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Comparative Life Cycle Assessment of Lamps Used in a Classroom at Arizona State University

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ASU-SSEBE-CESEM-2014-CPR-003
Course Project Report Series

June 2014

Comparative Life Cycle Assessment of T8 Lamps Used in a Classroom at Arizona State University

Life Cycle Assessment for Civil Systems – Dr. Chester
SOS 598 : Spring 2014

Final Report

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Background:

A typical classroom at Arizona State University uses T8 fluorescent light bulbs. Newer technologies include an LED T8 equivalent. Fluorescent bulbs use mercury vapor to produce visible light, and LED bulbs contain light-emitting diodes. A plethora of life cycle assessments have been conducted to compare different types of light bulbs. However, no existing LCAs which specifically analyze fluorescent and LED T8 lamps could be found. The goal is to fill this gap by analyzing the environmental and economical impacts of these different lamps in a specific scenario relevant to Arizona State University.

Introduction:

The ultimate goal of this LCA is to give Arizona State University specific advice on possible changes in lighting systems that will reduce environmental impacts and support ASU's sustainability efforts. The aim is to assess the potential for a decrease in specific environmental impacts (CO2 emissions and energy use) and economic impact (cost) from changing to a different type of lighting in a prototypical classroom in Wrigley Hall. The scope of this assessment is to analyze the impacts of T8 lamps lasting 50,000 hours. Thus, a functional unit was defined as 50,000 hours of use, maintaining roughly 825 lumens. To put this in perspective, 50,000 hours is equivalent to 8 hours of use per day, 365 days per year, for approximately 17.1 years.

An attributional LCA was conducted comparing two T8 lamps: a fluorescent 32 watt bulb, and an LED 22 watt bulb. Due to a lack of existing data on the T8 lamps, data from existing LCAs of screw-base CFL 15 watt lamps and LED 12.5 watt lamps was used for the raw material extraction and manufacturing phases. Actual LCI data on the T8s was used for calculation in the use phase of the Life Cycle Assessment. The indicators chosen were Global Warming Potential (GWP), measured in kg CO2 eq., energy, measured in kWh, and cost, measured in US dollars.

Methodology:

The methodology used in this LCA included the following steps, which are outlined below. Each step is elaborated further within this section:

Step 1: Defined the scope and system boundary of the study.
Step 2: Selected two types of T8 lamps for comparison in this study and defined a functional unit.
Step 3: Defined three indicators and used these to compare the two lamps.
Step 4: Collected Life Cycle Inventory (LCI) data from existing LCA studies of screw-base compact fluorescent and LED lamps for cradle-to-gate phases.
Step 5: Converted the LCI data for screw-base lamps to data for T8 lamps by multiplying by a mass ratio factor.
Step 6: Calculated the use phase of each T8 lighting option based on its energy consumption and associated impacts.
Step 7: Combined the LCI data gathered and calculated from Steps 4 and 5 to provide relevant data for analysis.

Step 1: Scope and System Boundary

The goal of this LCA study is to understand all that goes into the lighting of one basement room in Wrigley Hall each day. A basement classroom was selected in order to hold the amount of natural light constant at 0 lumens. The focus of this study is narrowed to scope of the impacts of just one light bulb for a certain period of time. This includes impacts associated with the lamps only, and not those associated with the fixtures, electrical hook ups, or other necessary lighting components such as ballasts. Not only does this study consider the production of each lamp, but also the electricity used to power the lamp, how the power is generated and the impacts of that generation. After the impacts from each individual lamp are assessed and analyzed, the results are compiled in order to discuss the impacts of an entire classroom.

The system boundary (illustrated in **Figure 1** and described in **Table 1**) for this LCA includes three life cycle phases: raw material extraction, manufacturing and use. It is a cradle-to-use analysis while disregarding the transportation phase.

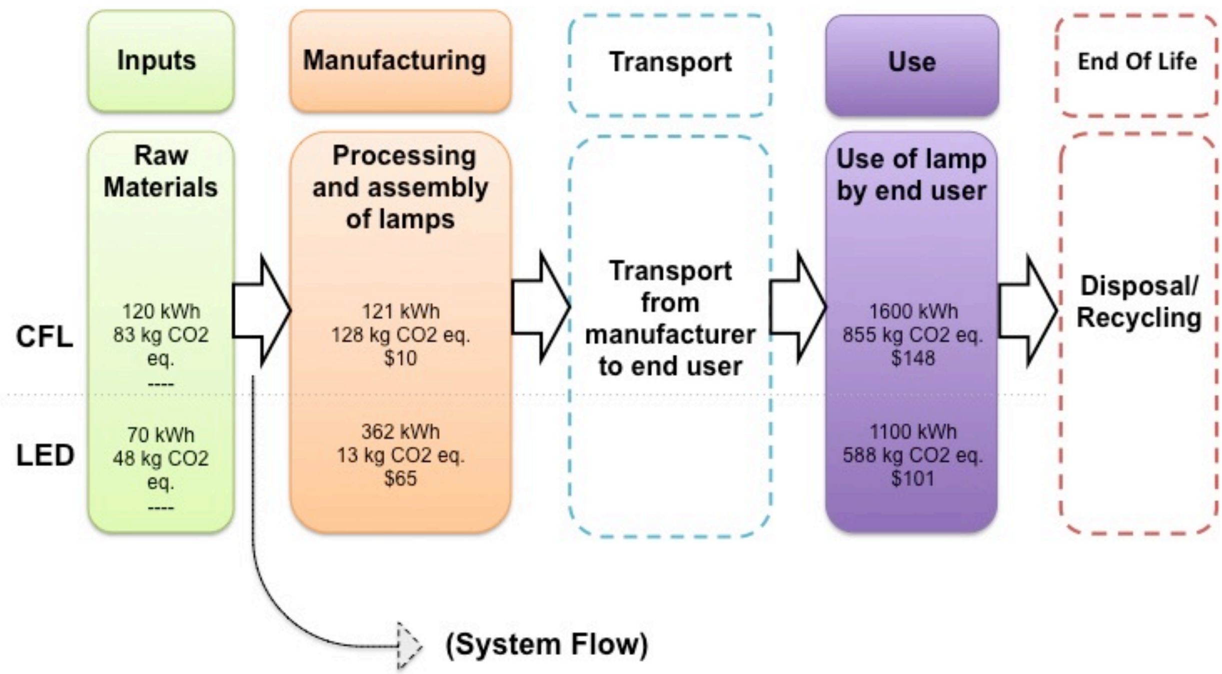

Figure 1: System Boundary used throughout the LCA

Table 1: Summary of Life Cycle Phases Used in the LCA

Life Cycle Phase:	Included?	Summary of Phase
Inputs (Raw materials extraction)	✓	This phase accounts for the emissions and resource usage resulting from the extraction of the raw materials needed to construct each lamp. Raw materials extraction associated with power generation for the electricity is not considered within the system boundary.
Manufacturing (Processing and assembly of lamps)	✓	The manufacturing phase considers the processes involved in manufacturing the lamp out of the raw materials and the assembly of the lamp at the manufacturing site. It considers the energy used throughout the process of manufacturing the lamp, as well as the emissions associated with fabricating each lamp.

Transportation (Transportation from manufacturing site to end user)	✗	The phase of the life cycle where each lamp is distributed from the manufacturer to the end user is not considered. Compared to other life cycle stages, the impacts associated with the transportation and distribution stages are negligible[1].
Use (Use of lamp by end user)	✓	The energy use, CO2 emissions and cost associated with this phase are calculated based upon the electricity consumed by 50,000 hours of use.
End of life (Disposal/recycling of lamps after use)	✗	This phase of the life cycle is not included in the system boundary. Lamps containing mercury are considered hazardous waste material and so the end of life choices for disposal or recycling are left up to the discretion of each end user and their regional regulations[2]. Under consideration for the scope of this LCA, it was determined that this phase in the life cycle of each light bulb could be determined by ASU's policies and did not need to be included for this study.

Step 2: Lamp Selection and Definition of Function Unit

This project is a comparative study, therefore two different lighting technologies were chosen for analysis. Fluorescent T8 lamps rated at 32 watts, which are currently used in the sample classroom, are being compared in this study to the possibility of 22 watt LED T8 replacements. Since published LCI data on T8 lamps is scarce this study chose to find data on a screw-base 15 watt CFL and a 12.5 watt LED lamp for the raw material extraction and manufacturing phases and then extrapolated that data for use in this study.

The average lifetime of one 22 watt LED T8 lamp - 50,000 hours[3] - was used as the functional unit. The average lifetime of one 32 watt fluorescent T8 lamp is 30,000 hours[4]. Therefore, two fluorescent T8 lamps must be manufactured and put into use in order to reach the lifetime of one LED T8 lamp.

Step 3: Defined Indicators

The three indicators for measuring environmental or economical impacts of each lighting option in this study are Energy, measured in kWh, Global Warming Potential (GWP), measured in kg CO2 eq., and Cost, measured in US Dollars. It is believed that these three impacts are the most relevant to ASU and will allow the responsible parties to make the best decision regarding which type of lamp to use in the future.

[1] US Department of Energy, 2012b, p. 13
[2] US Environmental Protection Agency, n.d.
[3] Premier Lighting, 2013
[4] Premier Lighting, 2013

Step 4: Collected Life Cycle Inventory (LCI)

The following information is used to gather data for the cradle-to-gate part of the study for the first two indicators, Energy and GWP. Due to a lack of data on T8 lamps, existing Life Cycle Inventory data was used for screw-base lamps instead. Actual data on T8 lamps was used for the cost indicator. In order to maintain a consistent period of operation two fluorescent T8 lamps need to be produced to match the lifetime of one LED T8 (see step 2). Therefore, the final data for the screw-base CFL lamps and fluorescent T8 lamps is multiplied by 2. It is assumed that the screw-base lamps have the same lifetimes as their T8 counterparts (30,000 hours for fluorescent, and 50,000 hours for LED).

Indicator 1: Energy

CFL:
Using a conversion factor of 6.9×10^{-4} metric tons of CO2 / kWh[5] for raw material extraction, the global warming potential associated with the raw material extraction for the production of screw-base compact fluorescent lamps (10.68 kg CO2 eq[6]) was converted to the equivalent energy usage of 15.478 kWh. During the manufacturing life-cycle phase 170 MJ/20 million lumen hours[7] was converted to 15.58 kWh (See Table 11 in Appendix). Thus, for one CFL screw-base lamp, the total energy used during the raw material extraction and manufacturing phases is 31.058 kWh x 2 (lamps produced) = 62.116 kWh.

LED:
Using the same conversion factor, the global warming potential associated with the raw material extraction for the production of screw-based LED lamps (12.752 kg CO2 eq[8]) as converted to the equivalent energy usage of 18.481 kWh. During the manufacturing life-cycle phase 343 MJ/20 million[9] lumen hours was converted to 95.28 kWh (See Table 11 in Appendix). Thus, for one LED screw-base lamp, the total energy used during raw material extraction and manufacturing is 113.761 kWh.

Indicator 2: GWP

CFL:
The global warming potential associated with raw material extraction of a compact fluorescent lamp is 10.68 kg CO2 eq[10] x 2 (lamps produced) = 21.36 kg CO2 eq. The global warming potential associated with manufacturing of a compact fluorescent lamps is 16.56 kg CO2 eq[11] x 2 (lamps produced) = 33.12 kg CO2 eq. Thus, for one CFL screw-base lamp, the total GWP for raw material extraction and manufacturing is 54.48 kg CO2 eq.

LED:
The global warming potential associated with raw material extraction of a LED screw-base lamp is 12.752 kg CO2 eq[12]. The global warming potential associated with manufacturing a

[5] US Department of Energy, 2012a, p. 43
[6] US Department of Energy, 2012b, p. 50, Table 7-2
[7] US Department of Energy, 2012a, p. 30, Table 4.5
[8] US Department of Energy, 2012b, p. 50, Table 7-3
[9] US Department of Energy, 2012b, p. 50, Table 7-2
[10] US Department of Energy, 2012b, p. 50, Table 7-2
[11] US Department of Energy, 2012b, p. 50, Table 7-2
[12] US Department of Energy, 2012b, p. 50, Table 7-3

LED screw-base lamp is 3.45 kg CO2 eq[13]. Thus, for one LED screw-base lamp, the total GWP associated with raw material extraction and manufacturing is 16.202 kg CO2 eq.

Indicator 3: Cost

It is assumed that the purchasing price of each lamp from a retailer includes the cost of raw material extraction and manufacturing. Average prices for both compact fluorescent and LED T8 lamps were used, $5 and $65[14], respectively. However, two fluorescent T8 lamps need to be purchased in order to reach 50,000 hours of use, so the price of the fluorescent T8 lamps is actually $10.

Step 5: LCI Data Conversion

The average mass of both a screw-base CFL and an LED lamp was calculated by using the information for CFL-1 and LED-1 in the EPA's LCA[15]. Based on this information, the average mass of a screw-base CFL bulb is 58.1 grams, and the average mass of a screw-base LED bulb is 179 grams. The mass of a fluorescent T8 lamp is 225 grams, and the mass of an LED T8 lamp is 680 grams[16]. For the raw materials extraction and manufacturing phases, it was assumed that impacts are proportional to mass. Thus, the final data for the screw-base lamps (see below) was multiplied by 3.873 for the CFL lamps and 3.799 for the LED lamps in order to calculate impacts for fluorescent T8 lamps and LED T8 lamps, respectively. These conversions by mass are displayed in **Table 2**. The cost indicator is not affected by this mass ratio.

Table 2: Energy and GWP for the Raw Materials Extraction and Manufacturing Phases of the Life Cycle

	Energy for Screw-base lamp	**Mass Ratio**	**Energy for T8 lamp**
Fluorescent T8	62.116 kWh	3.873	240.575 kWh
LED T8	113.761 kWh	3.799	432.178 kWh
	GWP for Screw-base lamp		**GWP for T8 lamp**
Fluorescent T8	54.48 kg CO2 eq.	3.873	211.001 kg CO2 eq
LED T8	16.202 kg CO2 eq	3.799	61.551 kg CO2 eq

Step 6: Use Phase Calculations

Indicator 1: Energy

The energy consumed by each lamp was calculated during the use phase based on the watts each lamp is rated for (32 watts for fluorescent T8s, 22 watts for LED T8s) and throughout

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13 US Department of Energy, 2012b, p. 50, Table 7-3
14 Premier Lighting, 2013
15 US Department of Energy, 2013, p. 35, Table 5-9
16 Osram Sylvania Warehouse Personnel, personal communication, February 27, 2014

the functional unit of 50,000 hours. Fluorescent T8s use 1600 kWh and LED T8s use 1100 kWh.

Indicator 2: GWP

The energy calculations from Indicator 1 were used along with the Arizona New Mexico (AZNM) subregion CO2 output emission rate from the EPA, 1177.61 lbs CO2 eq / MWh[17], to determine the use phase CO2 emissions for both types of lamps. Thus it was calculated that the global warming potential during the use phase is 855.42 kg CO2 eq for fluorescent T8 lamps and 588.10 kg CO2 eq for LED T8 lamps.

Indicator 3: Cost

In order to determine the price per kWh, the average monthly price of electricity was obtained using the SRP Standard Price Plan[18], which is used by commercial, business, and professional customers. This average was calculated to be $0.0924 per kWh. The cost of the use phase for each lighting option was then calculated by multiplying the energy used by this price. The operational cost of a fluorescent T8 was found to be $147.84 where as the operation cost of a LED T8 was $101.64.

Step 7: Aggregation of Data

The gathered LCI data was combined from Step 4 and Step 5, and was added to the use phase calculations in Step 6 for all three indicators to obtain the total life cycle impacts of each type of lamp (**Tables 3-5**).

Table 3: Energy Use (kWh) per 50,000 hours

	Fluorescent T8	LED T8
Raw Materials Extraction	119.892	70.209
Manufacturing	120.682	361.969
Use	1600	1100
Total	**1840.575**	**1532.178**

Table 4: Global Warming Potential (kg CO2 eq.) per 50,000 hours

	Fluorescent T8	LED T8
Raw Materials Extraction	82.727	48.445
Manufacturing	128.274	13.107
Use	855.416	588.098
Total	**1066.417**	**649.650**

Table 5: Cost (U.S. Dollars) per 50,000 hours

	Fluorescent T8	LED T8
Price of bulb(s) (represents raw material extraction and manufacturing)	10	65
Use	147.84	101.64
Total	**157.84**	**166.64**

[17] US Environmental Protection Agency, 2014, p. 1
[18] Salt River Project Agricultural Improvement and Power District, 2012, p. 3

Results:

As previously mentioned, the three indicators of interest are energy use, global warming potential, and economic cost. These indicators are based on cradle-to-use data, with a functional unit of 50,000 hours of roughly 825 lumens per lamp assuming quality of light is the same. For each indicator, the data provided is calculated for one T8 LED lamp (equivalent to one LED lifetime of 50,000 hours) and two fluorescent T8 lamps because two of them will be required to last for a lifetime of at least 50,000 hours.

Indicator 1: Energy Use

The largest impacts on energy come from the use of the lamps. Fluorescent T8 lamps consume more energy than LED lamps per 50,000 hours of use. The extraction of raw materials for fluorescent lamps consumes more energy than for LED lamps, because two lamps need to be produced in order to last for 50,000 hours. However, the manufacturing of one LED lamp consumes more energy than manufacturing two fluorescent lamps. Overall, fluorescent lamps consume more energy than LED lamps from raw material extraction through use. **Table 6** and **Figure 2** show the results for this indicator.

Table 6: Total energy use for each lighting option.

Phases	Energy (kWh) per 50,000 hours	
	Fluorescent T8	LED T8
Raw Materials Extraction	119.89	70.21
Manufacturing	120.68	361.97
Use	1600.00	1100.00
Total	**1840.58**	**1532.18**

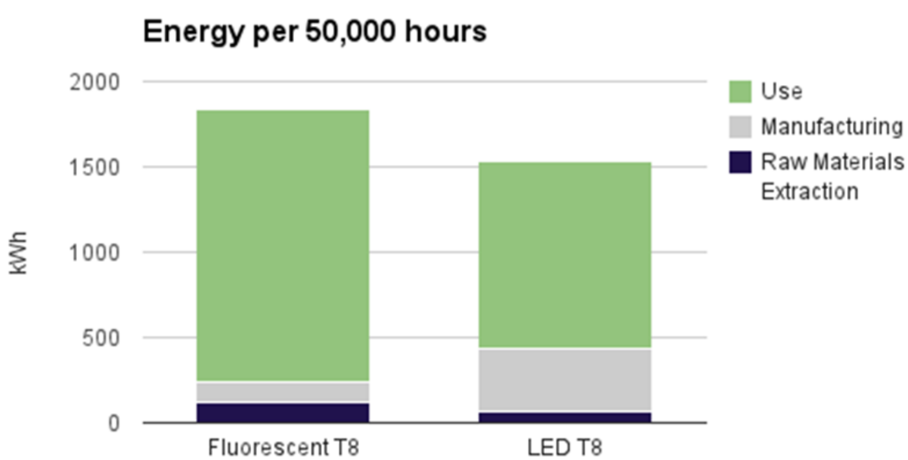

Figure 2: Total energy consumption for each lighting option, per 50,000 hours of use

Indicator 2: Global Warming Potential

Similar to energy, the largest impacts on global warming potential come from the use phase. This is largely due to the energy mix for this region in Arizona. Fluorescent T8 lamps produce more kg CO2 eq. than LED lamps do per 50,000 hours of use. Raw material extraction and manufacturing both produce more kg CO2 eq. for fluorescent lamps than for LED lamps as well. Overall, fluorescent lamps produce more kg CO2 eq. than LED lamps do from raw material extraction through use. **Table 7** and **Figure 3** show the results for this indicator.

Table 7: Total global warming potential for each lighting option.

Phases	GWP (kq CO2 eq.) per 50,000 hours	
	Fluorescent T8	LED T8
Raw Materials Extraction	82.73	48.45
Manufacturing	128.27	13.11
Use	855.42	588.10
Total	**1066.42**	**649.65**

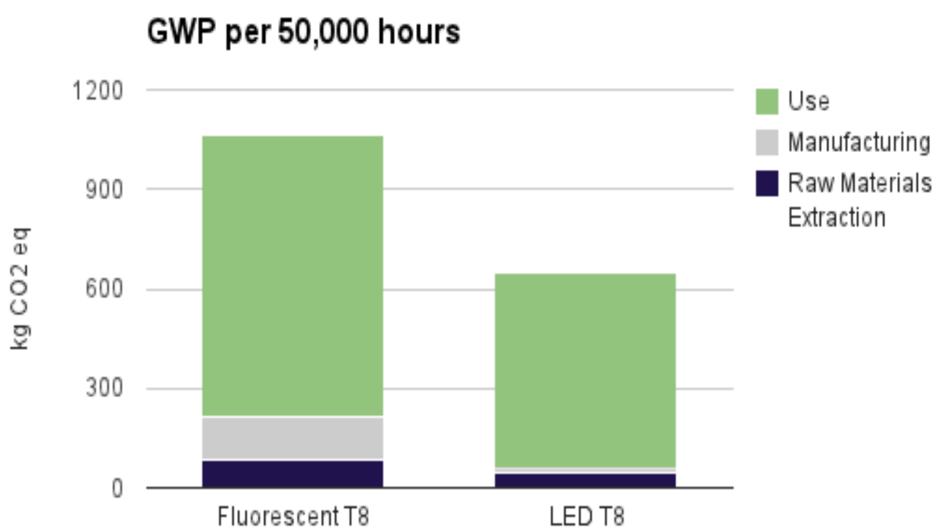

Figure 3: Global warming potential for each lighting option

Indicator 3: Cost

The current retail price of a light bulb is the largest impact for LED lamps. Fluorescent lamps are much less expensive than LED lamps. Even though two fluorescent lamps are needed to reach 50,000 hours, the two fluorescent lamps are still less expensive than one LED lamp. However, the cost of using the lamps for 50,000 hours is higher for fluorescents than for LEDs. Overall, LED lamps cost more than fluorescent lamps. However, these results are extremely sensitive to the price of the lamps. For instance, if the LED lamps only cost $40 instead of $65, the results would flip, and LED lamps would cost less overall than fluorescent lamps. **Table 8** and **Figure 4** show the results for this indicator.

Table 8: Total cost for each lighting option

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Phases	Cost (U.S. Dollars) per 50,000 hours	
	Fluorescent T8	LED T8
Price (Raw Materials Extraction and Manufacturing)	10.00	65.00
Use (Based on energy usage)	147.84	101.64
Total	**157.84**	**166.64**

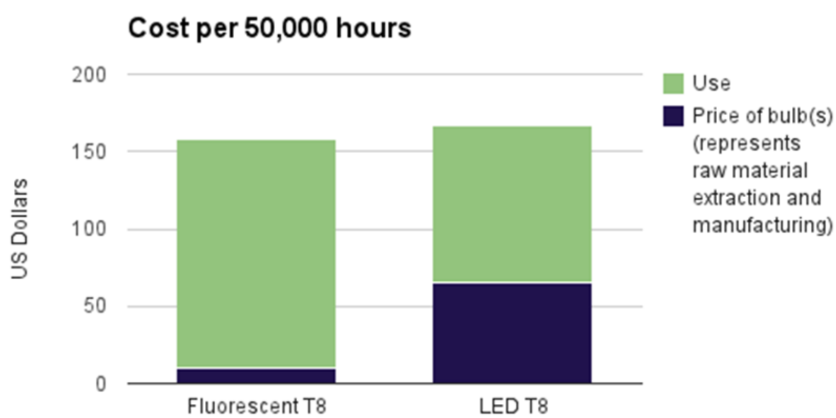

Figure 4: Total cost for each lighting option, per 50,000 hours use

Uncertainty:

There are two methods to address uncertainty within this project: uncertainty within the methodology and uncertainty within the data collected.

1. Uncertainty within the methodology:

There are many assumptions within the report that create an abundance of uncertainty. For instance, the lack of available life cycle impact assessment data on T8 fluorescent and LED lamps required us to approximate these findings. The procedure to do so is based on acquiring data for screw-base lamps and then extrapolating that data for use in our study based on mass proportionality between screw-base lamps and their T8 equivalents. Therefore, we are assuming that the impacts associated with one kilogram of the screw-base CFL are the same for one kilogram of the T8 fluorescent lamp. This assumption that the impacts we are researching are proportional by mass from the screw-base lamps to their T8 equivalents is a large uncertainty. It is very probable that T8 equivalents require a completely different manufacturing process, thus resulting in differing impacts associated with that phase. Also, it is known that the LED T8s have separate components to their fixture, and require an attached ballast system to function properly. The mass of this ballast was absorbed into the mass of the individual lamp to simplify the mass conversion calculations. This assumption was used to simplify the results for the purpose of this study, so impacts associated with raw material extraction and manufacturing of the ballast component were ignored.

As previously mentioned, the end of life phase for each lamp type was not taken into account. If end of life data were to be included in this study, the overall impacts for the three indicators would likely increase. The intentional exclusion of the end of life impacts is a point of uncertainty that has the potential to change the results to favor one lighting option more strongly than the other.

2. Uncertainties within the data collected:

All of the data used in the study is coming from secondary data sources and it is assumed that the data used is as accurate as possible for the purpose of this study. The data sources used for this study include some uncertainty because the data was not collected first hand by the team. Because the uncertainty of the data cannot be quantified, a pedigree matrix was used to assess uncertainty. The template used for scoring each uncertainty aspect in the pedigree matrix[19] is included in **Table 10** in the appendix. The scores assigned for each aspect of uncertainty are shown in **Table 9** below.

[19] Chester, M., 2014, p. 24

Table 9: Data Quality Assessment Pedigree Matrix

Criteria	Score
Impact on Final Result	2
Acquisition Method	2
Independence of Data Supplier	1
Representation	1
Temporal Correlation	1
Geographical Correlation	1
Technological Correlation	4
Range of Variation	5

As explained above, the main source of uncertainty in our project came from the mass equivalency assumption that is explained in the methodology. This is reflected in the high scores that we assigned to the “technological correlation” and “range of variation” indicators. The remaining indicators were all scored as either 1 or 2, indicating that there is not much room for improvement in those categories. If reductions in uncertainty are to be made, the best place to start would be in the mass equivalency assumption. If there were existing LCAs on Fluorescent and LED T8s this data would greatly reduce the uncertainty in the study.

Conclusion:

According to Sustainability Operations at ASU, "ASU takes seriously reducing consumption, maximizing efficiency and rethinking products and actions[20]." The results from this study prove to be very useful to ASU when looking at ways to maximize efficiency and move toward more sustainable operations. Results show that LED T8 lamps use less energy and have less of an impact on global warming potential for 50,000 hours of use compared to fluorescent T8 lamps.

In order to translate this data into useable information for ASU decision making, this study is applied to a prototypical ASU classroom. Specifically, this study used Wrigley Hall L1-14, where there are currently 36 lamps used to sufficiently light the room. Therefore, all of the indicators that are measured per lamp must be multiplied by a factor of 36 to get the total impact from illuminating one classroom. Switching to LED T8 lamps can lead to widespread effects across the campus, and may even be able to help in changing lamp use and purchasing policy. These effects determined within the scope of this study may include a 40% decrease in GWP and a 17% decrease in energy consumption. However, cost is estimated to increase by 6%.

Although LED T8s are more expensive than fluorescent T8s, it is still recommended that ASU transition to LED T8s. Over the lifetime of the LED T8 lamps, the savings in energy use will help offset the higher cost of the new lamps. In addition, if ASU is able to receive bulk purchasing rates for the LED T8s, the cost indicator may switch to show that LEDs are more cost efficient. The cost indicator is very sensitive as previously mentioned, and this may be a deciding factor in ASU's decision. According to Nick Brown, Director of University Sustainability Practices, ASU does not have an overarching body that regulates lamps purchased for campus facilities[21]. It is recommended that ASU creates a standard purchasing policy that will allow for uniformity in implementation of LED T8s in campus facilities. Going forward, this study can be used as a starting point for analyzing the entire cradle to grave life cycle for both LED and fluorescent T8s.

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[20] Arizona State University Global Institute of Sustainability, n.d.

[21] Personal communication with Nick Brown, February 28, 2014

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Appendix:

Table 10: Data quality assessment pedigree matrix scoring guidelines

Criteria	Indicator Score				
	1	2	3	4	5
Impact on Final Result	Parameter is the top contributor to final result	Parameter is within the top 5 contributors to final result	Parameter is within the top 10 contributors to final result	Parameter is not likely to affect final results significantly	Parameter contribution is unknown
Acquisition Method	Measured data	Calculated data based on measurements	Calculated data partly based on assumptions	Qualified estimate (by industrial expert)	Nonqualified estimate
Independence of Data Supplier	Verified data, information from public or other independent source	Verified information from enterprise with interest in the study	Independent source, but based on nonverified information from industry	Nonverified information from industry	Nonverified information from the enterprise interested in the study
Representation	Representative data from sufficient sample of sites over and adequate period to even out normal fluctuations	Representative data from smaller number of sites but for adequate periods	Representative data from adequate number of sites, but from shorter periods	Data from adequate number of sites, but shorter periods	Representativeness unknown or incomplete data from smaller number of sites and/or from shorter periods
Temporal Correlation	Less than three years of difference to year of study	Less than five years of difference	Less than 10 years of difference	Less than 20 years of difference	Age unknown or more than 20 years of difference
Geographical Correlation	Data from area under study	Average data from larger area in which the area of study is included	Data from area with similar production conditions	Data from area with slightly similar production conditions	Data from unknown area or area with very different production conditions
Technological Correlation	Data from enterprises, processes and materials under study	Data from processes and materials under study, but from different enterprises	Data from processes and materials under study, but from different technology	Data on related processes or materials, but same technology	Data on related processes or materials, but different technology
Range of Variation	Estimate is a fixed and deterministic number	Estimate is likely to vary within a 5% range	Estimate is likely to vary within a 10% range	Estimate is likely to vary more than 10%	Estimate is likely to vary under unknown ranges

Table 11: Calculation Spreadsheet

			MJ	1MJ/20 Mlm-hr	kwh/MJ	Mlm-hr/bulb	kwh/bulb	# of bulbs needed for = lifetimes	kWh	Mass ratio	T8 equivalent	Total kWh
Energy	(Manufacturing)	CFL (15 W)	170	20	0.28	6.6	15.58	2	31.16	3.873	120.68268	1840.575268
		LED (12.5 W)	343	20	0.28	20	95.28	1	95.28	3.799	361.96872	1532.178039
				kg CO2 eq./bulb	Metric Tons CO2/kWh	kg/metric ton	kwh/bulb					
	(Raw Material Extraction)	CFL		10.68	0.00069	1000	15.478	2	30.956	3.873	119.892588	
		LED		12.752	0.00069	1000	18.481	1	18.481	3.799	70.209319	
				Lifetime (hrs/bulb)	Watts	kW/Watt	kwh/bulb					
	(Use)	Fluorescent		30000	32	0.001	960	1.66666666666667	1600		1600	
		LED		50000	22	0.001	1100	1	1100		1100	
							kg CO2 eq. /bulb	# of bulbs needed for = lifetimes	kg CO2 eq.	Mass ratio	T8 equivalent	Total kg CO2 eq.
CO2	(Manufacturing)	CFL					16.56	2	33.12	3.873	128.27376	1066.416944
		LED					3.45	1	3.45	3.799	13.10655	649.649832
							kg CO2 eq. /bulb					
	(Raw Material Extraction)	CFL					10.68	2	21.36	3.873	82.72728	
		LED					12.752	1	12.752	3.799	48.444848	
			lbs CO2 eq/MWh	MWh/kWh	kg/lb	kwh/bulb	kg CO2 eq. /bulb					
	(Use)	Fluorescent	1177.61	0.001	0.454	960	513.2495424	1.66666666666667	855.415904		855.415904	
		LED	1177.61	0.001	0.454	1100	588.098434	1	588.098434		588.098434	
								Dollars	# of bulbs needed for = lifetimes	Total price of bulbs		Total cost (dollars)
Cost	Price of bulb (Manufacturing and Raw Material Extraction assumed to be included)	Fluorescent						5	2	10		157.84
		LED						65	1	65		166.64
			Lifetime (hrs/bulb)	Watts	kWh/Watt	kwh/bulb	Price per kWh (average) (dollars)	Price of use per bulb (dollars)	# of bulbs needed for = lifetimes	Total cost of use for 50,000 hours per bulb (dollars)		
	(Use)	Fluorescent	30000	32	0.001	960	0.0924	88.704	1.66666666666667	147.84		
		LED	50000	22	0.001	1100	0.0924	101.64	1	101.64		