THE OHIO STATE UNIVERSITY

COLLEGE OF FOOD, AGRICULTURAL, AND ENVIRONMENTAL SCIENCES

# Viability of Implementing Smart Street Lights at The Ohio State University's Columbus Campus
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AEDE 4567 Capstone Final Report

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# Executive Summary

The objective of this report is to examine the viability of implementing LED smart street lights on The Ohio State University's (OSU) Columbus campus. Using data collected from the City of Columbus, OSU's department of Facilities Operations and Development (FOD), and ENGIE North America (ENGIE), we conducted a cost-benefit analysis on the incremental benefits of replacing 10%-100% of the lights located at OSU. We also provide comparisons with Detroit, Michigan and Cheyenne and Castor, Wyoming. We chose to work with Detroit, Michigan due to its close proximity to Columbus and similar geographic features. The Wyoming project was chosen because it is one of ENGIE's previous projects. The purpose of these comparisons is to provide background information on other LED street light conversions and utilize the benefits that worked with their project. This report also recommendations on how to proceed on further research of implementing Wi-Fi and dimming features, which has the potential to further decrease energy consumption and add social benefits. Based  on our analysis, replacing the current street lights on OSU's Columbus campus with LED lights will result in immediate and long-term sustainability improvements, such as monetary and energy consumption savings, that will not only benefit Ohio State, but will also benefit the City of Columbus and serve as an example to other communities.

# 1. Introduction

The Ohio State University (OSU) is an institution implementing many sustainable measures throughout all of their campuses (citation needed here). In July 2017, OSU entered a 50-year partnership with ENGIE and Axium to manage and maintain the university's energy infrastructure (The Ohio State University, 2017). These are both private consulting companies with a focus on sustainability. ENGIE's purpose is to work toward green mobility through solutions in fuels, infrastructure, transit systems, and designs. This work is to improve the efficiency of these outlets to ultimately require less consumption. Axium is an infrastructure firm focused on long-term returns by energy savings and cost effectiveness. (The Ohio State University, 2017; ENGIE, 2017). To address some of its sustainability goals, OSU and ENGIE want to reduce energy consumption by upgrading existing streetlights to energy efficient LED lights as a part of the Smart Street Light Project. By converting to LED street lights, OSU can save up to $80,660 annually.

This specific project has the potential to act as a pilot project for Smart Columbus, providing information that can be useful for a city-wide streetlight upgrade by providing information on how much the conversion from the current street lights can be saved in energy. The City of Columbus has expressed interest in doing something similar, and the sustainability benefits gained from converting to LED will align with the goals of the Smart City Challenge. The primary research goal of this study is to provide information and data on the potential savings of replacing OSU's current street lights with LED. The secondary research goals include providing a Cost-Benefit Analysis (CBA) at intervals of 10% conversion rates to display the associated savings of incremental conversion of metal halide to LED. As well as utilizing previous projects to present a benchmark analysis and case study in order to compare OSU to the city of Detroit, Michigan, and Cheyenne and Castor, Wyoming. Lastly, providing a basic understanding of the potential benefits associated with implementing light sensors/dimming features and WiFi in addition to the LED bulbs.

# 2. Cost-Benefit Analysis

## 2.1. Methodology

We conducted a cost-benefit analysis to determine monetary costs and benefits of implementing LED street lights on Ohio State's campus using the current street lights as a baseline for comparison.

## 2.2. Study area

According to Facilities Operatins and Development (FOD), Ohio State has 1,200 street light fixtures across campus. A map of their locations can be found in section 9.2. of the appendix. The current type of light found on campus is a 250-watt metal halide lamp that uses a total of 300 watts of electricity. OSU and ENGIE want to replace the metal halide fixtures with 80-watt LED lamps that use a total of 85 watts. Light bulbs in general are not perfectly efficient; they use slightly more electricity than their names suggests due to the ballast. It is also important to note that Central Ohio's 2016 average length of darkness was 12 hours and 3 minutes (Astronomical Applications Department 2016), and OSU's 2016 electricity rate was $0.0712/kWh. This information is necessary for conducting the cost-benefit analysis.

## 2.3. Energy Consumption and Electricity Costs

***Table 1*** depicts the energy consumption and costs per year of running the 1,200 lights for 12 hours and 3 minutes, 365 days a year. The *Total kWh used per year* and *Electricity cost per year* are shown as if 100% of the lights are 80 watt LED and 100% of the lights are 250 watt metal halide. From this calculation it is very clear that a substantial savings will occur with the conversion.

***Table 1*:** 250 watt Metal Halide bulb (currently in use) versus the 80 watt LED (not used yet).

| Energy consumption and cost per year for the two types of lights used by OSU | | | | | |
|---|---|---|---|---|---|
| ht Model | Total Watts used | Total kWh used per light per day | Total kWh used per day for ALL lights | Total kWh used per year | Electricity cost per year |
| watt LED | 85 | 1.02255 | 1,227.06 | 447,876.90 | $ 31,888.84 |
| ) watt Metal lide | 300 | 3.609 | 4,330.80 | 1,580,742.00 | $ 112,548.83 |

2.4. Incremental Costs and Benefits

The incremental energy consumption and associated cost for switching out a specific percentage of the current lights to LED are presented in Table 2. This is based on the reference scenario, where the "baseline" is 100% metal halide and "100% change" represents a total conversion to LED.

***Table 2:*** kWh consumed and monetary cost/benefit of converting to LED at 10% increments. The "total cost" column represents only the total cost of electricity.

| Incremental Electricity Costs and Savings of changing X% of lights to LED: | | | |
|---|---|---|---|
| | kWh (per year) | total cost (per year) | cost savings (per year) |
| Baseline (0% change) | 1,580,742.00 | $ 112,548.83 | X |
| 10% change | 1,467,455.49 | $ 104,482.83 | $ 8,066.00 |
| 20% change | 1,354,168.98 | $ 96,416.83 | $ 16,132.00 |
| 30% change | 1,240,882.47 | $ 88,350.83 | $ 24,198.00 |
| 40% change | 1,127,595.96 | $ 80,284.83 | $ 32,264.00 |
| 50% change | 1,014,309.45 | $ 72,218.83 | $ 40,330.00 |
| 60% change | 901,022.94 | $ 64,152.83 | $ 48,396.00 |
| 70% change | 787,736.43 | $ 56,086.83 | $ 56,462.00 |
| 80% change | 674,449.92 | $ 48,020.83 | $ 64,528.00 |
| 90% change | 561,163.41 | $ 39,954.83 | $ 72,594.00 |
| 100% change | 447,876.90 | $ 31,888.84 | $ 80,660.00 |

Using the information presented in section 2.2, we were able to calculate the incremental consumption above**.** This table shows that LED lights are so efficient that just a 10% conversion to LED will result in Ohio State saving $8,066 a year!

2.5. Total Cost of Carbon Emissions

The incremental benefits in terms of avoided carbon emissions associated with converting to LED are outlined in ***Table 3***. In order to quantify the $CO_2$ emission reductions, we first determined the carbon emissions created by the lights by computing a $CO_2$ emissions factor (in terms of pounds of CO2 emitted per kWh) along with the cost of $CO_2$ per short ton. We obtained the $CO_2$ emissions factor by using state-by-state data from the Energy Information Administration (EIA) and dividing estimated CO2 emissions from electricity generation in each state (metric tons of CO2) by the amount of electricity generated in each state (megawatt hours). We then converted the metric tons to short tons and pounds (lbs) and the megawatt hours (MWh) --to kilowatt hours (kWh) (EIA 2015). We estimated the $CO_2$ emissions factor to be **2.09 lbs/kWh**.

In order to find the amount of $CO_2$ emitted per year from operating the lights, we multiplied the emissions factor by the total kWh consumed in one year. The next step was to convert the pounds of $CO_2$ emitted per year (column 1) back to short tons of CO2 (column 2), because the cost of carbon information is in terms of $/short ton of $CO_2$. A moderately discounted price of $41 per short ton was selected. According to Synapse Energy Economics, this price reflects the adoption of federal policies that are "implemented with significant but reasonably achievable goals" (Synapse 2015), and closely aligns with the current economic and political climate of the US. The monetary value of the avoided carbon emissions represents the benefit to society from switching to more energy-efficient lighting on campus.

***Table 3***: The pounds and tons of carbon emissions produced reflect the total amount produced by annual consumption of energy noted in ***Table 2.***

| Carbon Emissions Per Year | | | | |
|---|---|---|---|---|
| | lbs/total kwh | tons/total kwh | Cost per year | Incremental Benefit |
| Baseline (0% change) | 3,303,750.78 | 1,651.88 | $ 67,726.89 | X |
| 10% change | 3,066,981.97 | 1,533.49 | $ 62,873.13 | $ 4,853.76 |
| 20% change | 2,830,213.17 | 1,415.11 | $ 58,019.37 | $ 9,707.52 |
| 30% change | 2,593,444.36 | 1,296.72 | $ 53,165.61 | $ 14,561.28 |
| 40% change | 2,356,675.56 | 1,178.34 | $ 48,311.85 | $ 19,415.04 |
| 50% change | 2,119,906.75 | 1,059.95 | $ 43,458.09 | $ 24,268.80 |
| 60% change | 1,883,137.94 | 941.57 | $ 38,604.33 | $ 29,122.56 |
| 70% change | 1,646,369.14 | 823.18 | $ 33,750.57 | $ 33,976.32 |
| 80% change | 1,409,600.33 | 704.80 | $ 28,896.81 | $ 38,830.08 |
| 90% change | 1,172,831.53 | 586.42 | $ 24,043.05 | $ 43,683.84 |
| 100% change | 936,062.72 | 468.03 | $ 19,189.29 | $ 48,537.61 |

## 2.6. Installation costs for Metal Halide vs. LED Lights

After computing the incremental energy consumption, energy cost, and carbon emissions, a total cost comparison between the metal halide lights and LED lights was created. The "Total Cost" includes the cost of installation (one-time, upfront payment), maintenance, and electricity consumption. The cost of carbon emissions are intentionally excluded due to the fact that it is not a physical cost incurred by the university. Because the university already plans to convert 100% of streetlights to LED lights, we chose to only look at total costs for 100% metal halide compared to 100% LED.

### 2.6.1. Installation Cost

The installation cost is only incurred one time, and only consists of materials. The materials needed were broken down into different parts of a street light because they can be purchased separately.

*note: the prices for the components listed below were compiled from research of different vendors. Unfortunately, Ohio State was not able to share their vendor information for this report and likely receives better pricing options.

**Metal Halide Light Fixture**
- Total Installation cost per light = $962
    - Approximately: $1,154,400 for all light fixtures located on the OSU campus
- Globe: approximately $350 each (Lamp Post Globes.com 2017)
- Pole : approximately $600 each (LightPolesPlus.com 2017)
- Bulb: approximately $12 each ( 1000bulbs.com 2017)

**LED Light Fixture**
- Total installation cost per light= $350
    - Approximately: $420,000 for all lights located on the OSU campus
- Bulb: approximately $100 each (LED Global Supply 2017)
- WIFI components: approximately $250 for each light (CableWholesale 2017)

*note: the conversion to the LED model will be a retrofit project, meaning, the original poles and globes will stay and only the bulbs will be changed. The WIFI component will also be added. This reduces the initial investment of this project significantly.

### 2.6.2. Maintenance Cost

Maintenance costs includes the cost of labor and the cost of material. ENGIE has provided 2016 maintenance data detailing the number of streetlight-related maintenance requests, the cost of labor to fix issues, and the cost of material. This totaled to be $8,213.72. We were unable to obtain any historical data for previous years' light maintenance, so the 2016 total will serve as the average yearly maintenance cost. Additionally, because we were unable to obtain the actual costs for maintenance for LED lights we assume they will be the same as for the conventional street lights ($8,213.72/year?)

### 2.6.3 Energy Costs

Energy costs are available in ***Table 1***, and are $31,888.84 for LED and $112,548.83 for metal halide.

2.6.4 Annualization of Installation Cost

Because the installation cost of both light types is only incurred one time, it needed to be annualized to be comparable with the maintenance and energy costs, since these are incurred year after year. This was achieved by using the following formula:

$$\text{Annual Payment} = \frac{\text{initial investment}}{\sum (1/(1+i))^t}$$

In this formula, $i$ is the discount rate and $t$ is the expected life. A discount rate of 5% was chosen, with an estimated life expectancy of a street light to be 20 years. The life expectancy of a street light is how long the pole and globe will last. It intentionally excludes the life of a bulb, because bulbs will need to be replaced more often. The next table, ***Table 4,*** outlines the annual costs for each light type

***Table 4*****:** Outlines the annual costs of a 100% conversion of LED from the current streetlights.

| **ANNUAL Costs of Old Lights** | | | **ANNUAL Costs of LED Lights** | | |
|---|---|---|---|---|---|
| installation | $ | 34,912.04 | installation | $ | 12,701.89 |
| electricity | $ | 112,548.83 | electricity | $ | 31,888.84 |
| maintenance | $ | 8,213.72 | maintenance | $ | 8,213.72 |
| **Total** | **$** | **155,674.59** | **Total** | **$** | **52,804.44** |

2.7. Payback Period

The final part of this cost benefit analysis determines the payback period of the LED retrofit investment. We have determined that at a discount rate of 5%, it will take approximately 8 years for the present value of the cumulative net savings to outweigh the initial investment of $420,000, which is the cost of buying the LED and WiFi components for 1,200 lights. Each year, OSU is expected to save $80,660 in energy savings with a 100% conversion to LED, and these savings will continue to accrue for 8 years to pay back the initial investment. This is outlined below in ***Table 5***.

***Table 5:*** The payback period of the LED streetlight conversion

| Payback Period | | | |
|---|---|---|---|
| Year | Expected Net Savings | Cumulative Net Savings | Present Value |
| 0 | $ 420,000.00 | $ - | $ - |
| 1 | $ 80,660.00 | $ 80,660.00 | $ 76,819.04 |
| 2 | $ 80,660.00 | $ 161,319.99 | $ 146,321.99 |
| 3 | $ 80,660.00 | $ 241,979.99 | $ 209,031.41 |
| 4 | $ 80,660.00 | $ 322,639.98 | $ 265,436.71 |
| 5 | $ 80,660.00 | $ 403,299.98 | $ 315,996.08 |
| 6 | $ 80,660.00 | $ 483,959.97 | $ 361,138.38 |
| 7 | $ 80,660.00 | $ 564,619.97 | $ 401,264.87 |
| **8** | $ 80,660.00 | $ 645,279.96 | **$ 436,750.88** |

# 3. Benchmark Analysis

A benchmark analysis was conducted on the following location: Detroit, Michigan. The benchmark analysis address the following bullet points:

- Climate/population
- Similarities / Differences in comparison to OSU
- Types of light fixtures
- Cost/benefit
- Emissions
- Timeline

## 3.1. Detroit, Michigan

Detroit, Michigan is the first location for the benchmark analysis. Detroit, Michigan has a population of 672,795 people as of 2016 (United States Census Bureau, 2016). Michigan was chosen due to its similar demographic, geographic, and climatic features in relation to Columbus, Ohio. Michigan has annual high temperature of 57.3F, an annual low of 39.1F, and an annual snowfall of 51 inches (US Climate Data, 2017). Michigan is also a state that neighbors Ohio.

As of 2013, Detroit had 88,000 high pressure sodium streetlight and only 50% of them were functioning, due to inadequate maintenance. The high pressure sodium bulb is in the same family of bulbs as the metal halide fixture used on OSU's campus currently. The primary difference is that the metal halide bulb emits white light and the high pressure sodium bulb emits amber orange. The Michigan Finance Authority was allowed a budget of 185 million dollars to implement 65,000 new LED conventional cobrahead luminaire street lights over a course of three years (Kinzey, 2015).

The 88,000 lamps were composed of four varying wattage levels with different prices associated. This project is quite larger than Ohio State's, as the campus has 1,200 lights. Fifteen thousand street lamps ($30.24 each) had the lowest wattage (70 W). 53,000 streetlights contained 150W bulbs with a cost of $64.80. 13,000 lights are 250W and $108.00 per light. The highest wattage (400W) was used for 7,000 streetlights and were purchased for $172.80. Each of these lights operated for 4,200 hours per year. Collectively, they consumed 75,768,000 kWh annually and cost of $6,048,000 in terms of electricity (Kinzey, 2015). The new LED lights are at three different wattage levels. The three wattages with the following units to be replaced are: 45,000 street lights at 150 watts, 13,000 streetlights at 250 watts, and 7,000 at 400 watts. The cost of electricity is $0.103/kWh for all three lights. The annual hours of operation remains at 4,200. The total annual estimated energy cost of the 65,000 LED lights is $3,103,704. There is an annual energy consumption of 30,174,900 kWh. The LED light system saves Detroit 46 million kWh in electricity, which results to 2.9 million in annual energy cost savings. A maintenance cost was not conducted in this study because the previous lighting system did not have up-to-date information. An estimated price quote for the LED lights to be implemented totaled to $12 million. The conventional cobrahead luminaire, the LED light model that was chose, has an estimated average cost of $100 each (Kinzey, 2015). The report estimates a payback period of 2.3 years. Detroit Michigan will save an annual amount of 40,418 tons of carbon dioxide with the change to the 65,000 LED lights compared to the 88,000 high pressure sodium streetlights. The emissions rate of the previous high pressure sodium street lights were based off a 2010 environmental emissions report, however the exact numbers were not included in the report.

Detroit's previous lights were on every residential block and alleyways. Due to the brightness of the new LED lights, there was a reduction in the typical amount of lights on a neighborhood street. Detroit is also the first city in the United States to be completely powered by LED street lights (Kenzey, 2015).

Detroit's conversion to LED lights is on a bigger scale than Ohio State's project; the difference in scales accounts for the higher ultimate savings. Detroit and Ohio State both are lacking information on maintenance cost, but the benefits of converting will still greatly outweigh the expected costs. Detroit has a shorter payback period compared to OSU's payback period, at 2.3 years vs. 8 years. Another difference is the type of LED lights chosen for both projects. Ohio State currently uses 250 watt metal halide lamps; this report states that the 80 watt LED lights would serve as the best conversion. Detroit began with four different types of lights as stated above, but upon conversion, three types of LED lights were chosen. While the savings for the conversions are on different scales, both projects will result in energy and money saved. Ohio State will have a yearly saving of $80,660 in energy costs and Detroit will have a yearly saving of $2.9 million in energy costs. A recommendation following the Detroit LED project for the Ohio State University is to consider implementing multiple forms of LED lights instead of one. Brighter fixtures would work best in areas of campus with minimal fixtures, and low wattage fixtures would work best in areas where buildings give off light.

# 4. Case Study

The purpose of this section is to provide insight on another light conversion project. ENGIE has successfully implemented LED lights in various locations around the United States. One of their projects was with the Wyoming Department of Transportation (WYDOT). Although WYDOT and Ohio State are different institutions, we wanted to explore ENGIE's previous work and thus, chose to research this project.

## 4.1. Wyoming Department of Transportation

The state of Wyoming has an average annual high temperature of 58.5 degrees fahrenheit and an annual low temperature of 34.3 degrees fahrenheit (US Climate Data, 2017). The LED light project was implemented in Casper and Cheyenne,Wyoming. Specifically, the LED lights will spread across the state and end in the Green River Tunnels of I-80(Wyoming Department of Transportation, 2014). The population totals to 64,019 59,324 for Cheyenne and Casper, repectively (US Census bureau, 2016). In 2012, the WYDOT began a statewide energy savings program that aims at retrofitting 5,267 light fixtures and updating WYDOT buildings to increase energy efficiency. Completed in 2015, this project cost a total of $10.7 million. Retrofitting the 150-watt high-pressure sodium lamps to 26-watt LEDs cost $8 million. The project is being funded by a 15-year bond, which will be paid off with the money saved on utility bills (Wyoming Department of Transportation, 2014). This project will save on utility bills and will result in rebate payments. WYDOT is expected to receive $145,000 in rebates from Rocky Power and Cheyenne Light Fuel and Power Company. The maintenance savings would be $40,000 yearly, and the LED lights will only require a change every 10-15 years. This project is also expected to cut highway light cost by 40 percent, and have $690,000 in yearly savings(Wyoming Department of Transportation, 2014). In terms of emission savings, this project will save 6.8M kWh per year. A payback period was not provided. An expected total $16.5 million is expected in savings.

The population for both of these cities, is similar to the population of the Ohio State University students. However, the area within its implementation is vastly different from Ohio State and much larger. There are 5,267 light fixtures being replaced in this report compared to the 1,200 on the OSU campus. This project will also be receiving rebates while Ohio State will not. This project will be using the amount it receives in savings to pay for the utility bills.

## 5. Recommendations

The first and foremost recommendation of this report is to convert 100% of OSU's street lights to 80 watt LED bulbs and to fully support ENGIE's efforts in doing so. Looking at the cost-benefit analysis, a $12,708.89 annual investment in this project will yield an annual benefit of $80,660.00 in electricity savings (benefits to OSU). I'd mention the public benefits of avoided carbon emissions as well. As a well-known and prestigious university that is often considered a role model, the conversion will provide an example for others to follow.

As technology continues to advance, the capabilities of smart street lights have also increased. The main purpose of the report thus far has been focused on the conversion of the current light models to LED bulbs. The purpose of this section is to discuss additional features to advance the street lights further. Some street lights have built in Wi-Fi, cameras, and sensors that can monitor pedestrian traffic, weather and air quality, and detect gunshots (Silver Springs 2017). After meeting with ENGIE, we determined that a dimming feature and wifi capabilities would be the best add-on features for the Ohio State University to invest in.

5.1. Dimming Sensors

The dimming sensor works by sensing pedestrian traffic, or the lack thereof. At night, street lights are typically running at 100% brightness for their full cycle. This is inefficient, as pedestrian traffic is usually lower during these hours and many of the lights are not being utilized. The dimming sensor can dim down or completely turn off the lights until they sense movement, saving even more energy and further reducing costs (Echelon 2017). Because there are too many variables affecting how much nighttime pedestrian traffic a single area would experience, calculating the potential energy saving from implementing dimming sensors is infeasible for the scope of our project. However, we think this is something to be considered at a later time. Another viable option is the 0-10v wireless dimmer. This controller is small and easy to add onto any existing light fixture to gain the ability to remotely dim the light. It has 10 settings ranging from 10 percent to 100 percent light output that can be remotely controlled or have preset settings (Echelon, 2017).

5.2. Wi-Fi

Implementing Wi-Fi into our smart street lights is important for OSU. One major issue with wifi reception is that wifi from university buildings only works when you are right next to a building or inside of it. This creates dead zones on the sidewalks and streets, and is problem is easily solved by adding wifi modems into the street lights.

Information about the current wifi was provided by a representative from the of the Chief Information Officer, Ryan Holland. As of 11/1/2017, only three street lights on the Columbus campus have wifi. Two are located on the east side of Thompson Library and one outside of Sullivant Hall. According to ENGIE, the new lights will includes the wifi feature. Exact costs for this feature will be available soon, as ENGIE is at the beginning stages of this project.

For future research considerations, as noted in the benchmark analysis of Detroit, it may be of benefit to consider implementing different LED light models in different areas around campus. This will account for areas who are in high and low pedestrian usage and could ultimately result in higher savings and lower energy consumption. The case study of WYDOT provided information that leads to recommending that future research be conducted in using the cost savings from the conversion of LED lights for other expenses. If not expenses, OSU could use savings on further sustainability efforts such as providing grants for research or allocation toward other projects. Additionally, research should be conducted on the amount of light that is projected from the conversion of street lights to determine if they will contribute to light pollution in Columbus. Lastly, attitudes and opinions of pedestrians needs to be considered.

## 7. Conclusion

After calculating the costs and benefits related to replacing OSU's current street lights with new energy efficient LED lights, we have found that switching to more energy-efficient street lights will generate significant private and public benefits. By converting old lights to the new LED lights, Ohio State could save anywhere from $8,066/year with a 10-percent conversion to $80,660/ year with a 100 percent conversion. With our recommendation of a 100 percent conversion, Ohio State would not only reduce its energy usage but reduce its yearly carbon footprint by 1,183.84 tons per year. This reduction benefits social value which is an effort of the goas of Smart Columbus and relates to the sustainability initiatives at OSU. Additional features like Wi-Fi can potentially also create significant benefits to decrease the dead zones without Wi-Fi signal that students and faculty face when commuting around Ohio State. Although the project may seem like a hefty investment, it is a smart one with a payback period of only 8 years and many savings to follow after. Drawing on the successful projects in Detroit, Michigan and in

Casper and Cheyenne, Wyoming, we believe that this conversion on OSU's campus can be successfully implemented. This conversion will also improve our progress towards sustainability, and we are excited to see the university and ENGIE pursue even more sustainability centered projects in the future.

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# 9. Appendices

## 9.1. Additional information about LEDs

**LED's- (Light Emitting Diode)** create light with the use of a semiconductor that converts electricity into light. These diodes are great because they are small, less than 1 square millimeter and create very little heat. LED's also project light in a specific direction reducing the need for light diffusers, reflectors and traps. The amount of light produced by LED's is also considerably higher than Incandescent and CFL's. A bulbs Luminous efficiency is calculated by the amount of emitted light in lumens divided by the power it draws in watts. If a bulb were 100 percent efficient it would produce 683 lumens per watt it uses. Incandescent bulbs rated from about 60-100 watts has an efficiency of 15 lumens per watt. Compared to a CFL bulb that has an efficiency of around 73 lumens per watt consumed. Both of these options are very poor compared to LED's that produce around 701120 lumens per watt with an average of 85 lumens per watt consumed. Although the average is not much higher, you are not using mercury in the production of these LEDS.

9.2. Map of street light placement around main campus

Each orange dot represents a street light's location on main campus. Courtesy of ENGIE.