To: Professor Cohen
From: Nicole Catino, Danny Ladd, Emerald Lagow, Cody Zaccagnino
Date: May 9, 2013
Subject: Solar Power Project

Introduction & Research Question

Our project began as a continuation of last year's project by Matt Bernhard '12 in which he built a temporary solar charging station for electric vehicles. We wanted to go beyond his research question of determining the feasibility of constructing a solar charging station at Lafayette and implement a permanent charging station for small electronics such as cell phones and laptops. **Our research goal for the project was to figure out how we could facilitate a scholarly, interdisciplinary discussion about renewable energy at Lafayette while educating the community on the advantages of moving from conventional grid energy towards solar and other sustainable energies.** Rather than asking whether or not solar charging can be implemented at Lafayette, we wanted to see if we could influence the future energy and sustainability decisions of Lafayette as an institution and as a community.

Context

The United States electrical grid is derived almost entirely from coal and other fossil fuels, constituting nearly 70% of the net generation for 2012. For this reason, electric vehicles are not necessarily more sustainable than vehicles which are gasoline or diesel driven (Anair). However, the major difference is that with electric vehicles, alternate power sources can be chosen that do not come straight from the grid. In an effort to make electric vehicles more environmentally friendly, solar charging stations may be used to reduce or eliminate the need for grid energy.

There are two main methods for construction of solar charging stations for electric vehicles. One involves connection to the grid, and one involves complete independence. The grid connection model is more typical in the United States and other developed countries because it allows the owner or operator of the solar charging station to sell any extra energy produced back to the grid and allows energy to be drawn from the grid if there was not enough power generated by the solar array. The basic construction is similar for either model. The solar panels are hooked up to electrical equipment which provide various functions including converting the current from DC to AC, allowing for control, and providing extra protection. The grid connection model typically includes a utility meter that regulates power supply and sells the energy back to the grid if there is a surplus. The grid connected model may also utilize a direct DC connection. This model allows for quicker charging and eliminates the need for an inverter, but it requires a stronger protection system. The grid-independent model includes some sort of extra battery to retain power when not in use or when the vehicle is fully charged. This battery becomes part of the fixture in addition to the batteries already inside the vehicle.

Grid-connected solar charging stations are available for commercial and domestic use in the United States, and there are a number of these stations across the country at homes, parking garages, offices, and businesses. While this type of station is on the rise, electric vehicle owners still face problems when tasked with taking long trips. The typical range of current electric cars is around 200 miles, and without a proper charging infrastructure, long-distance road trips in electric cars are impossible. However, a company called SolarCity (a partner of electric vehicle producer Tesla Motors) has already constructed solar charging stations on highways between San Francisco and Los Angeles (Vance). There are also stations under construction that will connect many of California and Nevada's major cities. If successful, SolarCity plans to continue building these solar charging stations across the United States, with the eventual goal of allowing an electric car to drive from ocean to ocean. Petrobras, a Brazilian energy company, has also begun construction on a similar system that will provide access between Rio de Janeiro, Sao Paulo, and other major Brazilian cities.

In countries and regions where grid energy is not available, such as Tanzania and Thailand, solar charging stations are being constructed to provide power for small electronics such as cell phones and laptops, which would otherwise be unusable (Greacen & Green; The Citizen Reporter). This concept can be applied locally as well. Though the United States has well developed grid infrastructure, there are still public areas in which electricity is unavailable, especially public parks. Various entrepreneurs have taken steps to set up cell phone charging stations in places where electricity may be unavailable. Examples of this include a station set up in front of Austin City Hall and a station at Bryant Park in New York City (Oaklander).

At Lafayette College, there are already some initiatives underway to promote sustainable energy. For the past few years Markle parking deck has had a grid-tied charging station for an electric vehicle, which is where Professor Carolyn Buckley charges her car. Though the charging does not use renewable energy, in some ways it can be seen as a step in the right direction, as it does grant Lafayette employees the ability to use electric vehicles and discourage the use of gasoline. Additionally, since 2009 there has been a 3.2 kW Windspire turbine at Metzgar Fields, Lafayette's athletic complex. Current student-led research is addressing technical problems at Metzgar to get both systems up and running with the ultimate goal of creating an electronic dashboard regarding energy production for public display.

Method

The first step of the project was to conduct research regarding current solar charging technologies and their place in the existing grid infrastructure. From this research we found out what parts and equipment we would need to capture energy from the solar panel and convert it to a reliable power source.

Once we knew what parts were needed, we talked to our non-EGRS contacts to see what Lafayette specifically had to offer in terms of existing equipment and implementation feasibility. We worked with Mary Wilford-Hunt, and although she is an Engineering Studies professor, her primary role in this context was that of Lafayette's Director of Facilities Planning and Construction rather than as a faculty member. Wilford-Hunt knows a great deal about Lafayette's existing renewable energy projects, as well as the existing grid-connected charging station for electric vehicles at the Markle parking deck. We also worked with Professor David Veshosky to design and build the actual solar charging stations, as well as to secure funding for the project. Veshosky directed us to Tom DeFazio, Coordinator of Chemical & Environmental Engineering labs, who showed us solar panels, frames, and inverters that Lafayette had in storage.

We eventually decided to focus on the solar charging station for the small electronics and not on the solar vehicle charger. Part of the reason is that Lafayette already has a recently built charging station for electric vehicles and would be unwilling to build and pay for another station. Another part of the reason is also that building a permanent station is the responsibility of facilities planning and plant operations, and is largely out of our hands. While we can influence the college to adopt sustainable practices, we are unable to actually implement and build permanent fixtures ourselves, due to Lafayette policies. A portable charging station on the quad for small electronics is visible to more of the Lafayette community, and therefore a better tool for promoting sustainable practices.
It was also important to establish guidelines and expectations for future maintenance of the solar charging facilities. Since we will not be here to look after the system ourselves, future students working on the project should enlist the help of college employees such as Plant Operations or the Sustainability Committee to ensure continued upkeep and use throughout the years.

Description

The final product of this capstone project is a solar charging station for small electronics. While not permanent, this solar charging station will be on display on the quad during spring finals week, May 13th, 2013. The display is visible and helps educate the Lafayette community on the possibilities of solar power. Additionally, a list of all parts and contacts (APPENDIX A, B) will assist future EGRS students in implementing a permanent solar charging station.

The optimal location for the small electronics charging station is over an existing bench on March Field (Figure 1). Unlike the quad and Anderson Courtyard, March Field still lacks accessible outlets outside. Additionally, the bench pictured below is on the north side of the field facing south. Its location and orientation place the bench in sunlight throughout the day. The panel will be fixed to a hollow steel frame and wiring will run from the panel to the bottom of the bench where the inverter and the battery will be placed. There will be outlets on the frame where students will be able to plug in their electronic devices to charge them. This design also ended up being too expensive and difficult to implement within the time we were allotted. We ended up building a more portable, smaller structure. While To spread awareness this product, there is a sign attached to the frame outlining what the project was, how solar energy works, and why renewable energy is an important component for the future energy grid (APPENDIX C).

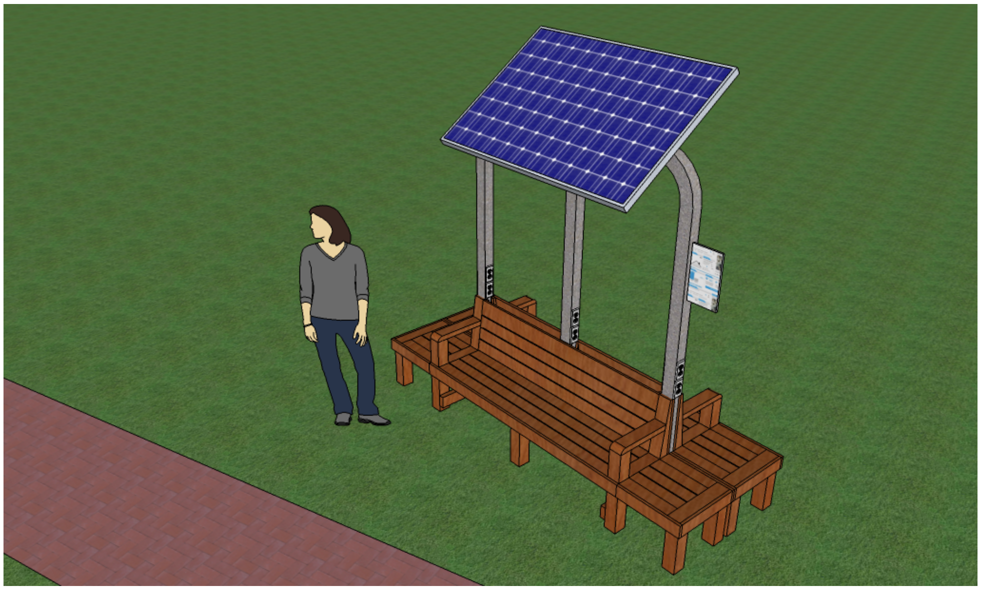


Figure 1: Authors' rendition of solar charging station for small appliances

Since it is not feasible to install a permanent solar charging station for electric vehicles within the timeframe that we have, we intend to outline a method for achieving this goal for a future capstone project.

Conclusion

Ultimately, both stations serve our greater goal of facilitating a campus-wide discussion on renewable energy. Last year the electric vehicle charging station and solar information was presented through a poster hung in Farinon Student Center, but the larger Lafayette community remains unaware of these efforts. While a couple faculty members own electric vehicles, it does not compare to the widespread use of small electronics on campus. For this reason, the small charging station will be our most visible implementation and call greater attention to the vehicle charging station, electric vehicles, and the potential of solar technology to provide renewable energy in the move toward a more sustainable future.

Future capstone projects could put into action the steps needed to install a permanent solar charging station for electric vehicles as per our guidelines. This will continue the conversation about renewable energy on Lafayette College's campus and help promote a sustainable lifestyle.

Nicole Catino

Daniel Ladd

Emerald Lagow

Cody Zaccagnino

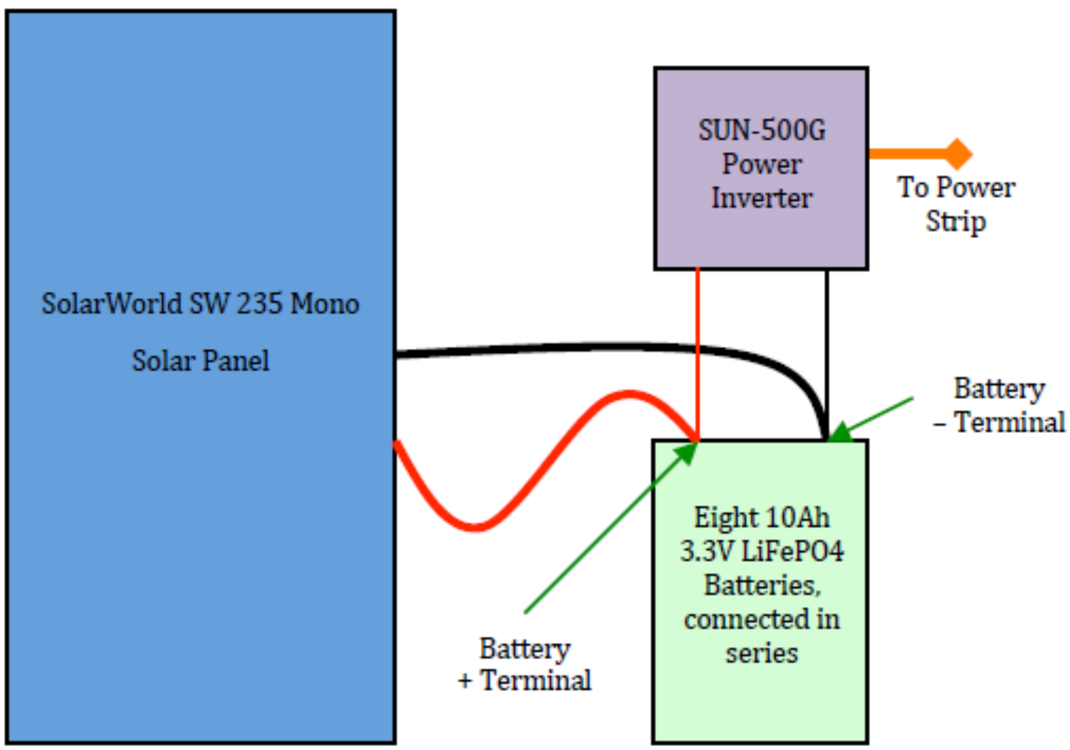
LIST OF APPENDICES

APPENDIX A
List of Parts

List of Parts:

(1) SolarWorld SW 235 Mono panel
(4) 10 Ah 3.3V LiFePO4 batteries
(1) SUN-500G Power Inverter
(1) Outlets (Surge protector)
(1) Frame (for future use)
(1) Bench (for future use)
(1) Charge Controller (for future use)

Full Wiring Diagram:



For future implementation, it is suggested that a charge controller is implemented. This extra safety measure would be between the solar panel and the battery pack and prevents overcharging of the batteries. The controller may even be implemented into the battery pack. It is suggested that Professor Nadovich or another ECE professor be contacted in the future regarding implementation of charge controllers.

APPENDIX B
List of Contacts

Mary Wilford-Hunt

Director, Facilities Planning & Construction
Email: wilfordm@lafayette.edu
Mary has information about campus construction and can help with project development and implementation.

Tom DeFazio

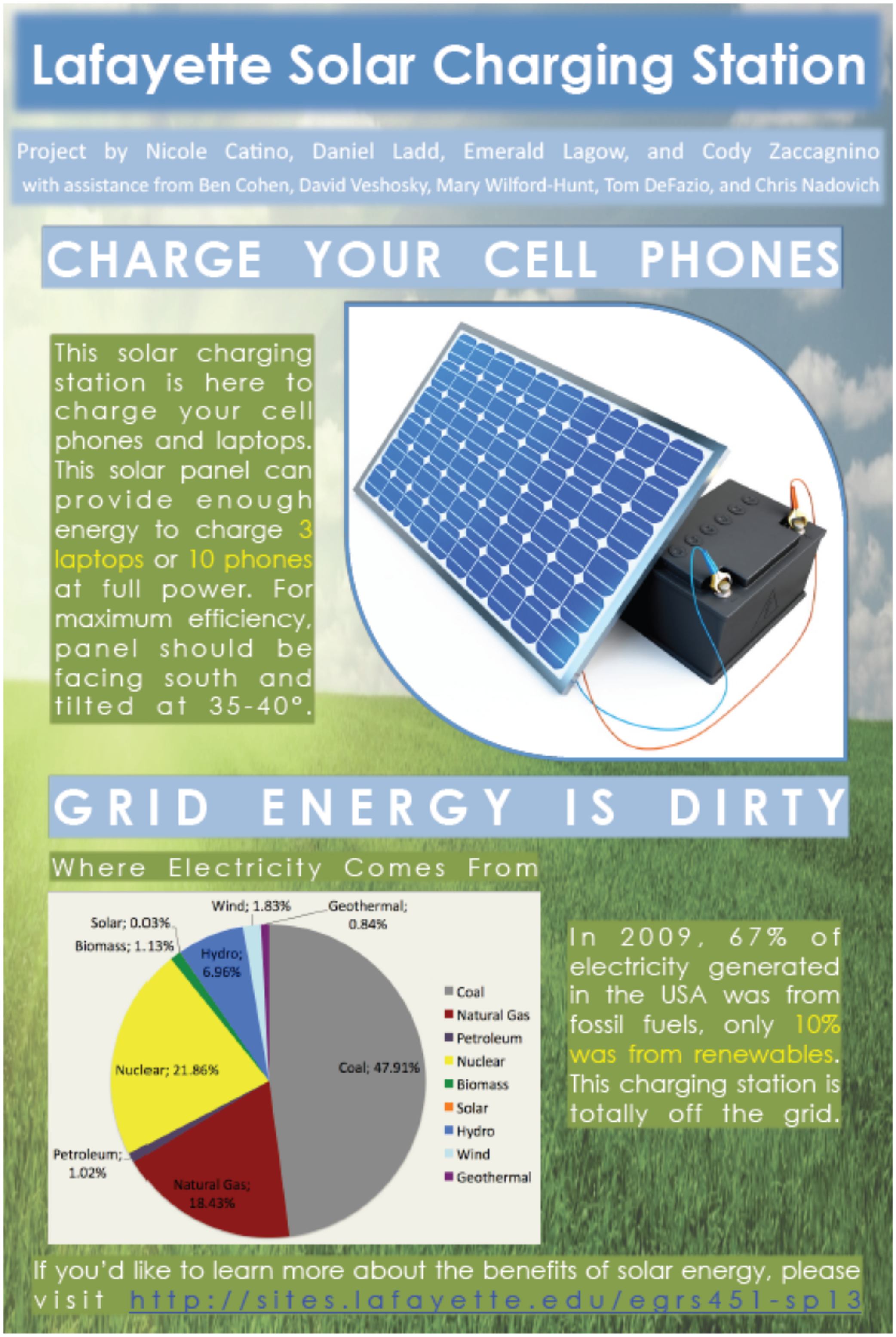
Coordinator of Chemical & Environmental Engineering Labs
Email: defaziot@lafayette.edu
Tom has access to the solar panel, inverter, and wiring.

Christopher Nadovich

Director of Laboratories, ECE
Email: nadovicc@lafayette.edu
He has access to the lithium ion batteries. These batteries are more environmentally friendly than the lead acid batteries Tom has.

APPENDIX C

Educational Poster



APPENDIX D
Pictures of Demonstration

Figure 2: Full Set up

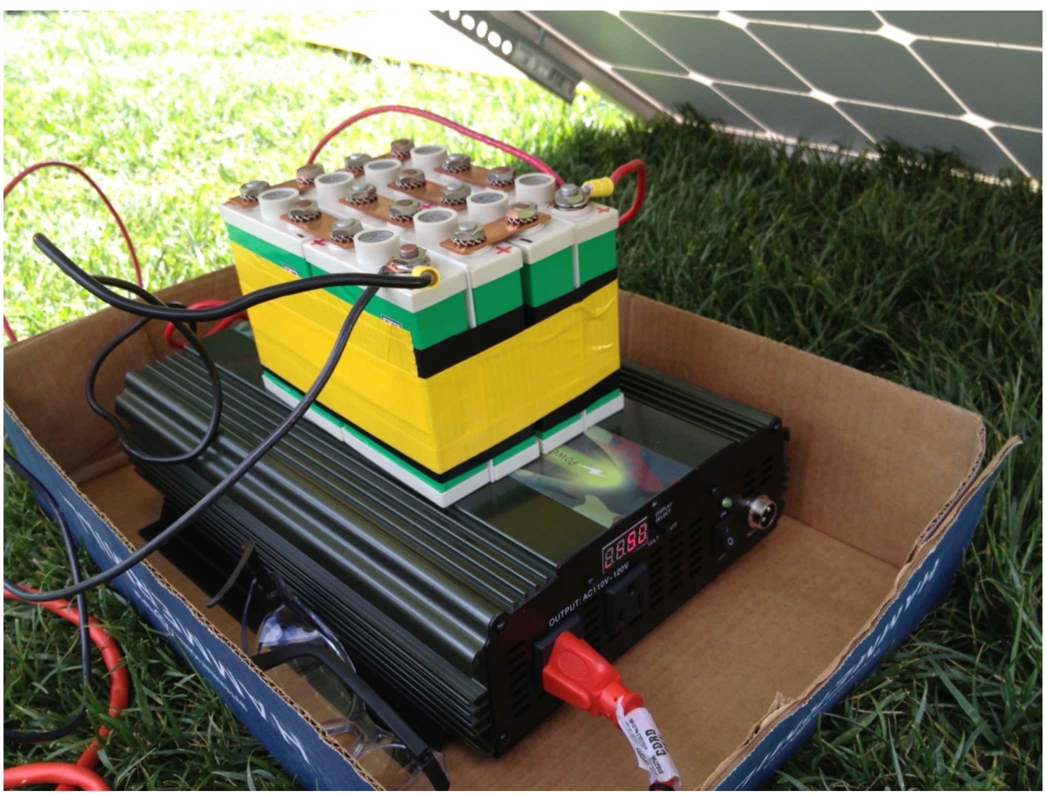


Figure 3: Wiring

APPENDIX E
Annotated Bibliography

Al-Alawi, B. M., & Bradley, T. H. (2013). Total cost of ownership, payback, and consumer preference modeling of plug-in hybrid electric vehicles. *Applied Energy*, *103*488-506. doi:10.1016/j.apenergy.2012.10.009

This paper aims to develop a full detailed cost analysis for electric vehicles. This study constructs a comprehensive ownership cost model that is used to analyze different electric vehicle designs within four vehicle classes. The authors then perform a sensitivity analysis to understand the sensitivity of total ownership cost and payback period to model parameters and the modeled components of ownership costs. The result is a comprehensive ownership cost model that has a lower net cost of ownership than studies to date. This means electric vehicles or more viable than previously believed. This study's results are time sensitive, but are still relevant as the paper was only made available in November of last year. The authors are a graduate student and an Assistant Professor at the Department of Mechanical Engineering at Colorado State University.

Anair, D. (2012). How Clean Are Electric Vehicles?. *Catalyst (1539-3410)*, 7-9.

This magazine article in *Catalyst* pushes readers to understand how environmentally friendly electric vehicles are. The author advocates government policies to help quicken the transition to electric vehicles from gas powered and hybrid vehicles. The author does back up all of his cost and environmental impact claims with figures, yet not all of them are cited. The author, Don Anair, is a senior engineer in the UCS Clean Vehicles Program. The goal of this program is to phase out consumer dependence on gasoline for cars. While the author definitely has a bias towards electric vehicles, the article is well written and supported by reasonable figures. This article will assist us in broadening our outlook on the issue with an article dedicated to the average consumer.

Bedir, A., Ozpineci, B., & Christian, J. E. (2010, April). The impact of plug-in hybrid electric vehicle interaction with energy storage and solar panels on the grid for a zero energy house. In *Transmission and Distribution Conference and Exposition, 2010 IEEE PES* (pp. 1-6). IEEE.

While being completely off the grid ensures electric vehicle charging from renewable energy, such setups can provide inconsistent energy if there is not adequate battery storage. This article proposes a zero energy house (ZEH) that is connected to the grid. The authors are concerned that future consumer adoption of electric vehicles may increase loads on the power grid at peak hours. Using solar PV panels and batteries, the system can rely on the renewable energy as well as feed it into the grid during peak hours and rely on the grid during non-peak hours if needed. The result is a system that is net zero energy and takes advantage of peak hour energy rates increasing the economic feasibility.

Birnie, D. 2009. Solar-to-vehicle (S2V) systems for powering commuters of the future. *Journal of Power Sources*, 186(2), 539-542.

This article discusses analyzes the feasibility and implications of solar electric vehicle charging during the day and off the grid. Though the analysis focuses on the impact of daytime recharging using solar PV arrays built over parking lots at commuters' work sites, it can also be applied to home use. The author does not assess the economic, utility, or environmental benefits and practicality of the system.

The Citizen Reporter. (2013, February 23). Vodacom finally brings off-grid solar phone charging to rural TZ. *The Citizen*. Retrieved from http://thecitizen.co.tz/business/13-local-business/29068-vodacom-finally-brings-off-grid-solar-phone-charging-to-rural-tz.html

This Tanzanian newspaper article is extremely relevant to our project, as it discusses the implementation of solar charging stations to power cell phones, which is an option we are considering. In certain off grid regions of Tanzania, cell phones and cell service may be accessible when electricity is not. These charging stations enable the citizens of these regions of Tanzania to use their cell phones and grant access to communication. Part of our project is an attempt to bring similar charging stations to Lafayette. Though electricity is bountiful in Easton, a charging station such may be used to educate about projects such as the one in Tanzania.

Dijk, M., Orsato, R. J., & Kemp, R. (2013). The Emergence of an Electric Mobility Trajectory. *Energy Policy*, *52*(1), 135-145. doi:http://0-dx.doi.org.libcat.lafayette.edu/10.1016/j.enpol.2012.04.024

The argument that this paper makes is that electric mobility has crossed a critical threshold and can continue to grow because of high oil prices, carbon constraints, and rise of organized car sharing and intermodality. But the authors find that continued adoption of electric vehicles is only possible with changes in (fueling) infrastructure, changes in mobility, changes in the global car market, evolution of energy prices, climate policy, and changes in the electricity sector. They make the case that momentum in developments has propelled the electric vehicle into adoption. The authors do not prioritize social or technical elements. Instead they view them as inexorably linked. This paper is written by professors from universities in the Netherlands and Brazil, yet the paper contains global coverage on electric vehicles and proposes alternatives that are applicable in all countries.

Edelstein, Steven. When will EVs overcome short range, long charges and big price tags? Digital Trends. N.p., 26 01 2013. Web. Web. 11 Mar. 2013. Retrieved from http://www.digitaltrends.com/cars/whats-in-store-for-electric-cars-in-2013/

This article discusses the current outlook for electronic vehicles in 2013. The author cites the persisting issues of limited range, long charge times, and high costs of EV in discussing manufacturers skepticism about the future of EV technology, despite the emergence of new EV models, such as the luxury Tesla Model S, car companies are selling few models and remain skeptical about the future of the EV industry. Edelstein is an automotive news writer and contributor to Digital Trends, a technology news and information website that is primarily focused on current technology and consumer electronics products. These are important issues to address when educating the Lafayette community on the validity and accessibility of a future EV technology.

Egbue, O., & Long, S. (2012). Barriers to Widespread Adoption of Electric Vehicles: An Analysis of Consumer Attitudes and Perceptions. *Energy Policy*, *48*(1), 717-729. doi:http://0-dx.doi.org.libcat.lafayette.edu/10.1016/j.enpol.2012.06.009

With the technological momentum pushing electric cars, these two authors observe the current barriers slowing down progress. The largest barrier being consumer perceptions and attitudes. In spite of the benefits of electric vehicles, consumers tend to resist new technologies that are considered alien or unproved, thus, policy decisions that consider their critical concerns will have a higher level of success. This paper looks into the attitudes of consumers across gender, age, and education groups. The uncertainty of battery range and the high cost prove to be the biggest negative perception held by these groups. While the authors propose policy decisions to change attitudes on a national level, we can address these perceptions on a campus level. The authors are a PHD student and Associate Professor from the Department of Engineering Management and Systems Engineering at The Missouri University of Science and Technology.

Farrington, Dana. Flipping The Switch: What It Takes To Prioritize Electric Cars. The two-way. National Public Radio, 23 02 2013. Web. Web. 11 Mar. 2013. Retrieved from http://www.npr.org/blogs/thetwo-way/2013/02/23/172778466/flipping-the-switch-what-it-takes-to-prioritize-electric-cars

Estonia has recently become the first country worldwide to implement a nation-wide, publicly serviced charging network for EV's. Contributors discuss the current US climate with regard to EV technology, highlighting issues such as the need to invest in power generation to meet the demand of automotive travel as well as environmental standards. In regard to current US tax credits for EV's,

energy inventive analyst Adelle Morris notes that EV manufacturers can sell credits to other automakers toward their fuel economy standards, negating the environmental benefits. The broadcast brings to light several important factors shaping US energy and transportation politics, from the private and publicaly funded non-profit membership media organization NPR.

Froehlich, J., Findlater, L., & Landay, J. (2010, April). The design of eco-feedback technology. In *Proceedings of the 28th international conference on Human factors in computing systems* (pp. 1999-2008). ACM.

Eco-feedback technology is a method for transmitting information about environmental impact with the goal of influencing people to become more environmentally sustainable. The authors studied how effective eco-feedback technology actually is, and what part human-computer interaction (HCI) has in the process. The study reveals that the design of the eco-feedback technology, including how information is laid out, is integral in determining how humans will react. Two identical environmentally sustainable technologies may be perceived completely differently based upon how their information and specifics are presented. The authors suggested that most eco-feedback technology model energy usage, but we should be working to use eco-feedback technology to explore other forms of environmental behavior change. A major purpose of the paper was to start discussion between HCI and environmental psychology disciplines, in order to utilize eco-feedback technology to its greatest ability. The authors seem to think that eco-feedback technology will become essential to the way we think about and act on environmental sustainability.

Gautam, N. K., & Kaushika, N. D. (2002). Reliability evaluation of solar photovoltaic arrays. *Solar energy*, *72*(2), 129-141.

This article is an analysis of the reliability and durability of solar photovoltaic cells. However, the article is based mostly on theoretical probability evaluation rather than on actual empirical data, so the results are not based on life expectancy or efficiency of the solar panels. The article does compare a few different configurations of solar arrays, and how they may affect the functionality of the panels. While our project may deal mainly with single solar panels, the article is still useful to consider future steps for Lafayette College and our solar energy strategy.

Gevorgian, V., Corbus, D. A., Drouilhet, S., Holz, R., & Thomas, K. E. (1998).*Modeling, testing and economic analysis of a wind-electric battery charging station*. National Renewable Energy Laboratory.

This article conducted research on wind powered battery charging stations, to be implemented in regions around the world that do not have grid access. Though the article deals with wind energy rather than solar energy, it is interesting to study the use of batteries for power in regions where grid energy is unavailable. The article is mostly technical results from the analysis, but the authors do suggest that a battery charging system may be affordable in rural regions in developing countries, more so than pure solar power or grid connectivity. The article also discusses the use of car batteries. Though the car batteries in the study are used for electricity rather than to power cars, the fact that car batteries are being charged is relevant. The article also suggests using these charging stations for personal residential use, which is applicable to our topic of creating a solar charging station for small electronics.

Gibson, T. L., & Kelly, N. A. (2010). Solar photovoltaic charging of lithium-ion batteries. *Journal of Power Sources*, *195*(12), 3928-3932.

This article is largely quantitative, and deals with a scientific analysis of using solar photovoltaic panels to charge batteries for electric vehicles. Though the article is useful in that it lets us know how to set up a photovoltaic charger in connection with batteries, a lot of the technical knowledge may not be necessary, and may be more in depth than we need. The test was conducted on a battery smaller than the typical electric car battery, though the authors suggests that the future step is vehicle charging from residential roof mounted solar photovoltaic panels, very similar to what we are considering.

Goebel, C. (2013). On the Business Value of ICT-Controlled Plug-In Electric Vehicle Charging in California. *Energy Policy*, *53*(1), 1-10. doi:http://0-dx.doi.org.libcat.lafayette.edu/10.1016/j.enpol.2012.06.053

This paper investigates the savings potential of electricity retailers resulting from the ability to control the charging behavior of a fleet of Electric vehicles using information and communication technology. The author believes that the savings could jumpstart the development and implementation of charging stations. Through the usage model, the author finds a potential 45% savings, which may apply to a similar charging station at Lafayette. The author is a professor at the Technical University of Munich in Germany. This article is very relevant as it proposes cost saving measures for charging stations, is recent, and most importantly the contexts within the United States are similar allowing us to replicate the author's proposed model.

Greacen, C., & Green, D. (2001). The role of bypass diodes in the failure of solar battery charging stations in Thailand. *Solar energy materials and solar cells*, *70*(2), 141-149.

This article discussed using solar battery charging stations to power rural villages in Thailand otherwise without access to electricity. Though not related to the Gevorgian et al. article, this Greacen & Green article discusses the implementation of similar charging stations discussed by Gevorgian. The main purpose of this article was to analyze the failure of these solar battery charging stations, and assess why the Thai government chose to install the stations in the way they did. Similar to the case studies discussed in the Lucena book and the Nieusma & Riley article, this article discussed the failure of an engineering for development project, funded in part by American agencies. Gracean & Green discuss how the addition of bypass diodes to the design of the charging stations did not take into account the fact that villagers may not know how to charge batteries. The failure of the stations was due to connecting batteries with reverse polarity. The article also discussed a lack of feedback from villagers to the government, which may be seen as another reason for failure. The article teaches us that education is a large part of implementation, and should not be left out of our project.

Greene, D. L., & DeCicco, J. (2000). ENGINEERING-ECONOMIC ANALYSES OF AUTOMOTIVE FUEL ECONOMY POTENTIAL IN THE UNITED STATES. *Energy and the Environment*, *25*, 477-535. http://dx.doi.org/10.1146/annurev.energy.25.1.477

This article offers conclusions for the varying methods and estimates of studies that look into the fuel economy of automotives. The information comes from a governmental and political perspective— Greene works at Oak Ridge National Laboratory and DeCicco at the American Council for an Energy-Efficient Economy. Therefore, the qualitative and quantitative facts in this article come from a prestigious source which is reflected in the 70 other publications that have cited this as a reference. The authors raise questions as to how to best approach changing technology and offer recommendations for further research. This is applicable for our capstone project because it is valuable to look at a broader context of the methodologies behind fuel economy comparisons and to see the direction of where current research is heading.

He, F., Wu, D., Yin, Y., & Guan, Y. (2013). Optimal Deployment of Public Charging Stations for Plug-In Hybrid Electric Vehicles. *Transportation Research: Part B: Methodological*, *47*87-101. doi:http://0-dx.doi.org.libcat.lafayette.edu/10.1016/j.trb.2012.09.007

This paper determines the optimal charging station locations based on availability of public charging opportunities, prices of electricity, and destination and route

choices of plug-in hybrid electric vehicles at regional transportation and power transmission networks coupled by plug-in hybrid electric vehicles. Based on the resulting allocation mathematical model, the authors believe they can maximize social welfare with the minimum amount of charging stations needed. Using a game theory approach, the paper is based on the a critical assumption that availability of public charging stations and prices of electricity will affect destination choices of electric vehicles. By using the model given in the paper, we may attempt to estimate the optimal amount of charging stations in the Lehigh Valley. The four authors come from the Engineering Department of the University of Florida.

Helmers, E., & Marx, P. (2012). Electric cars: Technical characteristics and environmental impacts. Environmental Sciences Europe, 24(1), 1.

This article reviews current literature data to assess the energy efficiency and environmental impact of the battery electric vehicle (BEV) in comparison to an internal combustion energy vehicle (ICEV). In terms of the tank to wheel efficiency factor (TTW), the BEV is four times as efficient as the ICEV, and coupled with renewable energy production the Life cycle assessment yields 30 gCO_2/kWh. They estimate the life cycle of a grid-connected vehicle to be 500-600 gCO_2/kWh. Authors discuss disadvantages such as the acidification potential associated with the smelting processes of certain elements essential to any electrical component and many battery types on the market. The e-conversion from new or used ICEV to BEV's introduces an compelling strategy for environmental and economic efficiency by making use of existing infrastructure. The LCA can be used in educating the Lafayette community on what EV, and more importantly, solar energy can offer.

Liu, Z., Wen, F., & Ledwich, G. (2013). Optimal planning of electric-vehicle charging stations in distribution systems. IEEE Transactions on Power Delivery, 28(1), 102-110.

The progressive exhaustion of fossil energy coupled with enhanced awareness of environmental protection, more attention is being paid to electric vehicles (EVs). Inappropriate siting and sizing of EV charging stations could have negative effects on the development of EVs, the layout of the city traffic network, and the convenience of EVs' drivers, and lead to an increase in network losses and a degradation in voltage profiles at some nodes. The authors recommend a model for identifying sites of EV charging stations, with environmental factors and service radius of EV charging stations considered. A second model for optimal sizing of EV charging stations is developed to minimize total cost associated with EV charging stations. Though these models are geared toward larger scale implementation of EV charge stations than ours, the optimal sizing and minimized costs models can be used for our small scale, site-specific implementations.

Locment, F., Sechilariu, M., & Forgez, C. (2010). Electric vehicle charging system with PV Grid-connected configuration. *Vehicle Power and Propulsion Conference*, pp. 1-6. http://dx.doi.org/10.1109/VPPC.2010.5729016

Like the "Experimental solar-based charging station for electric vehicles" article by Maeght, Rasolomampionona, Cresson, Favier, this article presents an example of a system that charges a battery using a photovoltaic array. This article, however, is more credible in that is was presented at a 2010 conference hosted by IEEE and it has been cited by 4 as opposed to just one from last year's capstone projects. It is directly applicable to our project since it looks at grid-connected configuration and a control strategy to manage energy flow from the solar array to the battery.

Motavalli, J. (2013, February 5). 'Plug-In Ecosystem' Available at Indiana Mall. New York Times, Wheels Blog.

Similar to the New York Times article from 2011, this article provides a more recent example of a solar powered charging station at Indiana mall. This pilot system is intended to create a source of energy that draws from a battery and so does not overload the grid when multiple electric vehicles are plugged in. This article is another great example of real-world applications of solar powered electric vehicle charging stations and provides a useful insight into the current market demand.

Musk, E. (2013, February). Interview by Chris Anderson [Video Tape Recording]. The mind behind tesla, spacex, solarcity. TED, Retrieved from http://www.ted.com/talks/elon_musk_the_mind_behind_tesla_spacex_solarcity.html

Entrepreneur Elon Musk is widely known as the founder of PayPal, Tesla motors, Space X, and recently a solar system buying and leasing company called 'Solar City'. In an interview with TED talks founder Chris Anderson, Musk discusses his own efforts to address the challenges of implementing EV technology, and confidence in the future of solar technology to provide sustainable energy production and consumption. Musk addresses the three commonly cited drawbacks of EV charge time, range, and costs with ideas such as a battery swap station, and stresses the need for an infrastructure and network to meet these challenges and lower installation and finance costs through a buy and lease solar system companies like SolarCity to operate as a giant distributed utility. Musk is a key figure in US solar energy strategy and the EV industry, making him an inspirational figure for education and promotion of our own solar implementation.

Neuman, L., & Knox, D. (2013, March 5). NRG begins operations at 26 MW Borrego solar photovoltaic facility. *Business Wire*. Retrieved from http://www.businesswire.com/news/home/20130305006562/en/NRG-Begins-Operations-26-MW-Borrego-Solar

> This article discusses a solar facility being constructed near San Diego that will provide as much power as a typical coal power plant. This is the eighth solar facility constructed by NRG Solar, which is the largest solar provider in California. The article also discusses NRG's investment in electric vehicle charging infrastructure, which is relevant to our project. NRG's plan is to construct solar charging stations throughout California, Texas, and the Washington, D.C. area, and these stations are to be constructed at a variety of locations, including homes and retail locations. Though the project has not been undertaken yet, it may be a useful education tool for our project.

Oaklander, M. (2012, May 31). An idea charged up in Zuccotti Park . *The New York Times*. Retrieved from http://green.blogs.nytimes.com/2012/05/31/an-idea-charged-up-at-zucotti-park/

> This article discusses two separate solar charging station projects in the United States. The first is a design by Tommy Mitchell that can charge cell phones. This station has been on display in Zuccotti and Bryant Parks in New York City, and as of the writing of the article, the parks are in discussions with Mitchell's company, called Green Barrel Energy, to implement permanent stations. The second project was a thesis by University of Texas at Austin graduate student Beth Ferguson. Ferguson has grown her idea into a company called Sol Design Lab, which has stations set up at such places as Austin City Hall, Wellfleet Bay Wildlife Sanctuary in Massachusetts, and at music festivals around the country such as Bonnaroo and Coachella.

Peterson, S. B., & Michalek, J. J. (2013). Cost-Effectiveness of Plug-In Hybrid Electric Vehicle Battery Capacity and Charging Infrastructure Investment for Reducing US Gasoline Consumption.*Energy Policy*, *52*(1), 429-438. doi:http://0-dx.doi.org.libcat.lafayette.edu/10.1016/j.enpol.2012.09.059

> This paper covers the cost effectiveness of electric vehicles as well as the required infrastructure investment in order to reduce the reliance on gasoline in the United States. The authors compare whether it is more cost effective to increase battery capacity or increase the locations of charging stations. The results show that the least cost solution is to install more charging stations and have drivers adopt cars with a lower range and gasoline reserves for when needed. This argument underlies the importance of more installed charging stations. The authors then look into current shortcomings of US subsidy policy and propose alternatives that that will align subsidies and fuel savings. Scott Peterson was an engineering PHD

student at Carnegie Mellon University and Jeremy Michalek is an Associate Professor in Engineering at Carnegie Mellon University. This paper was published recently in January of this year.

Rahman, S., & Shrestha, G. B. (1993). An investigation into the impact of electric vehicle load on the electric utility distribution system. *IEEE Transactions on Power Delivery*, *8*(2), 591-597. http://dx.doi.org/10.1109/61.216865

This article voices concerns about the state of the electric grid if the power demand due to electric vehicles increases. Using case studies as examples, Rahman and Shrestha warn that an increase in electric vehicles puts pressure on the grid to be able to accommodate the increased power load, that charging during off-peak hours will create a new peak when owners plug in their car after returning home from work, and that the "present state" of EV technology may not be able to allow for mainstream use. However, this article was published 20 years ago and so some of the authors' claims may be not as relevant today since technology has rapidly advanced over the past two decades. The fact that it has been cited 75 times lends to its credibility in the field as a source that has been widely used. However, many of the citations have been in the past few years and only after closer investigation would we be able to discern to what extent this article has been used as a reference - it could be that recent publications provide counterexamples to this article since the technology within is outdated. Nonetheless, it is a useful source for our capstone project because it looks at the future of incorporating EVs into the grid which, in the big picture, is what we are advocating in our project as a sustainable alternative to the current transportation system.

Rasolomampionona, D., Maeght, F., Cresson, P.-Y., & Favier, P. (2011). Experimental solar-based charging station for electric vehicles. *Przeglad Elektrotechniczny*, (6), 58-62.

This article outlines the results from a collaborative university project of creating a rechargeable battery station powered by solar panels. The tone in this article is more to extol the approach to the project in terms of renewable energy research and international cooperation in education rather than give precedence to the end product. The academic focus is because three of the authors are professors at the Institut Universitaire de Technologie at the University of Artois in France, and the fourth is a professor at the Institute of Electric Power Engineering, Warsaw University of Technology. The article was published in 2011 in Przeglad Elektrotechniczny (Electrical Review) journal, the "Oldest magazine of Polish electrician" according to the English version of their website. There is also an article by the title of "Wireless supervision on a photovoltaic recharging station" that has the same authors and abstract and was published in COMPEL in 2013, so these may be different versions of the same thing. Some parts of this article appear to be in Polish or Czech, and the common grammatical errors in the

English take away some integrity in the article. Moreover, the lack of citations (only one which is from last year's EGRS capstone project) brings into question its credibility in the field. However, it is still beneficial for our capstone project because although we have a different focus, we can use the article as an example around which to design our project and learn from the students' successes and failures.

Richardson, D. B. (2013). Electric vehicles and the electric grid: A review of modeling approaches, impacts, and renewable energy integration. Renewable & Sustainable Energy Reviews 19:247-54.

This article reviews current literature on EVs, the electric grid, and renewable energy integration, assessing the economic, environmental and grid impacts of EVs. Findings indicate the EV's ability to significantly reduce the amount of excess renewable energy produced in an existing electric grid.

Samaras, C., & Meisterling, K. (2008). Life Cycle Assessment of Greenhouse Gas Emissions from Plug-in Hybrid Vehicles: Implications for Policy. *Environmental Science & Technology*, *42*(9), 3170-3176. http://dx.doi.org/10.1021/es702178s

In this article, Samara and Meisterling compare the greenhouse gas emissions from plug-in hybrid electric vehicles to those from conventional vehicles and hybrid vehicles. The authors explore other fuels and battery types for PHEV as well, and provide quantitative data for emissions calculations. They assert that "meaningful GHG emissions reductions with PHEVs are conditional on low-carbon electricity sources" which is what our goal in this capstone project is: the installation of a solar powered charging station. Cited by 214 sources, this article is both a well-known and credible resource.

Sinpetru, L. (2012, December 7). San Diego Zoo Installs Solar-Powered Charging Stations for EVs. Retrieved from Softpedia website: http://news.softpedia.com/news/San-Diego-Zoo-Installs-Solar-Powered-Charging-station-for-EVs-312969.shtml

This short article provides another example of how solar powered electric vehicle charging stations are being implemented. The San Diego Zoo has joined the market with five such stations in their parking lot. California is more green-oriented than most states in the US and so does not come as much surprise, but this article still demonstrates that there is a growing demand for such stations.

Srivastava, A. K., Annabathina, B., & Kamalasadan, S. (2010). The Challenges and Policy Options for Integrating Plug-in Hybrid Electric Vehicle into the Electric Grid. *The Electricity Journal*, *23*(3), 83-91. http://dx.doi.org/10.1016/j.tej.2010.03.004

In this article, Srivastava, Annabathina, and Kamalasadan explore the technical and economic challenges to plug-in hybrid electric vehicle. This perspective comes from two authors who are university professors and a third author who is a Planning Associate Engineer with the New York Independent System Operator. Having a source outside of academia provides an industry perspective and valuable market analysis. It is useful in our project because it is useful to know the potential challenges of the future of plug-in hybrid electric vehicles and what it will take to have widespread implementation.

Tulpule, P., Marano, V., Yurkovich, S., & Rizzoni, G. (2011, May). Energy economic analysis of PV based charging station at workplace parking garage. In *Energytech, 2011 IEEE* (pp.1-6). IEEE.

The most difficult obstacle in implementing solar charging stations is the high costs of the project. Therefore it is important to analyze projected costs to evaluate its economic feasibility. This article examines the overall cost of two potential parking garage charging stations in different areas of the country. The authors take into account solar energy potential, PV panel costs, installation costs, and local rebates to assess the economic impact on garage and vehicle owners. They found that with the right pricing model for use of the stations, the projects were both feasible. This article provides the necessary considerations and steps for an economic analysis, but does not provide data for Pennsylvania. Using the article, it is possible to adapt the authors' methods to similar case at Lafayette College.

Vance, A. (2012, September 25). Tesla fires up solar-powered charging stations. *Bloomberg Businessweek*. Retrieved from http://www.businessweek.com/articles/2012-09-25/tesla-fires-up-solar-powered-charging-stations

This article discusses an initiative by Tesla Motors (an all electric car manufacturer) to set up solar charging stations for electric cars in strategic places along California highways. Six of these stations are already in place and open for business, and allow electric vehicle owners to travel long-distance, on common routes such as Los Angeles to San Francisco. Tesla Motors plans to implement more of these stations across the US, but so far construction has only taken place in California. When the solar charging station is not in use, it still produces power that will feed back into the grid. Though our charging station may not be grid connected, the Tesla solar chargers are useful for inspiration.

Wald, M. L. (2011, January 24). If You Build It, Will They Charge? New York Times, Green Blog. Retrieved from http://green.blogs.nytimes.com/2011/01/24/if-you-build-it-will-they-charge/

This article explores a prototype of a carport with grid-connected solar panels that will charge batteries at the Electric Power Research Institute. Along with the Tennessee Valley Authority, these organizations will use this model to determine if such systems are useful based on their economics and practicality. Like our project, the photovoltaic array does not provide direct recharging of batteries; rather it is grid tied and so allows cars to be recharged even if the sun is not shining. This is a useful example for our project to see how current technologies are being used in real-world applications.

Woodruff, A., Hasbrouck, J., & Augustin, S. (2008, April). A bright green perspective on sustainable choices. In *CHI-CONFERENCE-* (Vol. 1, p. 313). ASSOCIATION FOR COMPUTING MACHINERY INC.

The authors studied 35 American households whose residents have made technological and lifestyle changes in order to be more environmentally sustainable. The data they collected was mostly qualitative, obtained through interviews and observations. They researched the motives for becoming more environmentally sustainable, and they discovered that self-reliance, bio-activism, and trending practice were three major motives. Participants in the study noted that being environmentally sustainable was at times very difficult, and one had to devote a significant amount of time and effort into staying sustainable. Despite the effort, the idea of being "green" was often enough to make the effort worthwhile. Passive and active solar energy technologies were a major aspect of environmental sustainability for many of the households. In a context broader than just the 35 households, the authors discuss the design of persuasive techniques and methods of influencing policy and regulation. Despite the comprehensive nature of the study, the authors only studied households in the United States, where environmental sustainability is less practiced, compared to other regions of the world. With a comparison study of environmental households around the world, one may begin to understand the context behind the unwillingness of the Americas to accept and implement environmental sustainability practices.