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16. Abstract

With the slowing of the American economy since 2008, it has become imperative that municipalities identify areas in which costs can be reduced while still providing needed services to its constituents. The use of traffic signals equipped with light emitting diodes (LED) provides opportunities for urban municipalities to conserve both tax dollars and energy. With other advantages, such as the reduced maintenance, a longer life span, and more illumination than the standard incandescent light bulb, LED's have become a viable option in cities around the globe as a first step in reducing municipal costs. Furthermore, LED traffic signals could be retrofitted to solar energy in the future thereby enhancing the move towards "green" technologies. The City of Houston is the focus of this case study evaluating the use of LED traffic signals at selected intersections in and near the urban core.

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The Impact of the Conversion of Incandescent Bulbs to the LED Light Source in Traffic Signals in Houston: A Step toward Sustainable Control Devices

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ABSTRACT

The use of Light Emitting Diodes (LED) Traffic Signals provides an opportunity for the City of Houston to save both money and energy. With other advantages such as reduced need for maintenance, a longer life span, and more illumination than the standard incandescent light bulb, LED's have become a viable option in cities around the globe as a first step in reducing costs. Furthermore, LED traffic signals could be retrofitted to solar energy in the future thereby enhancing the move towards "green" technologies.

EXECUTIVE SUMMARY

New infrastructure using renewable energy technologies that are both cost and energy effective have replaced aging infrastructure throughout the city. One of the ways Houston has made steps in this direction was the conversion of traffic signals from incandescent bulbs to the LED light source. This study examines multiple scenarios of incandescent versus LED light sources. A simulation is presented based upon previously calculated costs, power consumption data, and installation costs. These variables provide a base line for the retrofit of existing incandescent traffic controls to an LED based light source and the associated costs of each intersection. Although the retrofit to LED requires a substantial financial commitment upfront, it is anticipated that the cost savings will ultimately outweigh the initial investments when compared to the traditional incandescent light source.

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INTRODUCTION

As the fourth largest city in the United States, the city of Houston has developed into a world leader in the energy industries world-wide. As such, city leaders have embraced strategies that enhance this global positioning. Furthermore, local analysts anticipate continued population growth throughout the region, primarily due to the relatively warm weather, low cost of living, and a prosperous economy. Advances in infrastructure improvements are one of the ways the city has decided to go in order meet the needs of its constituency.

Through the installations of light emitting diodes (LEDs) in traffic signals, the city has an opportunity to save both money and energy while incurring other benefits like extended equipment life span, increased illumination, and a reduced maintenance. The conversion also serves as a stepping stone when city leaders decide to transition to solar powered traffic controls in the future.

BACKGROUND

As municipalities find ways to reduce costs, many have looked towards the retrofitting of traffic signals from traditional incandescent bulbs to LEDs. Recent studies indicate that the benefits of transitioning to LEDs vastly outweigh the short-term costs and inconveniences associated with replacing hundreds lights at intersections across the city. The following discussion represents the benefits of LED conversions, the costs of installation, and a comparison of power consumption by both incandescent and LED light sources.

In 2003, the Arkansas Department of Economic Development sponsored a study to research the advantages and disadvantages of converting traffic intersections to LED lights. The cost and wattage savings were then compared at six similar intersections, three with incandescent bulbs and the other three with LED. The study found that there was a 90% energy savings from the intersections retrofitted with LEDs consuming on average 111 kWh per month compared to the 1,203 kWh per month used at intersections with incandescent bulbs. With the many benefits that the retrofit proved, the city of Little Rock decided to retrofit all 263 signalized intersections in the city. ("Arkansas")

In Texas, the City of Houston has been designated as a solar city and has begun the conversion of 300 traffic lights to LED, finding that 85% less energy is being used. They acknowledge the benefits of using LEDs including reduced maintenance costs, a decrease in the amount of emissions produced, cost savings in replacing the bulbs, and also the long life span of the light source lasting around 100,000 hours, which equates to about 11 years. The city plans to continue expanding the retrofitting process to all other signals in the city and require all future signal installations to be LED. ("Green Houston")

The *Journal of Chemical Education* in 2001 published an article detailing the benefits of LEDs compared to the pitfalls of traditional signal lights and their utilization in the transportation industry. The authors compare the life spans of both light sources, 1000 hrs for the incandescent bulb and 100,000 for LEDs, and emphasize the reduced maintenance and replacement costs by switching. The energy consumption of the light sources is also mentioned heeding the significant differences in typical wattages, 150W for incandescent and 20W for LEDs, which produce the most energy and cost savings. The article also discusses how the brighter illumination of LEDs versus incandescent bulbs creates safer road conditions in the daylight as well as evening hours. (Condren, Lisensky, Ellis, and et al 1033-1040)

METHODOLOGY

In this simulation study, various data methods, including literature review, interviewing contracted consultants, and meeting with a local City of Houston representative were used. Literature review provided valuable information on the advantages and disadvantages of LEDs, as well as gave data that could be used to compare the benefits of LEDs vs. the traditional incandescent light bulbs. Talking to the contracted consultants and City of Houston representative helped to identify those strategies to improve intersection mobility and safety while reducing municipal expenses. Many intersections have already been converted to LEDs and have realized significant energy savings without sacrificing safety. Therefore, data exists that document the costs savings and the costs of installation. From this information several scenarios were identified that illustrate 1) how signalized intersections are set up, 2) the amount of signal heads used in these areas, and 3) identify the installation costs and monthly power analysis of the LED light source.

DATA

Advantages and Disadvantages of Light Emitting Diodes vs. Incandescent Bulbs

Both LED and Incandescent bulbs have specific advantages in traffic signals. Incandescent bulbs are fifteen times cheaper than LED. They are not sensitive to the persistent warm temperatures of Houston, and they give off a pleasant visible light that drivers find appealing. The bulb also uses so much energy that when the bulb goes out it will trigger a computer alert letting maintenance crews know that the bulb needs replacing.

Although a substantially lower up-front cost is desirable, it alone does not outweigh the many advantages the LED light. LED's have a much longer life span with 100,000 hours of visible light versus the 10,000 hours that incandescent bulbs provide, which equates to 11 years compared to a little over 1 year respectively. With a longer lifespan, yearly bulb replacement is unnecessary, reducing the need for additional maintenance costs. They also consume less power, typically less than 20 watts compared to over 100 watts for an incandescent bulb. LEDs also provide brighter visibility than incandescent bulbs, which is an additional safety measure. The LED "bulb" is comprised of several discrete LED elements, or "diodes". Each diode gives off its own light, and if some diodes fail; the remaining diodes will still allow the LED bulb to function efficiently.

With their many amiable features both sources also have their shortcomings. Some of the other disadvantages of incandescent bulbs, aside from the pre-mentioned visible hours and shorter lifespan, are that they give off more heat energy than light, making them less efficient. They also do not have a slow fade i.e. when the incandescent bulb is about to die it does not dim with ample visibility, but rather s huts off immediately. This does not give maintenance crews preparation time to replace the bulb, and although it does trigger the computer, crews are not sitting by waiting to replace it, possibly causing traffic congestion or accidents. For example, let's say a green bulb goes out on a one way street and there is only one right of way signal. If that green bulb is out traffic in that direction will not know it is safe to pass and will continue to wait there causing traffic congestion or the drivers may become impatient and drive through the intersection possibly causing an accident. The major disadvantage of the LED is that the install cost is very high compared to the incandescent bulb, but they will pay for themselves in a few years. Due to their low power consumption, LEDs may not trigger a computer signal like the incandescent bulb to alert that it has failed, but they do fade slowly so that technicians have to time to monitor and prepare for their imminent dissolve.

Installation Cost Wattage Comparisons of the Light Sources

In order to do a city wide retrofit it is important to know what costs are incurred, and the amount of power consumed for the project. Incandescent bulbs have an easier cost strategy due to the fact that they are simply bulbs with a colored lens in front, therefore each bulb will be the same price. LED's however are made into their specific colors and therefore have varying costs. Over the years the cost of LED's has dropped significantly and many manufactures sell them around market price with a discount for larger orders. The reasoning for the power consumption is similar in cause. The figure below comes from the Texas Department of Transportation Material Supply and Management System Database. This data will be referred back to in the scenario studies and used to calculate the wattage, kilowatt hours (kWh) used per month, installation cost, and per month electricity cost for each intersection.

Figure 1: The Cost and Wattage Consumption by Individual Light Sources (Texas Department of Transportation material supply and management system database)

LED Bulbs			Incandescent Bulb	
Type	Power (watts/hr)	Cost/Bulb	Power (watts/ hr)	Cost/ Bulb
Green Arrow	8	$ 41.41	135	$ 2.76
Yellow Arrow	6.5	$ 41.58	135	$ 2.76
Red Arrow	6	$ 34.00	135	$ 2.76
Green Bulb	12	$ 51.00	135	$ 2.76
Yellow Bulb	18	$ 53.48	135	$ 2.76
Red Bulb	10.5	$ 37.00	135	$ 2.76

Scenario Simulation

Several intersections will be looked at for this simulation study. They will vary in traffic volume, location, right of way direction, and number of signals in hopes of describing what many of the intersections of Houston look like. The figure above will be used to calculate the following scenarios for wattage and cost.

Scenario 1: One Way Streets

One way streets are characterized by having traffic flow in only one direction. In Houston, this is most heavily seen in the Downtown area with two one way streets intersecting, allowing a continuous flow of traffic. Many of them consist of either 2 signal heads on one street with 3 signal heads on the other, 2 by 2, or 3 by 3. This can be seen in the diagrams below.

Diagram A: One Way Intersection

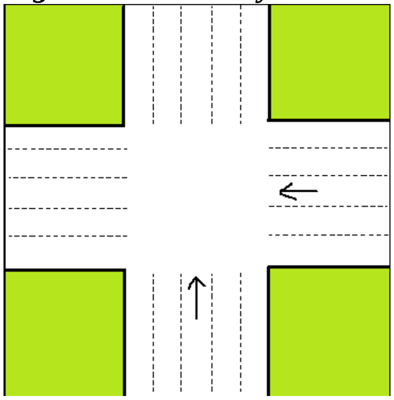
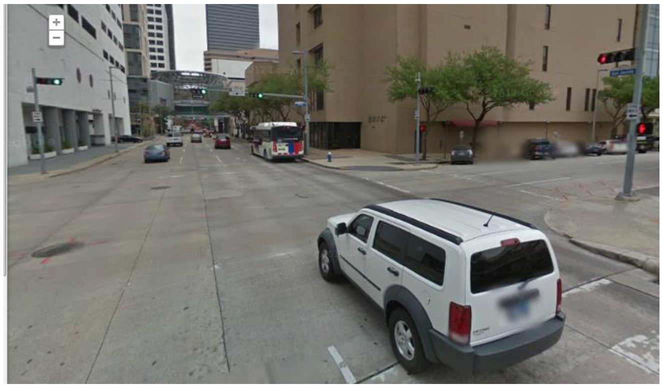


Diagram B: The Intersection of Clay at San Jacinto



The intersections of Clay and San Jacinto are represented as a 3 by 2, Dallas at Caroline as a 2 by 2, and Louisiana at Bell as a 3 by 3. There are 3 signal heads on Clay, and 2 on San Jacinto, all having a standard 3 color (red, yellow, and green) spectrum all in ball form. The Figure 2 shows the break down in cost and power consumption.

There are a total of 15 ball light sources at this location. If this intersection is installed with the LED light source, using $0.12 as the electric rate per kWh (blended rate), typically what Houston is charged, this intersection would cost $17.74 a month for electricity with 147.83 kWh used; compared to the $177.39 electricity cost with 1478.25 kWh that this intersection would cost with incandescent bulbs. On the other hand, the figure also shows that the cost for the retrofit of this intersection has a large discrepancy in install cost with $41.40 for incandescent bulbs versus $707.40 for LED installation. This gives a good idea for the cost and wattage cost and usage would be for intersections with similar set ups.

Figure 2: LED versus Incandescent Bulbs - Intersection of Clay at San Jacinto

Intersection of Clay at San Jacinto															
		LED Bulbs							Incandescent Bulb					
Type	# of lights	Power (watts/ hr)	Cost/Bulb	Total Wattage	Total KWH per month	Total Cost of bulbs for Intersection	Cost of Electricity for Month		Power (watts/ hr)	Cost/ Bulb	Total Wattage	Total KWH per month	Total Cost of bulbs for Intersection	Cost of Electricity for Month
Green Arrow	0	8	$ 41.41	0.00	0.00	$0.00	$0.00		135	$ 2.76	0.00	0.00	$0.00	$0.00
Yellow Arrow	0	6.5	$ 41.58	0.00	0.00	$0.00	$0.00		135	$ 2.76	0.00	0.00	$0.00	$0.00
Red Arrow	0	6	$ 34.00	0.00	0.00	$0.00	$0.00		135	$ 2.76	0.00	0.00	$0.00	$0.00
Green Bulb	5	12	$ 51.00	60.00	43.80	$255.00	$5.26		135	$ 2.76	675.00	492.75	$13.80	$59.13
Yellow Bulb	5	18	$ 53.48	90.00	65.70	$267.40	$7.88		135	$ 2.76	675.00	492.75	$13.80	$59.13
Red Bulb	5	10.5	$ 37.00	52.50	38.33	$185.00	$4.60		135	$ 2.76	675.00	492.75	$13.80	$59.13
Totals for Intersection	15	40.5	$ 141.48	202.50	147.83	$707.40	$17.74		405	$ 8.28	2025.00	1478.25	$41.40	$177.39

With modifications, this chart can be used to calculate what the intersections of Dallas at Caroline and Louisiana at Bell would look like, as well as other locations that have their basic set ups. For example, Louisiana at Bell has 3 signal heads in each direction with 18 balls for light and no arrows. Under a LED retrofit 117.39 kWh will be used per month with a monthly electricity cost per month of $21.29. To install the intersection with LED it would cost $848.88, whereas and incandescent installation will only cost $49.68. If the intersection keeps and incandescent infrastructure the intersection would consume 1773.90 kWh per month with electricity cost of $212.87. By installing the LEDs the city would have saving of 93% in kWh used per month and electricity savings of around 90%.

Scenario 2: Two way Traffic with One Way Intersecting

In this scenario traffic runs in two directions from one street and in one direction in the other. It typically has signals on three sides. For the parameters of this simulation, we will focus on this type of intersection with either two signals on all sides or two signals on two sides and one side with three signals. These intersections can be seen in the diagrams below.

There are 20 ball light sources at this location. With a LED installation this intersection would consume 192.72 kWh per month. In keeping with $0.12 as the electric rate per kWh (blended rate), the cost of electricity for the month would be $23.13. It would cost $922.88 to install the LED light source at this intersection. Under the incandescent system the total cost for bulbs at this intersection would be $55.20. It would consume 1971.00 kWh per month with a monthly electricity bill of $236.52. This is a monthly energy savings of 91%.

Figure 3: LED versus Incandescent Bulbs - Intersection of Fannin at Rosedale

Intersection of Fannin at Rosedale													
		LED Bulbs						Incandescent Bulb					
Type	# of lights	Power (watts/ hr)	Cost/Bulb	Total Wattage in (W)	Total KWH per month	Total Cost of bulbs for Intersection	Cost of Electricity for Month	Power (watts/ hr)	Cost/ Bulb	Total Wattage in (W)	Total KWH per month	Total Cost of bulbs for Intersection	Cost of Electricity for Month
Green Arrow	0	8	$ 41.41	0.00	0.00	$0.00	$0.00	135	$ 2.76	0.00	0.00	$0.00	$0.00
Yellow Arrow	0	6.5	$ 41.58	0.00	0.00	$0.00	$0.00	135	$ 2.76	0.00	0.00	$0.00	$0.00
Red Arrow	0	6	$ 34.00	0.00	0.00	$0.00	$0.00	135	$ 2.76	0.00	0.00	$0.00	$0.00
Green Bulb	6	12	$ 51.00	72.00	52.56	$306.00	$6.31	135	$ 2.76	810.00	591.30	$16.56	$70.96
Yellow Bulb	6	18	$ 53.48	108.00	78.84	$320.88	$9.46	135	$ 2.76	810.00	591.30	$16.56	$70.96
Red Bulb	8	10.5	$ 37.00	84.00	61.32	$296.00	$7.36	135	$ 2.76	1080.00	788.40	$22.08	$94.61
Totals for Intersection	20	40.5	$ 141.48	264.00	192.72	$922.88	$23.13	405	$ 8.28	2700.00	1971.00	$55.20	$236.52

Scenario 3: The Typical 4-way Intersection

The typical 4-way intersection has a combination of balls and arrows with at least two left turn signals. Some have just the left turn signals on the horizontal pole and some include an extra vertical turn signal on a vertical pole. It is also typical for this type of intersection to have 40+ traffic lights. This simulation examines three similar intersections with both types of left turn signals.

The intersection of Post Oak and Westheimer serves as a main entrance to the bustling Galleria/ Uptown Area. Home too many of the nation's largest malls, shops, restaurants, and office buildings this intersection sees a copious amount traffic at all times. This intersection holds 40 lights in the form of balls and arrows with traffic direction flowing 4 ways. If using Figure 3, with each light source aligned with it respective power wattage and cost, the initial install with LED for this intersection would cost $1759.80 compared to the $110.40 that an incandescent install would cost. Keeping the same $0.12 per kilowatt hour charged by the energy company, the cost of energy per month would be $473.04 on incandescent lighting and $40.82 running on LEDs. This can be seen in the Figure 9 below. In a year's time, the energy cost under an incandescent retrofit would cost the city $5676.48, however under LED it would only be $489.86. That is a difference of $5186.62 for that intersection alone.

Diagram C: Typical Four-Way

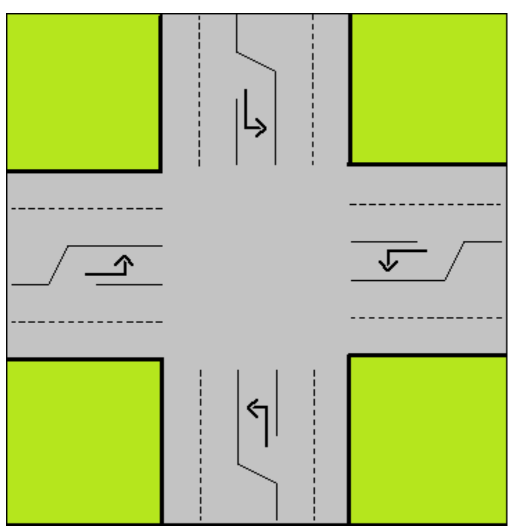


Figure 4: LED versus Incandescent Bulbs - Intersection of Westheimer at Post Oak

Intersection of Westheimer at Post Oak															
		LED Bulbs							Incandescent Bulb						
Type	# of lights	Power (watts/hr)	Cost/Bulb	Total Wattage	Total KWH per month	Total Cost of bulbs for Intersection	Cost of Electricity		Power (watts/ hr)	Cost/ Bulb	Total Wattage	Total KWH per month	Total Cost of bulbs for Intersection	Cost of Electricity
Green Arrow	4	8	$ 41.41	32.00	23.36	$165.64	$2.80		135	$ 2.76	540.00	394.20	$11.04	$47.30
Yellow Arrow	4	6.5	$ 41.58	26.00	18.98	$166.32	$2.28		135	$ 2.76	540.00	394.20	$11.04	$47.30
Red Arrow	0	6	$ 34.00	0.00	0.00	$0.00	$0.00		135	$ 2.76	0.00	0.00	$0.00	$0.00
Green Bulb	8	12	$ 51.00	96.00	70.08	$408.00	$8.41		135	$ 2.76	1080.00	788.40	$22.08	$94.61
Yellow Bulb	8	18	$ 53.48	144.00	105.12	$427.84	$12.61		135	$ 2.76	1080.00	788.40	$22.08	$94.61
Red Bulb	16	10.5	$ 37.00	168.00	122.64	$592.00	$14.72		135	$ 2.76	2160.00	1576.80	$44.16	$189.22
Totals for Intersection	40	61	$ 258.47	466.00	340.18	$1,759.80	$40.82		810	$ 16.56	5400.00	3942.00	$110.40	$473.04

Although there is less traffic flow, as compared to Westheimer at Post Oak, W. Fuqua at Chimney Rock encompasses a large intersection surrounded by single family residences. It houses 52 lights in a total of 16 signal heads. There are 8 red, green, and yellow balls, 8 yellow and green arrows, as well as 12 red arrows. The lanes of traffic, as depicted similarly in Diagram C, show that in each direction there is a left turn signal with 2 thru lanes. At this intersection there are three signal heads on each horizontal bar and a vertical one directing left turning traffic.

This intersection gives a good representation of what intersections with both balls and arrows look like. The cost of install and wattage will be higher of course due to the larger number of lights at the intersection. Under these credentials, this intersection would cost $2203.76 to install with LED compared to the install under incandescent of $143.52. However the cost of electric power for this intersection would be $614.95 per month with traditional lights consuming 2365.20 kWh per month, which is significantly higher than the $44.85 and 373.76 kWh per month that it would cost with LED.

Figure 5: LED versus Incandescent Bulbs - Intersection of W. Fuqua at Chimney Rock

Intersection of W. Fuqua at Chimney Rock													
		LED Bulbs						Incandescent Bulb					
Type	# of lights	Power (watts/ hr)	Cost/Bulb	Total Wattage in (W)	Total KWH per month	Total Cost of Install for Intersection	Cost of Electricity for Month	Power (watts/ hr)	Cost/ Bulb	Total Wattage in (W)	Total KWH per month	Total Cost of Install for Intersection	Cost of Electricity for Month
Green Arrow	8	8	$ 41.41	64.00	46.72	$331.28	$5.61	135	$ 2.76	1080.00	788.40	$22.08	$94.61
Yellow Arrow	8	6.5	$ 41.58	52.00	37.96	$332.64	$4.56	135	$ 2.76	1080.00	788.40	$22.08	$94.61
Red Arrow	12	6	$ 34.00	72.00	52.56	$408.00	$6.31	135	$ 2.76	1620.00	1182.60	$33.12	$141.91
Green Bulb	8	12	$ 51.00	96.00	70.08	$408.00	$8.41	135	$ 2.76	1080.00	788.40	$22.08	$94.61
Yellow Bulb	8	18	$ 53.48	144.00	105.12	$427.84	$12.61	135	$ 2.76	1080.00	788.40	$22.08	$94.61
Red Bulb	8	10.5	$ 37.00	84.00	61.32	$296.00	$7.36	135	$ 2.76	1080.00	788.40	$22.08	$94.61
Totals for Intersection	52	61	$ 258.47	512.00	373.76	$2,203.76	$44.85	810	$ 16.56	3240.00	2365.20	$143.52	$614.95

CONCLUSION

It is inevitable for the citizens of Houston to travel around and not encounter the copious amount of traffic signals the city possesses throughout. Although it is a large undertaking to retrofit all the signal lights to LED, both cost and labor wise, the long term benefits of energy and cost savings easily make it worthwhile. As the population continues to increase in the region, officials are actively making policies in order to create and maintain and infrastructure that is safe and efficient to serve the needs of the community now and in the future. The retrofitting of LED bulbs has become a vital part of those policies. Furthermore, in 2008 former Houston Mayor Bill White affirmed the City's commitment to reducing costs through the use of energy efficient lighting. He also cited the energy savings model used by Wal-Mart that provides the discount chain a competitive advantage in the marketplace (Olsen, 2008).

The types of intersections examined represent many of the intersection layouts within the city. According to average wattages for the incandescent light bulbs and LEDs, the energy costs are five times less when using the LED light source. Combining the installation cost of solar panels and LEDs gives the city an idea of the total costs incurred so that they can evaluate the upfront costs compares with the long-term savings. The literature shows the benefits of using solar energy and LEDs as well as the success of this approach as seen in the United States and abroad. The city has already seen significant savings in energy cost and consumption demonstrated by the 10 intersection analysis. Therefore, because the city has already been successful in seeing energy cost and consumption savings in the intersections it has already converted, it would behoove the city to continue this retrofitting to all the intersections in Houston.

References

"Green Power Partnership Partner Profile." *United States Environmental Protection agency*. EPA, July 30, 2012. Web. August 7, 2012. <http://www.epa.gov/greenpower/partners/partners/cityofhoustontx.htm>. ("United States Environmental Protection agency")

"Why Houston?." *The University of Texas MD Anderson Cancer Center*. MD Anderson Communications Office 9/11, n.d. Web. 7 Aug 2012. <http://www.mdanderson.org/library/files/whyhouston2.pdf>.

"Conventional Vs LED Traffic Signals: Operational Characteristics and Economic Feasibility." Arkansas Department of Economic Development, July 1, 2003. Web. July 11, 2012. <http://www.cee1.org/gov/led/little_rock.pdf>.

Green Houston. N.p., n.d. Web. 7 July 2012. <http://www.greenhoutsontx.gov/epr-energysources.html>.

Condren, S. Michael, George Lisensky, Arthur Ellis, et al. "LEDs: New Lamps for Old and a Paradigm for Ongoing Curriculum Modernization." *Journal of Chemical Education*. 78.8 (2001): 1033-1040. Web. 10 Aug. 2012. <http://condrenrails.com/p1033.pdf>.

Lewis, Nathan, and Daniel Nocera. "Powering the planet: Chemical challenges in solar energy utilization." *Proceedings of the National Academy of Sciences of the USA*. 103.43 (2006): 15729-15735. Web. 10 Aug. 2012. <www.pnas/cgi/doi/10.1073/pnas.0603395103>.

Olsen, Bradley. “Houston gives green light for energy–saving traffic bulbs.” Houston Chronicle, December 10, 2008. <http://www.chron.com/news/houston-texas/article/Houston-gives-green-light-for-energy-saving-1622739.php>

Tsoutsos, Theocharis, Niki Frantzeskaki, and Vassilis Gekas. "Environmental impacts from the solar energy technologies." *Elsevier*. 33.3 (2005): 289-296. Web. 10 Aug. 2012.

<http://tbm.home.tudelft.nl/fileadmin/Faculteit/TBM/Over_de_Faculteit/Afdelingen/Afdeling_Multi_Actor_Systems/Sectie_Beleidsanalyse/Medewerkers/Niki_Frantzeskaki/doc/Tsoutsos_Frantzeskaki_2006_EIA_ST.pdf>.