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An Investigation into Sustainable Lighting

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ABSTRACT

This project aims to inform and determine the most sustainable type of general lighting bulb on the market today. The three leading general lighting technologies currently are the incandescent, compact fluorescent lamp (CFL) and light-emitting diode (LED). A triple bottom line analysis (social, economical and environmental) was performed in order to determine the most sustainable general lighting solution.

It was determined that CFL's are currently the best lighting to use. While it was found that the LED's greatly outlast the incandescent and CFL bulb; there is currently no recycling knowledge or programs capable of handling LED's on a large scale. The CFL, while not as recyclable as the incandescent, is less harmful for the environment depending on how the power is generated during its usage.

As the LED technology develops and a method of recycling becomes available, it will be more beneficial to use LED lighting. The high efficiency and the long life time suggest that LED lighting may be the general lighting solution in the future. However, with the current technology and proper disposal and recycling infrastructure, the CFL is the best option for sustainable lighting in all aspects of the triple bottom line.

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LIST OF ABBREVIATIONS

UBC – University of British Columbia.

SUB – Student Union Building

CFL – Compact fluorescent light.

LED – Light emitting diode.

1.0 INTRODUCTION

The University of British Columbia (UBC) is currently researching and designing a new Student Union Building (SUB) on campus. As UBC constantly strives to be as sustainable as possible, every aspect of the design process is thoroughly being considered to produce a highly sustainable building. This involves analyzing and researching the environmental, social, and economical impacts of the components in the building.

The designers are planning to incorporate as much natural lighting as possible, however many spaces will need to be illuminated by artificial lighting both during the day and night. This report researches and discusses the various aspects to determining the most sustainable lighting options for the SUB when not only considering the usage of the light bulbs, but also the production, manufacturing, and disposal or recycling stages. The energy consumption and ecological footprint of these stages are analyzed together to cover many of the issues and concerns regarding sustainable lighting. Only general purpose lighting, incandescent, compact fluorescent (CFL), and light emitting diode (LED) lamps are considered in this report as they are most commonly used in social applications and commercially available.

2.0 INCANDESCENT LIGHT BULB

The incandescent light bulb has long been the primary source of domestic lighting throughout Canada. However, a green movement in society has resulted in Canada banning the incandescent light in 2012 (Ronald, 2008). This section aims to do a triple bottom line analysis on the incandescent light to determine if a banning of the incandescent light is an appropriate measure to help the environment.

2.1 COMPONENTS

The construction of the incandescent light bulb is rather simple, see figure 1 below.

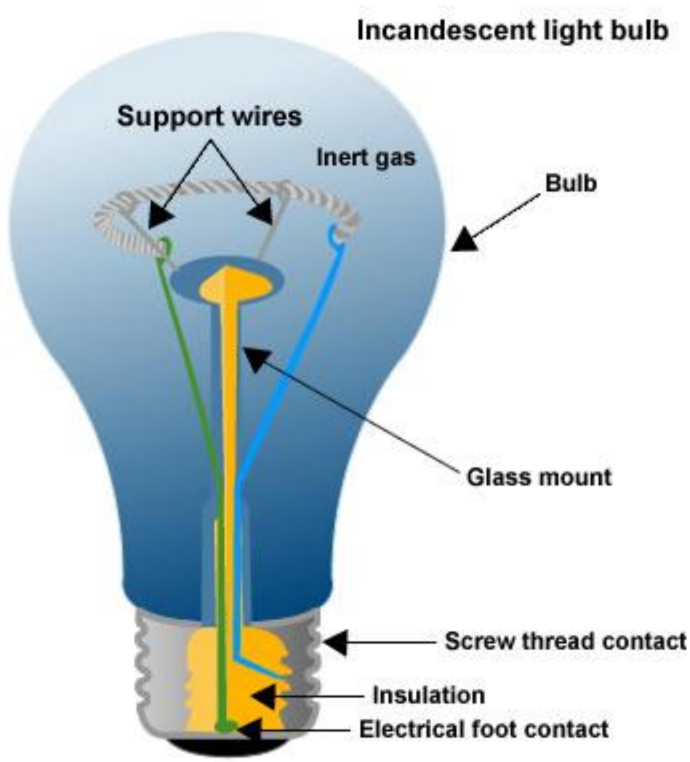

Figure 1. Incandecent light bulb diagram.

Standard Industries. (2006). *Incandescent Lamps*. Retrieved November 5, 2009, from http://standardindustries.net/pb/wp_80864606/wp_80864606.html.

Figure 1 shows that the majority of the material in the incandescent light bulb is glass. Laurie Ramroth, in a study comparing CFLs and incandescent light bulbs, weighed the components of the incandescent light bulb. Ramroth found that for the 100 W incandescent light bulb she tested, 82% of the total weight of the light bulb was due to glass from the bulb and insulation (Ramroth, 2008). While production of glass consumes a lot of energy, glass from light bulbs can ideally be recycled or reused. Therefore, it is important to look at the other materials in the incandescent light bulb.

The main components of the incandescent light bulb are the filament and the gas in the bulb. The filament is made of Tungsten and the gas in the bulb is a mixture of argon and nitrogen (Chemicool). The filament is attached to lead in wires made of copper and is supported by support wires made of molybdenum (Goodmart). The copper lead in wires attach to the socket that is made of brass or aluminum (Goodmart).

2.2 PRODUCTION

The largest component of incandescent light bulb production is transportation, mining, and smelting. Energy involved in transportation of materials is rather high because of the locations of mines in Canada. For example, Sylvania, one of the largest light manufacturers operates in Drummondville Quebec (Sylvania). However, the nearest Tungsten mine is in the North West Territories (NATC). Similarly, the gas used to fill the glass can be shipped from an air separation plant in Hamilton Ontario (Air Liquide), but the gas can also be produced in an onsite plant if demand is high enough to justify an onsite plant (UIG). The mining process occurs wherever the material may be present in or outside of the country. Mining consumes most of its power through a process called communition. Communition is the process of breaking ore and rock down into more useful sizes; the whole process is about 1% efficient and results in 65-80% of the total energy of a mining operation (Troman & Meech, 2002). Communition of cement results in an energy use of 27-54 kWh/ton (ACEEE). The energy required for communition may be inefficient, but consumes much less power than smelting. The energy consumed of smelting metals, varies depending on the metal. Smelting copper requires 3,000 kWh/ton and for zinc 6,000 kWh/ton are required (Kazakhmys).

2.3 DISPOSAL/RECYCLING

After use, the incandescent light is often simply thrown out with the trash. As a result, the light bulb ends up in an incinerator or lays in a landfill (Gydesen & Maimann, 1991). It is important to determine what environmental impacts each material will have if it lays in a landfill or is emitted into the atmosphere.

Aluminum used for the socket, does not significantly bioaccumlate in plants and animals (ELC). Aluminum can be recycled and the energy required to recycle scrap aluminum is 5% that of mining and refining new aluminum (ELC).

Brass can also be used for the socket. Brass is an alloy consisting of copper and zinc (Made How). While it is not listed that copper production is one of the largest contributors to green house gases, copper has known health and environmental effects. Lenntech states "Long-term exposure to copper can cause irritation of the nose, mouth and eyes and it causes headaches, stomachaches, dizziness, vomiting and diarrhea" (Lenntech, 2008). Environmentally, copper accumulates in plants and animals and as a result animals may experience copper poisoning and plants may die (Lenntech). Similar to copper, zinc also has significant health and environmental effects. Lenntech states "…too much zinc can still cause eminent health problems, such as stomach cramps, skin irritations, vomiting, nausea and anaemia" (Lenntech, 2008). Zinc, can bioaccumulate in the environment and damage plant life and harm animals (Lenntech).

The other materials used in the incandescent light bulb have shown little to no environmental effect.

3.0 COMPACT FLOURESCENT LIGHT BULB

Compact Fluorescent Lights (CFL) are currently one of the most popular low-energy alternatives for the incandescent light bulb. They are composed of two glass tubes filled with approximately 5 mg of mercury gas and an inert gas, such as argon. Electrodes at either ends of the tubes stimulate the mercury atoms to emit UV-light while a phosphor coating found on the inner side of the glass tubes convert this to visible light. (Gydesen & Maimann, 1991) The CFL also contains an electronic ballast which provides the proper starting and operating electrical conditions. Once fully illuminated, the ballast is used to limit current to the lamp (EPD). These parts can be seen assembled in the diagram below.

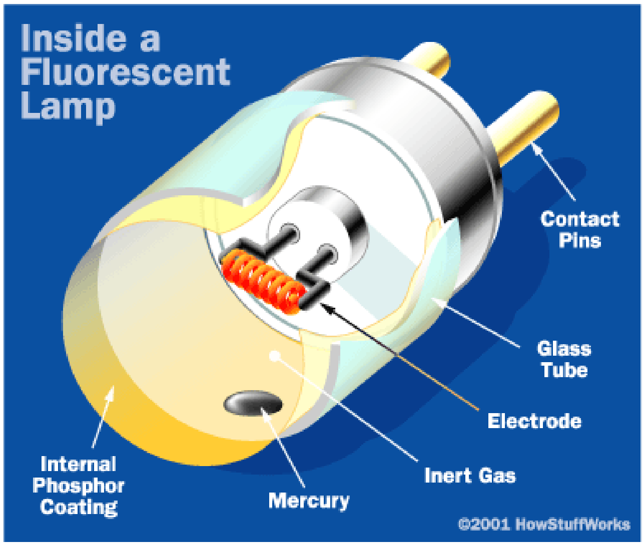

Figure 2. Fluorescent light bulb diagram.

How Stuff Works (2001). *How Fluorescent Lamps Work*. Retrieved November 6, 2009, from http://home.howstuffworks.com/fluorescent-lamp2.htm#

Although you can find many sources of information regarding the large amounts of energy saved during the operation of fluorescent lighting, it is not as easy to come by information showing the amounts of energy used or saved in the production or disposal process. The following section analyses these key topics and evaluates their environmental, economical, and social effects.

3.1 PRODUCTION

The extraction and production phase takes into account both the energy required to remove the materials from the earth, that are needed for production, as well as the energy required to assemble the CFL in manufacturing plants. The extraction and production phase brings up many of the arguments that can lead to negative views of the CFL. The CFL requires approximately 1.7 kWh for extraction, shipping, and production for various types of fluorescent bulbs; however, some sources (Stanjek,1991) state that it can take as much as 6 kWh to make and assemble CFL's if all the components separate extraction and manufacturing processes are taken into account as well as the energy required for packaging and shipping. This is compared to the energy consumption required for the incandescent bulb, which can be anywhere between .15 and .3 kWh (The Watt). As shown in the above introduction, many more parts are required to create CFL's than incandescent light bulbs. The larger numbers in energy consumption for extraction and production accounts for this; as well as some of the more valuable types of gasses and metals used. These numbers state that CFL's require approximately 10 times more energy (up to 40 times from some sources) to move the product from the earth to the shelves on our stores; a long time before the CFL gets to save energy during its usage. Many manufactures neglect to state the energy required for these processes and only state the energy saved during usage. However, since the CFL lasts 8 to 10 times longer than an incandescent light bulb, 8 to 10 more incandescent light bulbs are required to span the lifetime of the CFL. This results in the extraction and production energy consumption anywhere between 1.5 kWh and 3 kWh for the incandescent. Although the energy required for the CFL's manufacturing is larger when comparing bulb to bulb, it is smaller when considering the amount of energy required to manufacture the amount of incandescent bulbs to match the lifetime of the CFL.

3. 3 DISPOSAL/RECYCLING

A large concern regarding the end of the CFL's life is with the amount of mercury that is released into the environment, approximately 5-10 mg per bulb (Soneji, 2008), when not disposed of properly. The correct procedure requires the bulb to be brought to a company that is able to properly and safely recycle the bulb, however approximately only 2% of the American population actually recycled their CFL's. This extremely low number leads to excess amounts of mercury progressing towards the dump, where it will disperse into the ground, food supply, drinking water etc. (Soneji, 2008) However, since the incandescent light bulb uses considerably more amounts of energy during its usage, the amount of mercury released into the environment from electricity produced by coal-fired power plants to power incandescent lights, assuming 40.3% of the total energy reduced by using CFL's, is also greater; approximately 15.9mg (Soneji, 2008). Thus, there is an overall reduction in the amount of mercury released into the environment by using fluorescent lighting, assuming that it is not recycled properly. Another concern with the disposal process is with the electronic ballast. Disposing of the CFL not only results in mercury being released into the environment, but also results in many other harmful chemicals being disposed of with the "e-waste", which poses its own serious threat to the environment. The electronic ballast can be seen in the figure below.

Figure 3. Beneath the compact fluorescent light bulb.
The Watt (2008). *Compact Fluorescent Light Bulbs – A Tale From Dust to Dust*.
Retrieved October 28 , 2009, from http://www.thewatt.com/node/175

This combination of multiple materials also makes the recycling processes more difficult; and much less convenient (Stanjek, 1991). A negative view towards fluorescent lighting is that it is must be recycled due to the hazardous chemicals which compose it, where as other types of light bulbs can just be thrown out. This argument has been used against the CFL; however, if a convenient and effective recycling on the environment than simply disposing the bulbs and increasing the garbage in the landfill.

4.0 LIGHT EMITTING DIODE

LED lamps are different from regular bulbs. They are semiconductors that emit energy in the form of light when electricity passes through them. LED lamps convert the majority of electric energy into light, as opposed to incandescent bulbs that produces its light from resistive lighting, which is inefficient (Harris, 2002). LED lamps have been used in many applications such as, automotive lighting, billboards, traffic lights, and many other applications (Morris, 2006).

It is widely known that LED lamps present many advantages over incandescent and CFL's. In terms of energy consumed during usage, LED lamps consume less energy and last longer. Other advantages of the LED include improved robustness, smaller size, and the ability to switch faster. However, they are relatively expensive and require more precise current and heat management than incandescent or CFL (OSRAM). The diagram below shows how the components are assembled in a common LED.

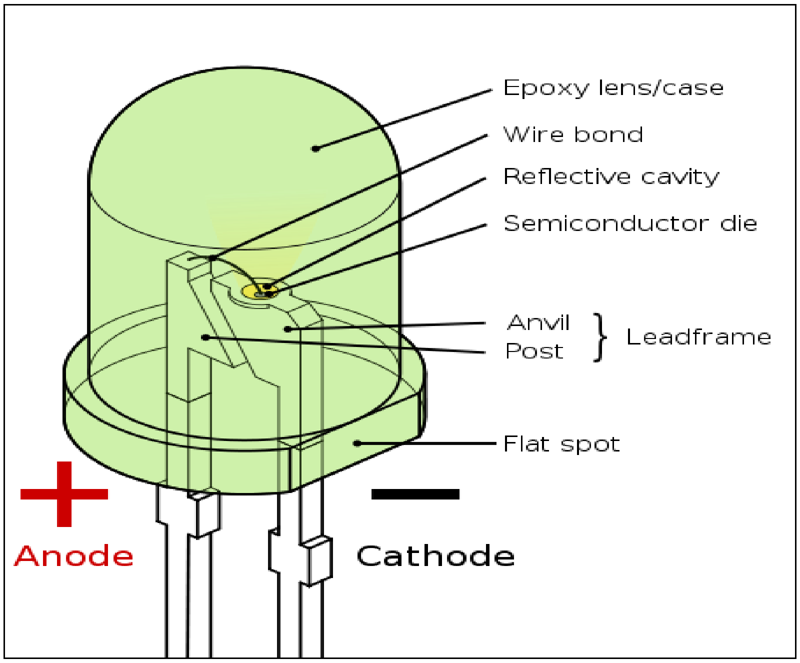

Figure 4. LED components.

Wikipedia (2008). Light-emitting diode

Retrieved October 29 , 2009, from http://en.wikipedia.org/wiki/Light_emitting_diode

It is hard to find the sources showing how intensive it is to make LED lamps during production including the energy used to retrieve raw materials and the processing. However, information about assembly of LED’s can be found and is useful when considering production stage.

This section analyzes the environmental, social, and economic impact of an LED lamp over its entire life cycle.

4.1 PRODUCTION

To evaluate the efficiency of lamps in terms of energy and resources, it is necessary to consider the energy consumption during the production and disposal stage. However, details about energy consumed during material processing are hard to find. It is sufficient to analyze the manufacturing stage as it provides details on how to improve the quality of the LED.

The study conducted by experts at Siemens Corporate Technology shows that over 98% of the energy used is consumed to generate light (OSRAM). Less than two percent is allocated to the manufacturing stage. Even though the manufacturing stage does not involve a huge amount of energy during its life cycle, it is very crucial in determining the life-time.

It is interesting that the lifetime of an LED is not limited to the semiconductor components inside. The cover of an LED also plays an important role in determining the lifespan of the LED. Therefore, during manufacturing, a silicon coating is applied to the cover of the LED (OSRAM).

4.2 DISPOSAL

From the above information, it is clear that the manufacturing stage is crucial for the quality of the lamps. Sometimes the manufacturer strives for the best quality of the product without considering environmental issues.

Packaging has been a problem for the environment. For example, reducing the amount of cardboard used for packaging and choosing a right material that is easy to recycle promotes sustainability (OSRAM).

The fact that LED components are simpler than CFLs and LEDs' life spans are five to six times longer than CFLs, recycling LEDs is easier. In terms of durability, since LEDs do not have a filament, they are less likely to break. Using more durable lamps, landfill waste can be reduced.

Although the initial cost can be three to five times more than the CFL or Incandescent, the extra cost can be repaid from energy savings during usage, and the bulbs are expected to last more than 10 years (Taub, 2008). Also, the increased LED lifetime means a reduction of landfill waste.

5.0 USAGE COMPARISON

It is vastly known how much more energy efficient it is to use fluorescent and LED lighting than incandescent lighting. For a normal 60W and 100W incandescent light bulb, the CFL and LED will only require 15W and 25W respectively. Also, CFL's can last up to 10,000 hours, 8-10 times longer than the incandescent. (USDOE: Energy Savers). More so, the LED's lifetime can last between 25,000 and 50,000 hours; which is much longer than the incandescent or CFL lamps (USDOE: Solid State Lighting).

A typical 60-Watt incandescent light bulb's initial purchase cost is approximately $0.27 per bulb, where as a 13-15 Watt CFL equivalent is approximately $3.77 (GE). Although the initial cost of the CFL is much greater when comparing bulb to bulb, approximately 8-10 incandescent bulbs must be purchased to compensate for the difference in lifetime, which lessens the gap in purchase cost. Again, the LED's purchase costs are considerably more than the incandescent and CFL's and vary with type/model and production site, which on average, range from $10-$30$ (LEDlight).

The energy cost during the CFL's usage is also greatly lessened because the CFL uses approximately 75% less energy than the incandescent during its lifetime. In general, only 5-10% of the energy required to power incandescent light bulbs is going to produce visible light, where as 90-95% will dissipate as heat. The CFL improves on this as approximately 25% of the energy required is used to produce visible light (The Watt). LED's greatly outperform both the incandescent and CFL in its usage by producing light with approximately 90% of the applied energy (EternaLEDS). The most common way to compare the quality of different bulbs is to calculate the lumens/watt, which is the amount of light coming out per the amount of energy coming in. The figure below shows the maximum light output for the three lights under discussion.

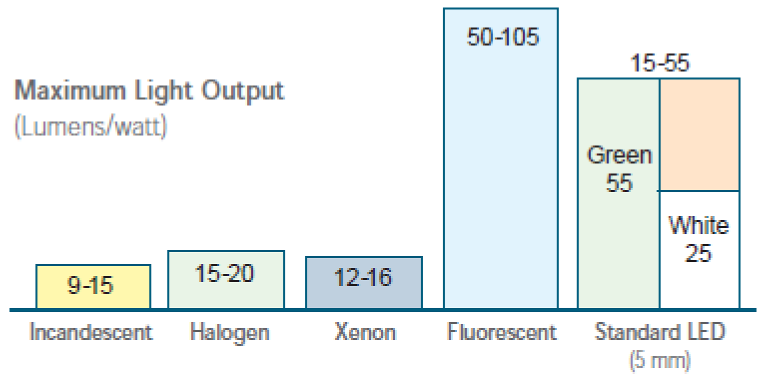

Figure 5. Lumens/watt comparison between lighting solutions.
imtra Marine Lighting. (2007). *What you should know when selecting marine lighting*. Retrieved November 11, 2009. From http://boatelectric.com/Imtra%20FAQ.pdf

A social concern regarding CFL's is with the quality of light output. CFL's do not provide the full spectrum of natural light and some people believe that the flickering rate of the CFL's can affect mental and nervous system functions. (Tharumarajah, Koltun, Issa, Taniguchi & Cock, 2005). Another concern with the CFL is that there is a large amount of time required to reach maximum illumination; whereas the incandescent and LED's both fully illuminate almost instantaneously.

The diagram below implies that the LED is the best choice among alternative light sources, such as the CFL and incandescent bulb, in terms of electricity consumption in Tonne Watt Hours. This also implies that by using LEDs lighting, we can greatly reduce the CO2 emission.

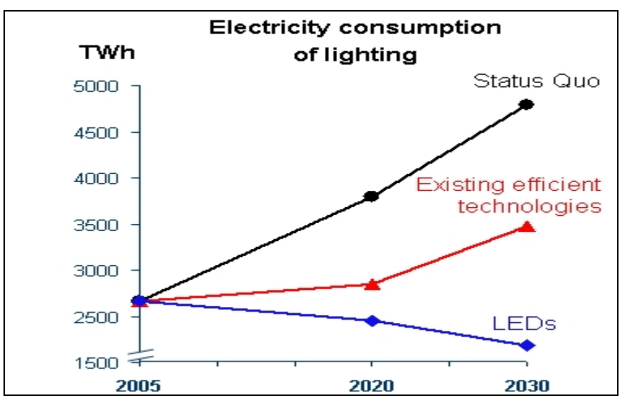

Figure 6. Electricity consumption comparison.
OSRAM (2005). *LED Benefits*. Retrieved November 3, 2009, from http://www.osram-os.com/osram_os/EN/About_Us/We_shape_the_future_of_light/Our_obligation/LED_life-cycle_assessment/LED_Benefits/index.html

6.0 IMPROVEMENTS ON THE DISPOSAL AND RECYCLING PROCESS

A light bulb has reached the end of its usage when it dies or burns out, however this is not the end of its full lifecycle. The disposal or recycling process of the light bulbs is very important as the entire life-cycle of the light bulbs is being analyzed to determine their sustainable and unsustainable properties.

The incandescent light bulb is safe to dispose of in the garbage as it does not contain the toxic chemicals that the CFL has. However, there are many parts on the incandescent which could be recycled, such as the copper base and glass casing. More related to CFL's, LED's are electronic components and simply disposing the LED's would have similar negative impacts on the environment as a result of e-waste. If a convenient method to recycling these bulbs were available for the consumers, it would have a positive effect on the environment, as well as positive economic and social impacts.

As was mentioned in section 3 above, it is necessary that the CFL's are recycled as it is very destructive to the environment to simply dispose them, not only because of the amount of mercury they contain, but also because of the e-waste, copper, glass, and other harmful chemicals. However, it is currently not very convenient for consumers to recycle their CFL's. Having the consumer forced to make a separate trip to a local establishment that accepts CFL's for recycle and with little personal incentive to do so can lead to disposal. If the consumers were provided with a personal incentive when the CFL was recycled, such as a small amount of money, or to have a convenient return method, such as combining door to door pick up with the other normal household recycling items, there would be much less reason to throw the CFL into the garbage. As Vancouver already has in place an average household recycling pick up program, pick up for CFL's could easily be added or included to this service. Also, the recycling service could deliver the dead bulbs to preexisting companies that accept CFL's; as there are many around the lower mainland (BC Hydro).

7.0 CONCLUSION AND RECOMMENDATIONS

Table 1. Triple bottom line analysis of the incandescent, fluorescent, and LED lamps.

Incandescent					
Environmental		Social		Economical	
Pro	Con	Pro	Con	Pro	Con
- No mercury in the physical bulb - Glass, socket and wire can be reused/recycled.	- Copper, zinc accumulation - High green house gas emissions for metal production. - Mineral transportation emissions. - Large mercury output depending on power production method (i.e. Coal powered) - Short lifetime requires more replacement.	- The need for minerals creates local work in smaller communities. - Easy to dispose of. - Warmth in cold places - Quality of light output - Easy to purchase and replace	- Prolonged exposure to manufacturing materials can have negative health effects.	- Cheap initial capital.	- Short lifetime requires more replacement. - Large energy consumption during usage
Compact Fluorescent					
Environmental		Social		Economical	
Pro	Con	Pro	Con	Pro	Con
- More efficient than incandescent lighting (requires much less energy during usage) - Low energy consumption during usage emits less mercury into the environment by means of coal power plants	- Contains mercury. - Contains an electronic ballast ("e-waste") - Must be properly disposed of or recycled. - More energy required for production	- Visually appealing in design and light output. - Fits in standard light sockets.	- Flickering and reduced visible spectrum of light output - Broken lights must be carefully treated as they contain mercury. - Workers are exposed to harmful gasses. - Must be recycled	- Long lifetime requires less replacement - Long lifetime lessens energy costs during usage.	- More initial capital - Cost of recycling

Light Emitting Diode					
Environmental		Social		Economical	
Pro	Con	Pro	Con	Pro	Con
- Doesn't contain mercury - Recycling is easier than CFL as it contains fewer components (i.e. less complex) - Very low energy consumption during usage	- Contains plastic - Considered "e-waste"	- Doesn't attract insects - Durable – not easy to break - Immediate illumination - Multiple color selection	- Difficulties of informing the public - Quality of light output - Large percentage manufactured overseas (Working Conditions)	- Extremely low usage cost - Long lifetime requires less replacement	- Very high initial capital due to low demand and new technology

A comparison of the triple bottom line analysis for the incandescent, fluorescent, and LED lamps are shown in the table above. We found that the three bulbs environmental and economical aspects seem to have a linear relationship; as the initial capital increases, then environmental impacts decreases. Although the cost and required energy for production of the incandescent light bulb is very low, the amount of energy required for its usage greatly reduces any benefits gained from this. Also, frequent replacement due to short lifetime has negative effects on both the environment and economical aspects. Although the LED has made a large improvement on efficiency, compared to the incandescent and CFL lamps, the extremely high initial cost, because it's a developing technology, and limited commercial availability makes it is economically undesirable. However, as the technology develops and the initial capital decreases, the LED would become the best solution.

From our research, we found that CFL's are currently the best solution to providing illumination on a large scale, such as a University building. The CFL provides the most balanced triple bottom line assessment. Their widespread availability and relatively low initial capital makes them economically appealing, where as the low energy consumption during usage reduces the environmental impact. A major concern with CFL's is the amount of mercury they contain, however, the amount of energy required to power an incandescent light bulb over its usage releases more mercury into the environment. Thus, while LED technology is still relatively new, the CFL should be used in the SUB.

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