healthy, wealthy, and wise.*

- Benjamin Franklin, *Poor Richard's Almanack*, 1735

Before the widespread use of other types of artificial light, people sought illumination at their fireplaces, supplementing that light with homemade candles. An abundantly-lit home signalled wealth and prestige, while a home completely unlit indicated its residents' poverty. Poor Richard's pithy adage at the beginning of this section is not only a maxim discouraging laziness but an acknowledgement that day and night presented a natural work schedule. "To the ordinary American colonist bright light was not worth the candle. The need of more light, that is, was secondary to the cost and inconvenience of providing it" (Davidson 1944). Candles remained practical staples for domestic illumination; the cheapest were made of tallow, grease residue that built up in kitchens (Dillon 2002). Those who could afford to furnished their homes with candles made from beeswax, but even the most "damnable rich merchants' reported in Boston as early as 1663" did so only on special occasions to demonstrate status and affluence, opting for whale oil candles much of the rest of the time (Davidson 1944).

Colonists in coastal parts of the United States encountered what they called "wax myrtle" growing there, "whose berries when boiled down yielded wax for bayberry candles" (ibid). The wax yield was small compared to the weight of berries boiled, so the berries were quite expensive for buyers who did not live near a source of the plant. Demand for these better-smelling illuminants proved to be the impetus behind quite possibly the earliest instance of U.S. lighting policy: "Occasionally colonial legislatures had to forbid eager persons from plundering the bushes before the berries were ripe" (ibid). Even when lighting was difficult to acquire, uncomfortable, and inconvenient to use, it still played a primary role in the life of the individual, as well as in the culture.

Until 1780, not a single development in lighting improved the efficiency of illumination. Candle upon candle had been developed with no drastic increases in quality or decrease in cost. That year, a Swiss man named Aimé Argand patented the first lighting device of higher efficiency, an oil lamp that fed air to the outer and inner surfaces of its wick for a brighter light (Davidson 1944). The lamp "provided illumination equivalent to that of six freshly snuffed tallow candles" and "consumed its own smoke." (ibid). Affluent customers sought out this latest fashion in lighting technology, including several American founding fathers. Argand lamps, however, did not capture the American market. Early models, built of porcelain, bronze, silver, and crystal, were too expensive for general consumption, and even tin models manufactured domestically as early as 1786 "did not win any broad popularity. Absurd as it sounds they gave

too much light” (ibid). Some people found the intensity of the light hurt their eyes and built screens and shades to protect them from lamp light. Additionally, the large lamps easily cast light across an entire room, a novel concept for Americans, who neither needed nor desired so much illumination. Smaller versions of the lamp were more inefficient than a single candle, and so Argand lamps did not prove useful for most American domestic applications. As the methods of providing light were entrenched in the American lifestyle, even considerable improvements were unable to achieve popularity.

John Miles’ “Agitable lamp” saw slightly greater success in the U.S. marketplace. Patented by a Birmingham native in 1787, the new lamp was “more congenial to the common purse and irritable eyes alike” (Davidson 1944). Although it too never surpassed candle use, the Agitable lamp presented a new advantage over the Argand lamp in its portability (ibid). Operating on the same fuels, Agitable lamps contained an enclosed oil reservoir to prevent spills and two small wicks to increase light output. Its popularity in the United States as the second most prevalent lighting device created a more pressing demand for sources of oil. Of the most significant fuels, whale oil remained expensive, and tallow undesirable (except as a last resort), so the focus shifted to the search for cheaper and more available fuels. For consumers who could not afford or tolerate traditional fuels, new fuel sources and blends presented not insignificant risks of explosion and fire that made shifting from candles undesirable (ibid).

Over the following decade, steamboats, railroads, and factories turned to gas to satisfy the need for more intense illumination to establish all-night operations. Gas was not easy to sell to the general public, however. Cost, of course, limited most, but issues about smoke, human error, risk of fire, and reliability revealed themselves as gas use increased. Some affluent households ventured into fitting their homes with gas pipes for lighting, a costly investment in view of the actual installation as well as essential staff for maintenance of equipment and vigilance against spark fires and soot buildup. The simplicity of operation and relative effectiveness of this technology allowed it to become successful in niche markets despite its dangers.

Expectations of lighting quality and reliability changed as gas simplified the illumination of rooms far larger than previous lighting technology could using the same amount of labor. The exhaust from gas light smelled better than that of most candlelight, fixtures could be more permanent, and wax dripping were eliminated completely. Wealthy homeowners and successful businesses saw great advantages in fitting their buildings for gas installations to express luxury and grandeur. It also demonstrated a new kind of demand for interior illumination and the exclusivity it portended. New Yorker Philip Hone wrote of an experience he had on December 30, 1836:

“I went this evening to a party at Mrs. Charles H. Russell’s...The splendid apartments of this fine house are well adapted to an evening party...The house is lighted with gas, and the quantity consumed being greater than common it gave out suddenly in the midst of a cotillon. This accident occasioned great merriment to the company, and some embarrassment

to the host and hostess, but a fresh supply of gas was obtained, and in a short time the fair dancers were again 'tripping it on the light fantastic toe.'" (Hone 1910)

Reliability had never before been an important consideration in lighting technology, but gas installations imparted a sense of dependability. When gas light failed, something was amiss, the oversight in maintaining it an “embarrassment” as Hone remarks above. Cost and impracticality kept gas lighting from overtaking candle use yet. Hone affirms, “Gas is a handsome light, in a large room like Mr. Russell's, on an occasion of this kind, but liable (I should think) at all times to give the company the slip, and illy calculated for the ordinary uses of a family" (ibid). The search for pleasant, cheap, dependable, and bright light continued.

The Entrenchment of the Incandescent Light Bulb

From the very beginning, the incandescent light bulb was created with cost-effectiveness in mind. In early installations, wires were even threaded through gas lines in order to reduce cost of the new system (Brox 2010). When Edison began commercially distributing the incandescent light bulb, the other benefits were immediately apparent. Compared to the gaslights that were popular before, incandescent bulbs give off little heat, lasted about the same 1000 hours, and produced a higher quality of light (about 15-20 lumens/watt) than they do today (Brox 2010, Descottes 2011). Incandescent lights were especially attractive for manufacturing businesses. Because machines are more economical when constantly running, electric lighting extended the workday, increasing both employee productivity and output. Edison and his electric bulb “fully established the three shift day and [was] the final erasure of natural times in the factory (Brox 2010).” Incandescent bulbs are also considerably safer than the alternatives, most of which were oil- or gas-based, and proved themselves to be considerably more reliable.

The early days of incandescents were not all glamorous. The first residential installation, in the Madison Avenue home of J.P. Morgan, required an expert engineer to be on duty at all times of the system’s operation. The generator was noisy, odorous, and at one point even caused an electric fire. But despite these early setbacks, the light bulb became a symbol of 19th century innovation and progress at the World’s Columbian Fair Exposition in Chicago in 1893.

At the fair, 200,000 incandescent bulbs lined the “White City,” as the grounds of the Exposition were called. The spectacle dazzled 19th century eyes and created a “dream city... without the burden of reality” (Brox 2010). Electric light soon became the symbol of modernity and in the next few decades spread from the cities into the suburbs. By the 1920’s, most of America was electrified except for city slums and rural areas, branding these areas as filthy and uncivilized. Farming families soon grew resentful of their absence of electricity and felt as though it inhibited them from being part of the greater society.

It was not until Franklin Delano Roosevelt’s 1933 New Deal that electrification was seen as a right of American citizenship. The Tennessee Valley Authority was created to relieve the impact of the Great Depression along the Tennessee River and its tributaries – with a special

emphasis devoted to lighting the darkest part of the United States. Roosevelt saw electricity as a way to modernize rural areas and strengthen community ties. The battle against the Great Depression was fought with the light bulb as a weapon. Government and industry cooperated on the grand projects that electrification and illumination required, such as the construction of the Hoover Dam. Such hydroelectric and other energy projects ran parallel to rural electrification programs, creating employment opportunities as American lives changed due to the incandescent bulb. As a result of these policies, Americans began to conceive of the right to light as “the basic assurances of our social system” (Davidson 1944). This normalization made artificial lighting less an indicator of wealth in the United States. The incandescent bulb began to become common and iconic.

Marginal improvements on the incandescent bulb were made after its first debut. A change to tungsten filament from the original carbon, stronger glass, and brighter light were among the major improvements. Incandescent bulbs continue to dominate the home market. It wasn't until the volatility of energy prices in the last half of the 20th century that the incandescent's leading role was finally challenged.

3. Pathways to More Efficient Lighting Regimes:

The Arab Oil Crisis as a Catalyst for Policy and Efficiency.

Although for first half of the 20th century the US produced most of its own energy, oil imports began growing in the late 1950's. Increasing demand and reduced production led to a dependency on foreign imports. The problems with foreign oil dependence came to a head on October 20, 1973 when the Arab members of OPEC (Organization of Petroleum Exporting Countries) cut off the US oil shipments for five months as punishment for supporting Israel during the Yom Kippur War. These energy shortages brought reforms in 1975 in the form of corporate average fuel economy (CAFE) standards for new cars, incentives for domestic energy production, and a Strategic Petroleum reserve. In 1977, Jimmy Carter convinced Congress to create the Department of Energy and promised to reduce America's dependence on foreign oil with funding for energy efficiency with renewable energy research and development through the National Energy Policy Act of 1978. Unfortunately, this progress was halted in the Reagan years with falling energy prices compounded with the slashing of funds for energy efficiency and conservation programs. A haphazard attempt to restore Carter's policies came in the form of a non-regulatory approach with Clinton's 1992 Energy Policy (Mantel 2006).³ The rising energy prices of the 2000's led Congress to pass a more comprehensive Energy Policy Act of 2005,

³ Some environmental advocates cite the 1992 Rio Earth Summit as a meaningful turning point in America's political action on energy initiatives. Although American rhetoric suggested action, no lasting, meaningful action resulted at the summit and so we will not go into further detail about this event. For more information about the United State's failure to deliver on their commitments at Rio, please see <http://www.nature.com/news/earth-summit-rio-report-card-1.10764>

which was then amended into the Energy Independence and Security Act of 2007.

The Development of Compact Fluorescent Light Bulbs

Because of the Arab Oil Crisis, energy became a trendy issue and energy saving alternatives to common household items began to hit the market. In 1973, a General Electric (G.E.) engineer named Edward Hammer invented the design for the modern compact fluorescent light (Humphreys 2008). Researchers at G.E. were aware that fluorescent bulbs could be designed to fit the common light socket, but until the urgent press for efficiency due to the 1973 oil crisis, GE and other lighting companies had not yet patented the CFL. However, the company deemed it a poor investment at the time, and did not follow through with the innovation to bring it to market. Not until 1995 did the helical design by Hammer break into the marketplace (ibid), and sales have been on the rise since then.

Compact fluorescent light bulbs distinguish themselves from the traditional kind of fluorescent bulb by their ability to fit into ordinary light sockets made for incandescent bulbs. Traditional fluorescent bulbs were widespread before the market introduction of compact fluorescent bulbs, but because of their peculiar shape and size, they were integrated mostly into niche markets in the form of long fluorescent tubes common in classrooms and in office spaces. Compact fluorescent light bulbs have been the focal point of the movement to replace current inefficient lighting systems with better ones in the United States. CFL's provide a comparable amount of "soft white" light while lasting much longer (with lifespans of 12,000+ hrs., compared to the 100 hrs. of an incandescent) (Descottes 2011) and using less electricity (~60-100 lumens/watt compared to the 15 lumens/watt of incandescents), (ibid.); however, they cost more initially than the incandescent bulbs they replace (Schubert and Kim 2005). Incandescent light sources are manufactured from relatively common and harmless materials, and they produce light by running electricity through a metal filament sitting within a vacuum. Fluorescent bulbs also create light by sending electricity through metal, but instead this technology relies on vaporized mercury, a toxic chemical. For this reason, the sustainability of fluorescent bulbs relies heavily on our ability to recycle this chemical once the bulb is no longer operational.

Because of the efficiency of these bulbs, conservation advocates were eager to replace incandescent bulbs with them. In order to see this goal to fruition, advocates were encouraged to introduce new technologies primarily in niche markets where there was a clear fiscal benefit for their integration (Mills et al. 1995). These included advertising to commercial buyers who could make bulk purchases, able to afford the high purchasing cost of CFLs and who were willing to invest in order to make savings from efficiency (Mills et al. 1995). This was effective for CFLs to gain some market share, but did not directly affect the large residential market. This is similar to the ways in which the traditional fluorescent bulb was adopted early on in workplaces because their size and shape makes them awkward for home lighting. Consumers have been encouraged to accept the different appearance of new technology; for example, compact fluorescent light fixtures have bulbs of a bizarre helical shape, but perform very similarly to incandescent bulbs

(ibid), providing a softer, whiter light than traditional fluorescent bulbs. To highlight the sustainability of the product, manufacturers and energy efficiency groups coordinated to set standards on this new technology, such as minimum performance requirements for compact fluorescent bulbs. Lastly, taking advantage of energy crises and other incidents that highlight the importance of efficiency and sustainability to help push new technology into the market (ibid). The development of CFLs shows that in order for a new technology to replace an entrenched consumer product, standards of assessment of the new technology must be established across the industry. Highlighting energy crises (such as the developing crisis of global climate change or the issues with U.S. energy security) can also be an important tool in integrating novel technology.

Light-emitting Diodes (LEDs): History & Future

Like CFLs, LEDs were unable to break into the market until the timing was right and the technology was better developed. Basic LEDs were invented in 1907, but the first LED device was not patented until 1961. LEDs were very expensive until the 1970's when small LEDs were successfully marketed for niche applications, including small lights on electronics, car interior lighting, and flashlights (Cheng and Cheng 2006). Once LEDs technology improved to emit brighter lights, they began appealing to wider markets. Today, manufacturers produce high-power LEDs at marketable costs, with low maintenance cost, that can have a lifetime of three to five times longer than fluorescent bulbs. LEDs are also considerably more efficient than fluorescents, and this is the primary reason they are seen as the future of efficient lighting (ibid). Light-emitting diodes (LEDs) are solid-state lights (SSLs) that use a semiconductor to create light of a variety of shades depending on the semiconductor property. Unlike incandescent and fluorescent bulbs, which require an area of trapped gas to function, LEDs can be designed to be very small while creating comparable levels of light. This means LEDs do not require glass fixtures, making them considerably more rugged than alternative lighting sources (Zehner 2011).

The high brightness, low energy usage, and long lifespan of LED light sources are some of the reasons LEDs have been touted as a technology with the potential to take over the market of general illumination, including interior lighting (Craford 2005). The 2012 winner of the Phillips L Prize, a prize given to the most efficient, longest-lasting lighting technology that could replace the incandescent or CFL bulb, was a solid-state (LED) light that was six times more efficient than an incandescent bulb and one and a half times more efficient than a CFL (90+ lumens/watt) with a lifespan of 15,000+ hours (DOE Life-Cycle Assessment 2012) The manufacturing cost of LEDs has been dropping consistently since they first entered the market. LEDs have been touted for their ruggedness; indeed, one of the early niches LEDs filled in popular consumer markets was the flashlight, in part for this reason (Steigerwald 2002). Many claim LEDs are more environmentally friendly because they do not contain mercury like CFLs. However, LEDs do require rare earth minerals including cerium, europium, gadolinium, lanthanum, terbium, and yttrium for their production (Wilburn 2012), the mining and recycling of which is very much in question by environmentalists and economists. Furthermore, LEDs

production requires a variety of chemicals toxic to humans and natural systems, including arsenic, copper, lead, iron, and silver (Lim et al. 2011). Some experts believe that a widespread integration of LED technology could result in environmental issues unless policy-makers and manufacturers take steps to limit the levels of these toxins and create robust recycling systems for LEDs (Jo 2013).

Market experts expect that LEDs will be able to achieve greater market penetration in the future in a similar fashion to the ways in which fluorescent bulbs overtook incandescents, by focusing on specific niche markets in which the particular technology of LEDs give them an advantage over other lighting technologies (Goulding et al. 2009). As LEDs surpass other feasible lighting alternatives in lifespan, they may be well suited for buildings in which replacing light fixtures would either be very difficult (in the case of sports facilities with high ceilings) or disruptive to the functioning of the building's operation (as in the case of hospitals). LEDs are also particularly suited to highly specialized lighting needs, such as aimed (rather than flood) lighting and colored light fixtures, as the LEDs can easily be manufactured to create such light. However, even with their higher efficiency and long lifespan LED light sources designed for general illumination are prevented from greater market penetration because of cost barriers relative to incandescents and CFLs (Zehner 2011).

Because of their efficiency, ruggedness, small size, long lifespan, ruggedness, and the lack of mercury, LEDs are a clear next step in energy technology in the United States. Because of the low upfront cost of incandescent bulbs and America's strong attachment to a bulb, government and private institutions must intervene to promote change. Incentivizing a shift in the way that our country lights our homes, offices, businesses, and academic institutions can occur with either a carrot or a stick. LEED, ENERGY STAR®, and other awards represent opt-in programs that are either governmental, quasi-governmental, or private in nature. Legislation, like EISA, forces cooperation through efficiency standards and enforcement. In the following sections, we discuss the various governmental and non-governmental approaches to incentivizing efficient lighting.

Energy Policy Act of 1992 and Governmental Opt-In Programs

The clear benefits of CFLs and LEDs over incandescent bulbs led the government to take action when public pressure mounted to address rising energy prices. The first government action relating to efficient lighting came in the Clinton administration's Energy Policy Act of 1992. The bill indirectly tackled the inefficiency of lighting by establishing new energy efficiency building standards and created ENERGY STAR®. ENERGY STAR® is the joint program between the Department of Energy (DOE) and the Environmental Protection Agency (EPA). This voluntary labeling program was intended to demonstrate the potential for profit in more energy efficient products. The ENERGY STAR® seal on various products from computers to air conditioners signifies to the consumer that the product uses about 20 percent-30 percent less energy than required by federal standards (EPA 2013a). ENERGY STAR® also certifies buildings and plants

that use less energy and cost less to operate than average buildings. An ENERGY STAR® qualified LED bulb must meet several key criteria, including an energy usage of 5W or less, an operating frequency of at least 120Hz, and a warranty covering repair or replacement for at least three years from purchase (EPA 2013b). The standards and warranty that the seal represents creates a sense of confidence in new products for consumers.

Economic theory underlies consumer preferences for sustainable products. According to a 2000 Gallup Poll, 89 percent of Americans made changes to their lifestyles over the previous five years to try to live more “green” (Jones 2008). The ENERGY STAR® program takes advantage of this increasing American eco-consciousness in part by capitalizing on a phenomenon coined by economists Steven and Alison Sexton as “conspicuous conservation” (2011). This idea stems from Carleton Alum Thorstein Veblens’s concept of “conspicuous consumption” where individuals feel compelled to purchase luxury items to bring themselves prestige and exclusivity. Conspicuous conservation, on the other hand, compels people to pay more to be perceived as environmentally friendly. The Sextons bring up the example of the Toyota Prius, which has a unique and easily recognizable design that identifies it as a hybrid vehicle. For this reason, the Prius sells better than other equally priced hybrids with a less distinct design. The Sextons also suggest that conspicuous conservation may be a valuable tool in improving social welfare and environmental goals. They state “that private actions can substitute, to some extent, for government policies to yield social-welfare-improving environmental outcomes” (2011). ENERGY STAR®, LEED (Leadership in Energy and Environmental Design), and similar programs provide a social incentive to pay more to be perceived as environmentally friendly, and so are good tools for incentivizing LED lighting.

Lessons from ENERGY STAR® have been adopted to encourage builders and owners to adopt more efficient energy technologies to gain recognition from an increasingly eco-conscious society. The most prominent example, headed by the United States Green Building Council (USGBC), is the Leadership in Energy and Environmental Design (LEED) program founded in 1998 to provide architects, contractors, building owners, and operators with a framework for practicing green building design, construction, and operation. LEED Certification has developed as a prestigious symbol of commitment to sustainability and environmental conservation. In addition to this change in attitude, LEED can have a significant impact on the value of certified buildings.

Unlike ENERGY STAR® products, in real estate, the returns on investments in sustainability and energy-efficiency are more clear. CoStar, a leading commercial real estate information company, conducted a study in 2008 in which they found that “sustainable ‘green’ buildings outperform their non-green peer assets in key areas such as occupancy, sale price and rental rates, sometimes by wide margins” (Burr 2008). LEED buildings have \$11.33 higher rent premiums per square foot and 4.1 percent higher occupancy than non-LEED similar buildings. ENERGY STAR® has a \$2.40 higher premium per square foot and 3.6 percent higher

occupancy. ENERGY STAR® and LEED buildings sell for \$61 and \$171 more per square foot, respectively, than their peers (Burr 2008). This indicates that people do value energy efficiency and sustainability, and proves that green buildings and efficient technology are good investments.

The US Environmental Protection Agency (EPA) and ENERGY STAR® have created a Green Lights Program designed to address concerns about the environmental and economic costs of lighting (Hoffman 1992). This program emphasizes the use of energy efficient fluorescent systems, reflective surfaces to maximize light availability, and turning off lights when they are not in use to reduce energy consumption. The Green Lights Program is a voluntary initiative “aimed at promoting energy efficiency through investment in energy-saving lighting” (EPA 2011). By emphasizing the opportunity for lighting to be an asset rather than part of overhead, this program has allowed organizations to earn a return of 30 percent or more on their investment in energy-saving lighting through reduced electricity bills. Hospitals, schools, utilities and various government programs have already signed a standard Memorandum of Understanding with the EPA. Organizations such as these that choose to commit to the Green Lights program are able to reduce their lighting costs, improve the quality of light, and increase worker productivity (Dazor Manufacturing Corp. 2013).

This history illuminates the ways in which crises scenarios can spur government and industry cooperation in pushing efficiency measures into the marketplace. While global climate change is not presented by the media as a “crisis” in the same way the oil crisis of the 1970’s was, and it does not yet have the quantitative impact that “pain at the pump” causes, this may change in the future. Efficiency advocates in the government, non-profit groups, and the lighting industry must be prepared to take advantage of the impending problems global climate change and U.S. energy security considerations could create to help them introduce new technologies to the market.

Government Investment in Lighting Technology Research and Development

Government investment in the research and development of lighting technology has been a major force in bringing us much of the efficient technologies we have today, and it promises to help move us to a more efficient future. Though Thomas Edison’s innovation laboratory managed to perfect the first marketable incandescent light bulb design unaided by government money, (Chesbrough 2003) many of the breakthroughs in early electrical design and research were supported by government funds (Granovetter and McGuire 1998). The research and development of fluorescent bulbs, both compact ones and other designs, have been supported by government funding initiatives, particularly after the Arab Oil Crisis (Miller 2012). Programs financed National Science Foundation and the Department of Energy have helped support lighting technology research in order to create a more energy efficient America, leading to widespread benefits (ibid). Indeed, one study (Geller et al. 1987) estimated that as of 1987, if the U.S. economy operated with the same energy intensity it did only 14 years earlier, 1973, the United States would have been spending \$150 billion a year on energy, and needing to import 4

times more oil, and points out government initiatives have been on the front lines in the battle for increased efficiency. In terms of lighting in particular, the study estimated that from 1976 to 2001, the investment of \$5 million the federal government made in efficient lighting technology (specifically, solid state ballasts for fluorescent lights) research and development created a return of \$25 billion, a return on taxpayers' investment of 8,000 to 1.

Light-emitting diodes and other solid-state lighting systems have always been seen as having high potential for a wide variety of applications as they can create very bright light in different shades of color while taking up little space and energy. For this reason, the U.S. Government has invested significant amounts of research and development funding in this sector, and may plan to invest even more (Brodrick and Christy 2004). In 2003, the Department of Energy initiated a national research and development program designed to accelerate the progress of solid-state lighting technology so these efficient systems could be designed and replace existing technology in the marketplace, helping secure America's energy future and position as a world technological leader. This policy paper (ibid) suggests that government investment in lighting research and development is a good investment in terms of the amount saved on electricity as well as the economic growth these technological advancements can produce.

Through workshops with industry representatives, this initiative hopes to advance solid-state lighting technology research along 6 primary pathways: quantum efficiency, longevity, sustainability, control, packing, infrastructure, and cost reduction. The last of these is perhaps the most important area of research in solid-state lighting research. According to the Department of Energy, research into the manufacturing, processing, and monitoring of solid-state lighting is needed in order to bring prices of these lights down to where they are competitive with existing technology for general illumination (DOE 2013). A combination of grants and prizes for innovation are part of the way this is being accomplished. However, there exists today a significant price gap between solid-state lighting technology and that of other less efficient, shorter lasting technologies, and further cooperation and support between government groups and industry R&D must continue or even increase to create a more efficient America in a timely manner.

Department of Energy and Solid-State Lighting Marketing Support

The Department of Energy (DOE) has applied considerable resources to not only developing lighting technology (as in their R&D Initiative mentioned earlier) in and of itself, but also strategizing the pathways new technologies must take to replace the old in the marketplace. The U.S. The DOE's May 2011 Strategic Plan states, "...the Department needs to cultivate the entire technology innovation chain, from enabling discoveries to research, development, demonstration, and deployment...In later stages of innovation, we must leverage our resources with those of the private sector to move promising technologies from the laboratory to the marketplace." This is a continuation of the policies that the DOE has been implementing in order

to further CFL market penetration for over a decade. In 1999, the DOE began to work with the Pacific Northwest National Laboratory to provide support for improving and marketing cheaper CFLs (Miller 2012), and in 2000, the DOE developed standards of efficiency, quality, and performance under the ENERGY STAR® label. These actions prompted energy efficiency advocates and industry groups to create the Program for the Evaluation and Analysis of Residential Lighting (PEARL), which helped ensure that CFLs on the market were indeed meeting the DOE's standards for efficiency, quality, performance, mercury limits, as well as requiring the bulbs be tested by an accredited laboratory and offer a two-year warranty (ibid). These projects set the stage for the grander-scale market introduction that was to follow.

The DOE has taken what it has learned from its successes with CFL market introduction and applied them to the next horizon in illumination, solid-state lighting, the kind of lighting that includes LEDs. A plan called the "Solid-State Lighting Multi-Year Market Development Support Plan" (DOE 2013) was developed by the DOE. The primary goals of this project are to "affect the types of SSL general illumination products adopted by the market, to accelerate commercial adoption of those products, and to support appropriate application of those products to maximize energy savings."

While the DOE acknowledges that it is primarily the role of private sector agents to push these products into the marketplace (ibid), its status as a government agency allows it to bring very valuable attributes to the table. Due to the DOE's extensive SSL development program, the agency has a deep understanding of the technology at hand. Since the DOE is an objective observer of markets, it is in a unique position to disseminate unbiased and accurate technical information about SSLs to consumers that might be skeptical of industry claims. Secondly, the DOE can influence the ways in which federal agencies purchase and use SSL devices to make sure the best choices are made and have a significant impact on the SSL market through these purchases. Third, since the DOE is not a direct market actor in the sense that it does not manufacture or advertise this technology, it is in a position to lead industry, and indeed has already been endorsed by the illumination industry to develop industry standards and test procedures for general illumination SSLs. Lastly, the DOE can partner with a wide range of groups, including nonprofits, the utilities industry, state agencies, and trade organizations that influence the rate at which SSL are brought to the general illumination market. This element of the Next Generation Lighting Initiative has been successful so far: the DOE has entered into a Memorandum of Understanding with Next Generation Lighting Industry Alliance in 2005 and 2010, the Illuminating Engineering Society in 2006 and 2011, and the International Association of Lighting Designers in 2008.

These projects demonstrate the remarkable organization and cooperation of powerful forces in the lighting industry and government, and show great promise that these industrial forces are meaningfully united with other groups in striving to make lighting regimes in America more efficient and longer-lasting through solid-state lighting technology. The fact that this

momentum and progress that has been created by the collaboration between government, industry, and other groups in research and development and marketing of new technology should not be lost; indeed, solid-state lighting technology must overcome considerable barriers before it can competitively enter the general illumination market. The Department of Energy, related government agencies, and industry groups must continue to work together at all levels of the development process and be involved in the advancement into the market of solid-state lighting technology.

Economic Theories and Market Shifts

Understanding why government should be involved in the marketplace requires some understanding on how markets function. The economic theory that underlies regulation draws on microeconomics, focusing on incentives at the level of individual households and firms.

Externalities occur when markets fail to incorporate the true social cost or benefit of a product into its price. Positive externalities, such as when individuals seek vaccinations, result in an artificially high price for a desirable good. In other words, the cost imposed on the individual who purchases a vaccine is inflated by not taking into consideration the benefits accrued by society -- or people that would have been infected if that person was not vaccinated. Negative externalities, however, fail to internalize costs or damages done to society. Negative externalities for electricity production, for instance, exist in the form of pollution, land damage, oil spills and, of course, the inevitable decline of our natural resources. Pigouvian taxes aim to capture the external marginal costs or benefits of consumption by levying taxes or subsidies respectively, thereby correcting an artificial market price. Raising a tax, even one that remedies a price distortion, is an unpopular political act in the United States. Even so, a tax credit or subsidy incentivizes some companies to voluntarily adjust their lighting schemes in order to reap the partial credit the policy allowed, reducing negative externalities.

Private Sector Awards and Voluntary Initiatives

The government is not the only source of voluntary efficiency programs and awards. Businesses and educational institutions have also developed programs that reflect growing awareness and support for energy saving practices.

Lighting technology manufacturers and distributors such as Philips, GE, and Home Depot have begun to shift their focus from traditional incandescent light bulbs to more energy efficient alternatives. The ease of access and increased availability from known suppliers may encourage consumers who are hesitant about the shift to energy efficient bulbs. In addition, the general public needs to be informed about the facts of energy efficient products and practices. The Energy Efficiency and Renewable Energy (EERE) office of the US Department of Energy supports workforce development and education projects to promote their “Energy Literacy” initiative. This initiative hopes to focus on essential areas of understanding for all citizens and “presents energy concepts that, if understood and applied, will help individuals and communities make informed energy decisions” (DOE 2012).

Colleges and universities are at the forefront of this movement, both creating research programs and setting examples in their own energy use practices. In the past, people often thought that universities and their buildings were simply vessels for knowledge. Not much consideration was given to the learning environment and what it says about the values being instilled in the students. David Orr, in his book *The Nature of Design*, points out that “buildings and landscape reflect a hidden curriculum that powerfully influences the learning process. The curriculum embedded in any building instructs as fully and as powerfully as any course taught in it” (Orr 2002). In addition, university aged students are absorbing vast quantities of information and forming their opinions on various subjects. Universities have a responsibility to promote an efficient use of energy and the best way to do this is by setting an example and actually implementing these ideals. “More than any other institution in modern society, colleges and universities have a moral stake in the health, beauty, and integrity of the world our students will inherit. We have an obligation to provide our students with tangible models that calibrate our values and capabilities – models they can see, touch, and experience” (Orr 2002).

The University of California at Davis is home to the California Lighting Technology Center (CLTC) whose mission is to “stimulate, facilitate and accelerate the development and commercialization of energy efficient lighting and daylighting technologies”. Innovations by the CLTC have influenced the requirements of California’s Title 24, recommending high efficiency bulbs, occupancy sensors, and dimmers as standards for homeowners (All Star Electrical 2012). UC Davis, in cooperation with the CLTC, has also created the Smart Lighting Initiative, which aims to renovate existing indoor and outdoor campus lighting and reduce overall campus electricity use by more than 60 percent of 2007 levels (UC Davis 2012).

Boston University College of Engineering runs a Research in Smart Lighting program that develops new technologies and applications to “change the way society uses lighting” (Smart Lighting Engineering Research Center 2013). In their mission statement, they declare that they want to “develop a culture of innovation and engage industry to help shape the center’s research and commercialize its results” (Smart Lighting Engineering Research Center 2013). This link to the lighting industry emphasizes their commitment to making their innovations accessible to the wider public. In addition, they have been promoting a shift from metal halide bulbs to LED bulbs in outdoor lighting across campus. They say this “project has resulted in synergy between environmental awareness and operational efficiency” (Smart Lighting Engineering Research Center 2013). The university has begun to extend this shift into interior lighting as well.

The Rensselaer Polytechnic Institute Lighting Research Center (LRC) explores various aspects of lighting- “from technologies to applications and energy use, from design to health and vision” (Lighting Research Center 2013). They focus on various areas of efficient lighting practices from application and design to daylighting, from energy and environment to LEDs. They also collaborate with companies and organizations to “advance specific areas of lighting

research, education, and technology development” (Lighting Research Center 2013). These alliances with private agencies are important in transforming their research into a reality for the general public.

This sort of extensive research and development, along with the successful implementation of many of these new technologies by the institutions that created them, have helped pave the way for a more sustainable energy future. Of course, these are first steps and there is more to be done before a majority of consumers adopt these new technologies. Support for and cooperation with these independent non-profit group both by government and industry agents can help streamline the introduction of more efficient lighting technology by providing more sources of information about these changes to the public, among other benefits.

Energy Independence and Security Act of 2007

The government has not limited its support for efficient lighting technology only through R&D and marketing support, but also by policy implementations. Signed into law on December 19th, the Energy Independence and Security Act of 2007 (EISA) directed federal attention toward enhancing energy efficiency in order to reduce the United States’ energy consumption. In addition to establishing efficiency standards for vehicles, appliances, and new construction, the bill created provisions for the future of lighting technology. Title III, Section B introduced a phase-out of low-efficiency bulbs, beginning with those exceeding 72 watts January 1st, 2012. The phase-out then prohibits the manufacturing or importation of incandescents over 53 watts in 2013, 43 watts in 2014, and 29 watts in 2015. Incandescent bulbs were not specifically a target of EISA, but effectively became a casualty of a policy crafted to eliminate low-efficiency lighting technology. The lamps, which rely on a design that remains virtually the same as when it was introduced in 1879, dispel about 90 percent of the energy they consume as heat rather than light (ENERGY STAR® 2006), and are quite possibly the worst offender when it comes to efficiency.

The EISA also outlined strategies for initiating higher efficiency products into the market, requiring screw-in bulbs manufactured after 2020 to be 3 times as efficient (NRDC 2011) as standard incandescents, and partnering with the Federal Trade Commission (FTC) to design new labeling providing information on light output in lumens, annual operating cost, and light appearance (EISA 2007). In addition to prescribing efficiency standards for general-use lamps, it apportioned \$10 million each fiscal year between 2008 and 2013 to fund national consumer awareness education programs through the Department of Energy (EISA 2007).

Surprisingly, utilities and trade associations stood behind energy efficiency policy, seemingly at odds to their own interest: selling power. The National Electrical Manufacturers Association (NEMA), a long-time proponent of stricter, universally-enforced standards in the electrical market, drafted formal reports in favor of reducing national electrical consumption as early as 1972, in response to oil shocks and wildly-oscillating energy prices (Brown and Koomey 2002). In 1977, NEMA headquarters relocated to Washington, D.C. in order to continue to participate in the conversation regarding regulation of energy and technology, where its leaders

would testify before Congress on multiple occasions in favor of the development and integration of higher efficiency technology as a means of reducing U.S. national energy consumption (ibid). Establishing and enforcing strict industry standards, however, remains the organization's primary initiative, and the greatest advantage for NEMA and other utilities, manufacturers, and energy consortiums is in the fact that a single Federal policy is easier to navigate than the previous confusing medley of state and local policies (Pitsor 2011).

In addition to NEMA support, when the policy was passed in 2007, it enjoyed overwhelming support from others in the industry. Proponents included The Alliance to Save Energy, funded by Exelon Corp and Dow Chemical Co., and the Edison Electric Institute, an association of U.S. shareholder-owned electric companies (Snyder 2011, Rosenstock 2011). Home Depot, seeing opportunity in developing a new product, introduced a home brand of efficient incandescent lights (Cardwell 2011).

Energy utilities also supported the EISA because they believed it would streamline our energy sector. States, Congress, the Department of Energy, and the Federal Energy Regulatory Commission all may create their own energy policies. The complexity and overlap of the system leads to redundancies and contradictions at all legislative levels. A comprehensive, unified energy legislation at the federal level would correct for these inefficiencies. Furthermore, an increase in energy efficiency could increase profit for utilities. Electricity pricing models of utilities are set by dispatch curves, which are graphic representations between variable operating cost and the system capacity available to meet the electricity demand. A utility runs three types of generators, a baseload generator that is always running at the same level, a less efficient intermediate generator which runs for about half the day, and an inefficient peak load generator which only runs for a few hours if at all. The peak load generator is so expensive to turn on and so inefficient once it is running, that the utilities maximize their profit margin by never turning it on at all. The dispatch curve shows that at times of day when electricity demand is highest, the profit margin of utilities is lowest. To smooth out this curve, in other words, to maintain a steady electricity demand, means the highest return for the utilities. For this reason, utilities were willing to support a lighting energy conservation legislation because it reduces the amount of electricity consumed during peak hours, decreases their operating costs, and increases their profit margins (EIA 2012).

The fact that key players in the lighting and electricity industry are willing to work together, and with the government, to design and enforce effective policies is one of the reasons there is great potential for improvement in the United State's lighting regime.

4. Barriers to implementation:

Changing the nature the market of such common, iconic, and necessary products as light bulbs is subject to a diversity of barriers, one of which is political maneuvering. Despite industry readiness, the House voted to delay enforcement of the phase-out until October 1st, 2012, in

response to resistance from consumers because of concerns over light quality and fears that the legislation symbolizes a violation of personal liberties (Cardwell 2011). On December 16th, 2011, Congressional Republicans de-funded the ban until October 2012. Ironically, manufacturers had already made the necessary shifts away from low-efficiency incandescent bulbs (Associated Press 2011) and would not invest to retrofit their machines to produce less efficient bulbs. In a statement to Congress, NEMA vice president of government relations Kyle Pitsor stated “NEMA is particularly disappointed with the House’s adoption of the Burgess Amendment, the reduction in [Advanced Research Projects Agency-Energy] ARPA-E and the failure to place sufficient value on the benefits on energy efficiency” (IES 2012). In this section, we will discuss details of the phase-out delay, the political and media theater that led to the delay, and the context for the unpopularity of CFLs.

Politics as Usual

Although the phase-out passed with hardly a partisan squeak in 2007, by 2010 it had become a hot issue. Perception of the policy shifted from a tactical approach for improving U.S. energy security to an ideological battle over government reach. Personalities like Glenn Beck and others, declared the phase-out an attack of the “nanny state,” even though the policy was signed in during the Bush era (Green 2011). This group found political representation with Michele Bachmann’s (R-MN) Light Bulb Freedom of Choice Act and with Joe Barton (R-TX) Better Use Of Light Bulbs Act that independently proposed to repeal the 2007 legislation. After these extreme legislations died and failed respectively, on June 15, 2011, the House of Representatives passed the Burgess Amendment to the Energy and Water Appropriations Act for the fiscal year 2012 which prohibits funding for the Department of Energy for the enforcement of national energy standards for certain light bulbs. The House of Representatives renewed the Burgess Amendment for the fiscal year 2013 and for 2014. In addition, the 2013 bill reduced funding to ARPA-E by 27 percent, which funds research for many lighting energy innovations (Behrens 2012). The defunding of the phase-out was described by Bloomberg Magazine as “a win for tea party advocates” (Snyder 2011).

Rep. Michael Burgess, a Texas Republican for whom the amendment is named, is a member of the congressional Tea Party Caucus. He has called for the impeachment of Barack Obama for ‘pushing his agenda’ (Epstein 2011) and often pushes for more libertarian policies. When asked about the amendment, Burgess responded that “this is about the consumer driving the market, not the federal government deciding the market.” (French 2011).

Once political ideology caused regulatory uncertainty, some companies did continue to produce 100 watt light bulbs, leaving those manufacturers that comply, including General Electric at a disadvantage (Snyder 2011). However, statements by the National Electric Manufacturers Association, an industry trade group, suggest that most manufacturers have already upgraded their production lines to produce more efficient light bulbs and regardless of the enforcement mechanism, bulbs would follow the phase-out schedule because it would cost

too much to undo the retrofit. This suggests that although a well funded enforcement mechanism may be necessary for some businesses, the large players will cooperate with just the threat of enforcement.

As is often the case, the ideology of politicians is difficult to separate from greater incentives driving their motivations. For this reason, we will explore the more general political climate at the time that the Burgess amendment was passed.

CFLs and Middle Child Syndrome

The Tea Party-led movement delayed implementation of the EISA phase-out partially due to the failure of proponents of lighting alternatives to cultivate consumer support for the phase-out. Like the quintessential middle child, CFLs had to compete with its more popular and established older brother, incandescent bulbs, while still paving the way for its prodigy younger sibling, LED. Three factors contributed most to the slow market penetration of CFLs. First, unresolved technological failures rebuffed many potential early adopters. Secondly, steep prices did the same. Furthermore, the fact that these drawbacks occurred in a market whose product was well-established, cheap, and familiar substitute that made CFLs' integration much more difficult. Several players and circumstances disinclined consumers from embracing the CFL, which suffered from obscurity for nearly two decades after its development in 1976.

Although the CFL was invented in 1976, Phillips introduced their commercial version to the market in 1980 in the form of the Model SL. The public expressed legitimate complaints. The Model SL's bulk made it incompatible with existing lighting fixtures and too heavy for lamps (Miller 2012). The light it cast was harsh and inconsistent. It cost 16 times as much as a standard 100 watt incandescent, and rebates offered to offset initial costs reinforced the impression that the bulbs were overpriced (ibid, Sandahl et al. 2006). Consumers complained of a loud buzzing noise and misrepresentations of the light brightness and quality (ibid). By 1990, after product iterations became smaller and ballasted on the same screw base as incandescents, 50 percent of CFL pioneers reverted to their tried and true incandescents (Goett et al. 1992). After failed first impressions, dissatisfied customers were less likely to repeat the purchase (Grover et al. 2002, Lighting Research Center 2013).

The transition was further thwarted by the times; Americans lived in an energy environment that seemed immune to scarcity. Electricity prices in the 1990s were relatively cheap, especially in contrast to those encountered by the first developers of the CFL in the midst of an energy crisis. The proffered electricity savings hardly seemed worth the cost and inconveniences of CFL technology. Rebate programs varied by region and manufacturer, creating greater confusion for consumers who could not begin to assign the bulbs a value (Sandahl et al. 2006). Further confusion emerged due to unfamiliar efficiency standards displaying lumens rather than watts, and inconsistent language describing the products of different companies.

In the case of the incandescent light bulb phase-out, the willingness of the public to accept the policy was heavily influenced by political discourse and the media. Although we may

not think of the incandescent light bulb as a point of contention amongst political radicals, the public outcry to the light bulb phase-out is surprising. From statements declaring “eco-fascism” to “pointless intrusion on personal rights” (Adams 2012), it seems as though the main push against the legislation has come from the public. There are two main reasons that public outcry was so strong. Either individuals do not like the look of the light produced by CFL bulbs (especially business owners who want to showcase their merchandise in more appealing light) (Green 2011) or they believe that efficiency standards for light bulbs is an overreach of government power.

Misguided individuals made claims like “I have a light-enough carbon footprint...so I can allow myself a lighting splurge (Green 2011).” Furthermore, this group of incandescent light bulb hoarders tend to be misinformed because EISA does not ban all incandescent light bulbs plus it makes exceptions for many kinds of specialty lights. The second group, concerned with government overreach, have also played into the media uproar because only the low efficiency bulbs -- and not incandescent bulbs altogether, are affected. Some of these individuals were confused by varying terminology between manufacturers and so were unable to choose the correct light bulb for their need. Even though CFLs had been commercially available for over 30 years, most people had not had enough exposure to be comfortable with the innovation. A 1992 EPRI study of lighting retailers found that many saw it as a temporary technology that would be replaced by something else within the decade - chain store light dept managers seemed to have no more technical knowledge about the technology than the average residential customer. Northwest LightWise Program evaluation found in 1996 that among retailers who did carry CFLs, over 70 percent were stocked in undesirable shelf location “2 to 3 feet above the floor or in dump bins”. Utilities intervened by incentivising more accessible shelving for CFLs. This lack of exposure let the public vulnerable to misinformation media campaigns.

Ideological barriers to changing lighting technology exist both in the political sphere and also in the minds of many members of the American public, which constitute the market for new lighting technology. Many initiatives can mostly avoid the problems this creates when attempting to integrate more efficient light bulb technology to the markets, such as DOE projects and the efforts of non-profit and industry agents, but some potential strategies necessitate political and public support. Therefore, education and outreach by all lighting efficiency actors should be used to ease the transition to a more efficient American lighting regime

5. Our solution:

All in all, we believe that the DOE’s SSL technology and marketing development program took many lessons from the CFL saga to foster a well thought out project to facilitate the adoption of LEDs. However, it falls short on a few key elements. In this section, we will first outline our assumptions for amendments to the DOE’s SSL program. We then offer suggestions to improve the program, gleaned from the struggle to popularize CFLs.

In order to consider a new policy, the LED must be thoroughly tested. When the CFL was introduced, early adopters were punished for their enthusiasm with a sub-par product. New LED products must make positive first impressions in order to ensure speedy adoption. Secondly, the manufacturers must find value in producing LED lights. If their profit will be diminished by switching over to LEDs, they may not support the policy and thus cause more political strife than otherwise would take place. Finally, the political climate must support appropriate funding and be committed to the idea of energy efficiency. Although the incandescent phase-out proved successful without funding, the government may have lost some of its credibility to pull the same stunt twice. Legislators must agree to the enforcement of such a policy and communicate the benefits to their constituents.

We believe that the DOE must take a stronger stance on disseminating accurate information since that was a pivotal issue in the CFL story. In addition to communicating the facts of policies better to both businesses and consumers, the stigma of government intervention must be reframed and the context of this policy emphasized. The DOE should specifically emphasize the job-creating potential of this policy, energy savings, and the positive impact on climate change.

The DOE should also establish new labeling and testing guidelines to standardize the language across bulbs. The brightness of the bulb should be qualified in terms of what wattage of incandescents and worth (in terms of lifetime savings), rather than cost, should be emphasized. Distributors should be discouraged from using rebates because they cause sticker shock during future purchases, though they should offer guarantees, warranties, troubleshooting, and support services. They should also showcase the technology in retail store displays in clear and standardized packaging (Sandahl et al. 2006). These details would familiarize consumers with the product and ease their discomfort with a new innovation.

There is considerable progress still to be made in the development of affordable SSL technology for many uses, including general illumination. While designing and propagating SSLs for general illumination and other common light sources should remain a primary goal, developers and marketers of SSLs should be creative in applying SSL technology to niche lighting uses. SSLs have great potential to be used in a variety of ways, and as they take up more and more of the overall lighting market, these light sources will get cheaper and consumers will be more aware and accepting of them.

Though LEDs may not be as unappealing aesthetically to consumers as CFLs, it still may be difficult for consumers to become accustomed to the appearance of LED lights. To combat this tendency, advertisers and the media should highlight the performance of LEDs rather than how they look. We do not today know what the light from a marketable general illumination LED will look like, but consumers should be encouraged to be adaptable in accepting this as well, knowing the efficiency benefits they are receiving personally.

The fact that LED bulbs are considerably more rugged than either CFLs or incandescents should be highlighted as their market integration takes place. Since it is possible that for a time LEDs will be more expensive than CFLs, their ruggedness and long life spans must be advertised thoroughly and convincingly in order for consumers to accept them. For example, images that demonstrate how many incandescent bulbs a consumer would have to go through before the LED they may be considering purchasing wears out should be used. Estimates about how much a consumer will save through this new technology should be utilized, along with reminders to consumers that LEDs will have to be replaced considerably less frequently than alternative technologies.

In order to establish consumer familiarity with SSLs, distributors should be encouraged by the DOE to give SSLs preferential placement in places where they are sold, and should be available in commonly frequented locations such as grocery stores and gas stations, as incandescent bulbs were. In-store demonstrations and informational pamphlets can help consumers understand how they can benefit from this new technology. Furthermore, retailers, manufacturers, and energy efficiency advocates should collaborate in creating the source material for these consumer outreach programs in order to ensure that consumers are receiving accurate and standard information about SSL products. Trade fairs and conferences between major players in lighting and efficiency should take place in order to achieve this.

Groups that are viewed as information sources by consumers about lighting should be encouraged to promote SSL technology. These include contractors, building designers, and retailers. Lighting industry representatives can provide educational workshops and informational brochures or mailings to these individuals, who should be encouraged to pass on this knowledge to the consumers with whom they work.

Energy efficiency should be presented as something that all of us should care about. By highlighting the varied dangers that energy overconsumption present to all of us and the threat of increasing resource scarcity, consumers can acknowledge the connected and complex nature of purchasing and energy consumption.

The lighting industry can provide two major services to the consumer during the process of market penetration of SSL technology. First, guaranteeing their product to the consumer will alleviate much of the perceived risk of transferring to a new lighting system. Second, well-advertised and easily accessible troubleshooting and support programs should be used by manufacturers of SSLs and/or other industry groups.

6. Conclusion

Although America's passion for conservation vacillates with energy prices, the importance and desirability of energy efficiency and energy independence should be stressed as energy sources are recognized as scarce and increasingly concentrated in unstable parts of the globe. In addition, growing concerns about climate change require us to conserve energy. In

many ways, lighting efficiency the low-hanging fruit for reducing energy consumption. With wide manufacturer and utility support, as well as promised long term savings for consumers, and \$13 billion a year in potential energy savings for the US, the switch to more efficient lighting promises to solve several problems at once. However, because of the deep connection that Americans share with the incandescent light bulb, this transition must happen carefully. Our suggestions focus on what those specific considerations may be, taking into account what we have learned from the issues plaguing the EISA phase-out.

Because of the limited scope of this project, there are several considerations that we did not have the time to address. First, if cheaper electricity is on our horizon, as advocates of hydraulic fracturing of shale gas reserves maintain, the shift to more energy efficient light bulbs may see a slower adoption. Better information regarding upfront costs versus lifetime savings may make the difference for consumers, but sometimes people do not act as rationally as classic economic theory suggests. Electricity is a classic case of a demand-determined market. Consumers may not pay attention to long term savings or externalities that result from pollution or other energy related environmental degradation. The price of electricity, eroded by subsidies and other distortions, may ultimately be the most important driving factor dissuading consumers from adopting more efficient technology, unless correcting policies or incentives are at work.

These correcting policies, as we know from EISA, often crippling obstacles. The EISA, in the wake of skyrocketing energy prices, was propelled through Congress due to broad political will, but lacked the teeth to keep it relevant in the event of an ideological shift. We believe that the phase-out funding, a casualty of ideological partisanship, could have been avoided with better communication between policymakers and the public as well as better planned introduction of CFL bulbs. These lessons are broadly applicable to other sustainability driven technological advances that compete against established rivals, from electric cars to solar panels. With the proper government institutions in place, desirable opt-in award programs and distinctions, and close cooperation with industry players, these products can be brought to market and adopted by consumers more rapidly than they could without any assistance.

When applying these corrections to the policy, one must keep in mind the change in the political climate since 2007. The Republican party's obsession with small government bred the Burgess Amendment and still remains salient today. As such, today's political polarization is not conducive to the passage of new policies, nor the increased role of government in the implementation of old ones. Confounded with the new production of cheap domestic natural gas, today's political climate may not be one in which funds for a massive educational campaign and government sponsored product adoption scheme is feasible. Given this polarization, the policy that requires the least amount of government spending is the one that will be the most politically viable. However, reducing government spending compromises our suggestion for broad educational initiatives.

In addition to the problem of shifting economic and political conditions, lack of data limited our ability to make decisive conclusions. Because the phase-out has only been in effect for two years, little data exists on the success of the policy in increasing energy efficiency or reducing energy use. Furthermore, it is impossible to isolate the impact that certain factors, like ENERGY STAR® or cheap energy from fracking have had on the adoption of CFLs. The effectiveness of the policy or the extent that any one barrier played a role can be heavily disputed.

Voluntary initiatives are in ways even more difficult to evaluate than government mandates. According to ENERGY STAR®, the program saved about \$18 billion in 2010 electricity bills, though we have not found any independent body confirming this number. Paton points out that “measuring the performance of ENERGY STAR® programs is problematic because program rules do not require participating firms to report data on sales volume for participating projects” (1999). In addition, sales of a product do not necessarily imply that the ENERGY STAR® seal was an important factor for the consumer. For this reason, the reported success of ENERGY STAR® should be taken with a grain of salt.

Similarly, the success of LEED can only be determined by assessing LEED certified buildings. Because the process of LEED certification is notoriously expensive and convoluted, many builders opt to follow their own ethics and construct a sustainable building, but just not certify it with the USGBC. Because data for sustainable non-LEED buildings is unavailable for comparison, we cannot know what percentage of the sustainable building market LEED covers.

Our integrative exercise details the history of artificial lighting and the barriers and implications of the incandescent phase-out in order to inform the cultural and market penetration of LEDs. However, the path to efficient lighting is paved with more than just solid-state lights. Other methods to reduce lighting energy consumption, such as architectural designs and smart building practices that harvest daylight, should be explored. These techniques may benefit from the same voluntary initiatives and government programs that supported CFL technology. While improving efficiency, it is important to encourage conservation as well.

This paper, with its qualitative analysis and large emphasis on context, was written for an academic audience rather than for policymakers. The findings of this paper can be adapted with the use of more quantitative methods to speak to policy makers and influence amendments to future DOE and governmental initiatives. The history of across-the-board cooperation in the research and development, standardization, and market introduction of CFLs by government organizations, industry groups, and other actors is particularly relevant to efforts to introduce SSLs into more diverse markets. The government’s role as not only a patron of technology research but also as a mediator between these diverse interests on behalf of the taxpayer is also especially valuable.

As mentioned previously, our analysis may inform policies that aim to support efficient technologies with established competition. For example, the effort to promote the electric

powered car encounters problems similar to those presented by the incandescent bulb to the introduction of CFLs and LED lights. By reviewing the history and efficacy of certain policies related to automobile regulation, future research can isolate the reasons that the electric car has not been widely adopted in the United States. By analyzing several similar cases, patterns may emerge that inform policymakers about the relative importance of certain marketing and educational strategies.

The threat of climate change and other energy issues necessitates a better understanding of how to bring new efficient technologies to market. The story of the rise and fall of incandescent light is inextricably linked with the history of technological advances, American culture, political theater, and economic theory. By emphasizing education and coordinating programs between government departments and private businesses, promoters will ensure that more efficient bulbs will gain market share as well as social acceptance. Our analysis is limited in terms of the data available to us. Further research on the effectiveness of the phase-out could better inform policymakers. However, by studying the reactions of businesses, individuals, and politicians to the EISA phase-out, we learned how to change America's perception of a sustainable product so that it can compete against an established unsustainable rival.

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Works Cited

- Adams, Cecil. (2012). "Why are Eco-Fascists Trying to Ban Incandescent Bulbs." *The Straight Dope*. 3 Feb. 2012. <http://www.straightdope.com/columns/read/3035/why-are-eco-fascists-trying-to-ban-incandescent-bulbs>
- All Star Electrical. (2012). "Understanding Title 24". All Star Electric Residential and Commercial Electrical Contractor. <http://www.allstarelectric.us/title24.html>
- Associated Press. (2011). "Congress flips dimmer switch on light bulb law". *Trib Live*. 17 Dec. 2012. http://triblive.com/x/pittsburghtrib/news/s_772480.html#axzz2Kvy5FmIO
- Behrens, Carl. (2012) *Energy and Water Development FY2012 Appropriations*. Congressional Research Service <http://www.fas.org/sgp/crs/misc/R41908.pdf>
- Brodrick, James R., and C. Eddie Christy. (2004). "Accelerating the Development of Next-Generation Solid-State Lighting Sources." *Optical Science and Technology, the SPIE 49th Annual Meeting*. International Society for Optics and Photonics.
- Brown, R., C. Webber, and J.G. Koomey. (2002). "Status and Future directions of the Energy Star program." *Energy* 27.5:505–520.
<http://linkinghub.elsevier.com/retrieve/pii/S036054420200004X>
- Brox, Jane. (2010). *Brilliant: The Evolution of Artificial Light*. New York: Houghton Mifflin Company.
- Burr, Andrew C. (2008). "CoStar Study Finds ENERGY STAR®, LEED Bldgs. Outperform Peers." *CoStar Group*. 26 Mar. 2008. <http://www.costar.com/News/Article/CoStar-Study-Finds-Energy-Star-LEED-Bldgs-Outperform-Peers/99818>
- Cardwell, Diane. (2011). "Despite Delay, the 100-Watt Bulb Is on Its Way Out." *New York Times* 16 Dec. 2011.
- Cheng, Y. K., and K. W. E. Cheng. (2006). "General Study for using LED to replace traditional lighting devices." *2nd International Conference on Power Electronics Systems and Applications*. Institute of Electrical and Electronics Engineers (IEEE).

Chesbrough, Henry W. (2003). "The Era of Open Innovation." *SloanSelect Collection Winter 2011: Top 10 Lessons on the New Business of Innovation: 35-41*. MIT Sloan Management Review.

Craford, M. George. (2005) "*LEDs for solid state lighting and other emerging applications: status, trends, and challenges.*" *Proceedings of SPIE*. Vol. 5941. 2005.

Davidson, Marshall B. (1944). "Early American Lighting." *New Series 3(1):30-40*. The Metropolitan Museum of Arts Bulletin.

Dazor Manufacturing Corp. (2013). "EPA Green Lights Program for Energy Efficient Lighting." <http://www.dazor.com/green-lights.html>

Descottes, Hervé. (2011). *Architectural Lighting: Designing with Light and Space*. New York: Princeton Architectural Press.

Dillon, Maureen. (2002). *Artificial Sunshine: A Social History of Domestic Lighting*. London: National Trust Enterprises Ltd.

Dockery, Douglas W., C. Arden Pope, Xiping Xu, John D. Spengler, James H. Ware, Martha E. Fay, Benjamin G. Ferris, and Frank E. Speizer. (1993). "An Association between Air Pollution and Mortality in Six U.S. Cities". 9 Dec. 1993. *The New England Journal of Medicine* 329:1753-1759.

DOE. (2012). "EERE: Energy Education and Workforce Development." *Office of Energy Efficiency and Renewable Energy*. 31 Aug. 2012. US Department of Energy. <http://www1.eere.energy.gov/education/>

DOE. (2013). *Solid-State Lighting*. US Department of Energy Office of Energy Efficiency and Renewable Energy. <http://www1.eere.energy.gov/buildings/ssl/about.html>

EIA. (2012a). *Annual Energy Outlook 2012*. U.S Energy Information Administration.

EIA. (2012b). *Electric Generator Dispatch Depends on System Demand and the Relative Cost of Operation*. U.S. Energy Information Administration. <http://www.eia.gov/todayinenergy/detail.cfm?id=7590>

EISA. (2007). *Energy Independence and Security Act of 2007*. Washington: One Hundred Tenth Congress of the United States of America.

ENERGY STAR. (2006). "ENERGY STAR Qualified Light Bulbs 2006 Partner Resource Guide." *Energy Star*. http://www.energystar.gov/ia/partners/manuf_res/CFL_PRG_FINAL.pdf

Environmental Defense. (2002). "Electricity Generation and Pollution". Nov. 2002.
Environmental Defense Air Quality Fact Sheet.

EPA. (2011). "Green Lights." US Environmental Protection Agency. 15 April 2011. <http://www.epa.gov/region7/p2/volprog/grnlight.htm>

EPA. (2013a). *ENERGY STAR*®. US Environmental Protection Agency. <http://www.energystar.gov/index.cfm?c=home.index>

EPA. (2013b). "LED Light Bulbs Key Product Criteria." *ENERGY STAR*®. US Environmental Protection Agency. http://www.energystar.gov/index.cfm?c=iledl.pr_key_product

Epstein, Reid J. (2011). "Impeach Obama, says Michael Burgess." *Politico*. 9 Aug. 2011.

French, Lauren. (2011). "Michael Burgess' Light Bulb Amendment Passes House." *Houston Chronicle*. 15 July 2011.

Geller, Howard, J Harris, M Levine, and A H Rosenfeld. (1987). "The role of federal research and development in advancing energy efficiency: a \$50 billion contribution to the US economy." *Annual Review of Energy* 12.1:357-395.

Goett, Andrew, Kent Van Liere, and Dan Quigley. (1992). "Customer Acceptance of Compact Fluorescents: Results from a Comprehensive Evaluation of PG&E's Program." *Program Evaluation - Proceedings from the ACEEE Summer Study on Energy Efficiency in Buildings* 7: 7.61-7.74.

Goulding, Charles, Jacob Goldman, and Taylor Goulding. (2009). "The Economic, Business and Tax Aspects of Light Emitting Diode Interior Building Lighting." *Corporate Business Taxation Monthly* 10:31-32.

Granovetter, Mark, and Patrick McGuire. (1998) "The Making of an Industry: Electricity in the United States." *The Law of Markets* 147-73.

Green, Penelope. (2011). "Light Bulb Saving Time." *The New York Times*. 25 May 2011. http://www.nytimes.com/2011/05/26/garden/fearing-the-phase-out-of-incandescent-bulbs.html?pagewanted=all&_r=0

Grover, Stephen, David Cohan, and My K. Ton. (2002). "Saturation, Penetration, Transformation: How Do You Know When a Market Has Changed?" *Program Measurement and Evaluation* 10:99–110.

Hoffman, John S. (1992). "Pollution Prevention as a Market - Enhancing Strategy: A Storehouse of Economical and Environmental Opportunities". *Proceedings of the National Academy of Sciences of the United States of America* 89(3):832:834.

Hone, Phillip. (1910). *Diary of Philip Hone: 1780-1851*. Edited by Bayard Tuckerman. New York: Dodd, Mead and Co.

Humphreys, Colin J. (2008). "Solid-State Lighting." *Materials Research Society Bulletin* 33:459-470.

IES. (2012). "House Votes Down Funding to Enforce Light Bulb Phase Out". Illuminating Engineering Society. http://www.ies.org/LDA/E-newsletter/2012/June/newswire/2012_06-phaseout.cfm

IPCC. (2007). "Climate Change 2007: Impacts, Adaptation, and Vulnerability". Intergovernmental Panel on Climate Change. http://www.ipcc.ch/publications_and_data/publications_ipcc_fourth_assessment_report_wg2_report_impacts_adaptation_and_vulnerability.htm

Jo, Wan-Kuen. (2013). "Photocatalytic Oxidation of Low-Level Airborne 2-Propanol and Trichloroethylene over Titania Irradiated with Bulb-Type Light-Emitting Diodes." *Materials* 6(1):265-278.

Jones, Jeffrey M. (2008). "In the U.S., 28 percent Report Major Changes to Live 'Green'." Gallup Inc. 18 April 2008. <http://www.gallup.com/poll/106624/US-28-Report-Major-Changes-Live-Green.aspx>

Lighting Research Center. (2013). Rensselaer Polytechnic Institute. <http://www.lrc.rpi.edu>

Lim, Seong-Rin, Daniel Kang, Oladele A. Ogunseitan, and Julie M. Schoenung. (2011). "Potential Environmental Impacts of Light-Emitting Diodes (LEDs): Metallic Resources, Toxicity, and Hazardous Waste Classification." *Environmental Science & Technology* 45(1): 320-327.

- Mantel, Barbara. (2006). "Energy Efficiency: Is Enough Being Done to Save Energy?" *CQ Researcher* 16(19).
- Miller, Peter. (2012). "A Brighter Idea: The Untold Story of the CFL." *The Electricity Journal*.
- Mills, Evan, Michael Siminovitch, Erik Page, and Robert Sardinsky. (1995). "Dedicated Compact Fluorescent Fixtures: The Next Generation for Residential Lighting." *3rd European Conference on Energy-Efficient Lighting*.
- Navigant Consulting, Inc. (2012b). *Life-Cycle Assessment of Energy and Environmental Impacts of LED Lighting Products*. DOE.
- Navigant Consulting, Inc. (2012c). *Energy Savings Potential of Solid-State Lighting in General Illumination Applications 2011 to 2035*.
- Orr, David W. (2002). *The Nature of Design: Ecology, Culture, and Human Intention*. New York: Oxford University Press.
- Paton, Bruce. (1999). "Voluntary Environmental Initiatives and Sustainable Industry". *1999 Greening of Industry Network Conference*. Department of Environmental Studies, University of California, Santa Cruz.
- Perera, Elizabeth Martin, Todd Sanford, and Rachel Cleetus. (2012). *Climate Change and Your Health*. Union of Concerned Scientists.
- Perry, Chad. (1998). "Processes of a Case Study Methodology For Postgraduate Research in Marketing." *European Journal of Marketing* 32 (9/10): 785-802.
- Pitsor, Kyle. (2011). "NEMA Comments on ENERGY STAR Program Lamp Specification." Correspondence between Kyle Pitsor, Vice President of Government Relations for the National Electrical Manufacturers Association and Alex Baker, ENERGY STAR Program Director. 9 Dec. 2011. http://energystar.gov/products/specs/sites/products/files/NEMA_Comments_on_Energy_Star_Lamp_Spec_December_2011_Final_0.pdf
- Samet, Jonathan M., Francesca Dominici, Frank C. Curriero, Ivan Coursac, and Scott L. Zeger. (2000). "Fine Particulate Air Pollution and Mortality in 20 U.S. Cities, 1987-1994". 14 Dec. 2000. *The New England Journal of Medicine* 343:1742-1749.

Sandahl, Linda J., et al. (2006). "Compact fluorescent lighting in America: lessons learned on the way to market." *Pacific Northwest National Laboratory*. Operated by Battelle for the U.S. Department of Energy.

Scheidt, Paul. (2008). "The Adoption of Lighting-Class LEDs into General Illumination Applications." CS MANTECH Conference, April 14-17, 2008. Chicago, Illinois, USA.

Schubert, E. Fred, and Jong Kyu Kim. (2005). "Solid-state light sources getting smart." *Science* 308(5726):1274-1278.

Sexton, Steven and Alison Sexton. (2011). "Conspicuous Conservation: the Prius Effect and Willingness to Pay for Environmental Bona Fides". University of California - Berkeley.

Smart Lighting Engineering Research Center. (2013). Boston University College of Engineering. <http://www.bu.edu/smartlighting/>

Rosenstock, Steve. (2011). "Building Energy Codes Cost Analysis Request for Information, Docket # EERE-2010-BT-BC-0046". Edison Electric Institute. 18 Nov. 2011. <http://www.eei.org/whatwedo/PublicPolicyAdvocacy/TFBpercent20Documents/111118RosenstockDoeResidentialBuildingEnergyCodes.pdf>

Snyder, Jim. (2011). "Congress Spares Incandescent Bulbs in Victory for U.S. Tea Party." *Bloomberg*. 17 Dec. 2011. <http://www.bloomberg.com/news/2011-12-16/incandescent-light-bulb-spared-in-u-s-lawmakers-spending-bill.html>

Steigerwald, D. A. (2002). "Illumination with Solid State Lighting Technology." *Selected Topics in Quantum Electronics* 8(2):310-320.

Trimble, David C. and Frank Rusco. (2012). Air Emissions and Electricity Generation at U.S. Power Plants. 18 April 2012. United States Government Accountability Office.

Wilburn, David R. (2012). *Byproduct Metals and Rare-Earth Elements Used in the Production of Light-Emitting Diodes—Overview of Principal Sources of Supply and Material Requirements for Selected Markets*. No. SIR-2012-5215. United States Geological Survey, 2012.

Vandenbergh, Michael, Jack Barkenbus, and Jonathan Gilligan. "Individual carbon emissions: The low-hanging fruit." *UCLA Law Review* 55 (2008): 08-36..

UC Davis. (2012). "Smart Lighting Initiative". *California Lighting Technology Center*. University of California Davis. 16 Nov. 2012. <http://sli.ucdavis.edu/index.html>

UCS. (2012). "Environmental Impacts of Coal Power: Air Pollution." Union of Concerned Scientists.

Zehner, Ozzie. (2011). "Light-Emitting Diodes." In *Green Technology*, edited by Paul Robbins, Dustin Mulvaney and J. Geoffrey Golson, 288-91. London: Sage.

Acronyms

ARPA-E: Advanced Research Projects Agency-Energy

CAFE: Corporate Average Fuel Economy

CFL: Compact fluorescent lamp

CLTC: California Lighting Technology Center

DOE: Department of Energy

EISA 2007: Energy Independence and Security Act of 2007

EPA: Environmental Protection Agency

FTC: Federal Trade Commission

GE: General Electric

GHG: Greenhouse Gas. Emissions associated with increasing heat trapped on earth

GLS: general lighting services, medium screw-base lamps designed to fit into places traditional A-shape incandescents occupy.

kwh: kilowatthour. Measure of electricity consumption.

LED: Light-emitting diode

LEED: Leadership in Energy and Environmental Design

LRC: Lighting Research Center

lm/W: lumens per Watt. Measure of light output efficiency.

Mcf: 1000 cubic feet. A measure of volume describing quantities of natural gas.

NEMA: National Electrical Manufacturers Association

NGLI: Next Generation Lighting Initiative

OPEC: Organization of the Petroleum Exporting Countries

PEARL: Program for the Evaluation and Analysis of Residential Lighting

R&D: Research and Development

SSL: Solid-State Lighting

TVA: Tennessee Valley Authority

USGBC: United States Green Building Council