Solar Powered Charge Stations: LCA Thinking

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Abstract

The United States is dependent on foreign oil largely because of the need to fuel vehicles. The introduction of plug-in hybrid electric vehicles (PHEVs) and electric vehicles (EVs) has the potential of reducing dependence on foreign oil, but much work is needed to develop best practices for powering these vehicles, as well as for developing successful transition to EVs.

Kansas State University is embarking on an effort to develop best practices for solar powered charge stations for PHEVs and EVs using multidisciplinary teams of educators and students.

The planned LCA component of the research will advance the science of integrating environmental, economic and social LCA to determine best practices in solving the problem of fueling vehicles of the future. The research results will be useful for communicating and educating students and community members on the different potential impacts related to use of PHEVs and EVs.

Keywords: Solar power; Charge station; Electric vehicle, Triple bottom line, Decision tool

Introduction

From the perspective of the triple bottom line of economic, environmental and social considerations, reducing use of gasoline for transportation seems essential. Dependency on foreign oil puts the United States economy at risk and is an ongoing social justice issue. Petroleum supplies are finite and the present transportation system with over $400 billion per year spent on gasoline is not sustainable (Williams et al. 2012). Yet, our need for reliable transportation continues to grow. Fuel combustion for transportation also pours an estimated 1,745 million metric tons of carbon dioxide into the air each year, which is about one-third of the U.S greenhouse gas emissions (EPA 2010). The introduction of plug-in hybrid electric vehicles (PHEVs) and electric vehicles (EVs) has the potential of reducing dependence on foreign oil, but much work is needed to develop best practices for powering these vehicles, building business models, and determining the appropriate level of government, as well as for developing successful transition to EVs.

Solar energy prices are decreasing while gasoline prices are increasing. There are continuing developments in the design and production of electric vehicles (EVs) and plug-in hybrid electric vehicles (PHEVs). New development in batteries and solar energy will continue to make solar powered transportation more attractive and competitive (Semonin et al., 2011). There are important research and educational issues associated with this great transition to solar powered transportation (Taylor et al., 2011), and the time to expand research and education related to solar powered charge stations for EVs and PHEVs is now. There are significant costs associated with climate change that provide additional reasons for moving toward solar powered charge stations. Williams et al., 2012 point out that transportation must be powered electrically and that electric power must reduce its dependence on fossil fuels to achieve an 80% reduction in greenhouse gas emissions.

A multidisciplinary team of researchers and educators at Kansas State University is embarking on an effort to develop best practices for solar powered charge stations for PHEVs and EVs. The plan is for the team to work cooperatively to develop triple bottom line systems decision support tools that will be made available to individuals, organizations, companies, and units of government to help them with the transition to solar powered charge stations and EVs.

The tool is envisioned to contain multiple functionalities and can be customized to work in support of all three constituents of the proposed parking structure – (1) the electric utility company; (2) the parking customer, and (3) the organization which provides the infrastructure (Kansas State University, in our case). The tool will integrate engineering, social and environmental aspects into overall systems analysis and provide a quantitative measure of the entire system utility.

Research Project Plan

Engineering and Computer Science Research

Research will be conducted to develop the science and technology associated with the parking station, the K-State micro-grid, and the larger issues associated with the development of solar powered charge stations for electric vehicles. Topics for research will include:

- Optimal design and control of the solar collectors, associated power electronic equipment, and charge station
- Flexibility of timing of battery charging and reliability of completing charging before a vehicle is moved
- Highly instrumented experimental charge stations to collect needed data

Economics Research

Many costs related to transportation are often overlooked. Preliminary research indicates that additional work is needed to estimate and include the following costs when making decisions about energy sources for transportation.

- Costs related to health effects and early deaths associated with poor air quality in urban areas due to vehicle emissions.
- Costs associated with manufacturing and powering large numbers of electric vehicle charge stations.
- Costs associated with meeting air quality regulations.
- Costs associated with depletion of fossil fuels.
- Costs associated with climate change.

Social Issues Research

Social issues related to conversion from gasoline powered vehicles to EVs need to be fully understood as new technology and practices are developed. There may be a broad array of opportunities related to new markets for solar powered charge stations to develop sustainable practices that promote social justice and human comfort. For example, if social justice issues are identified along the supply chain for solar panels, these can be addressed and corrected while the market is still developing. On the consumer side, the benefits of shaded parking are a social value for those who choose to drive PHEVs and EVs. Other potential social issues include:

- The value of convenience of charging a vehicle in parking spots versus driving to a gas station
- Social value of better personal health because of better air quality associated with clean energy to power charge stations and clean energy when driving electrically.
- Social value of living in a cleaner air environment; it is more pleasant.
- Increased social justice and a better quality of life because of reduced competition for fossil fuels.
- Social value aspects of climate change.

Life Cycle Assessment

The planned LCA component of the research will advance the science of integrating environmental, economic and social LCA to determine best practices in solving the problem of fueling vehicles of the future. The research results will be useful for communicating and educating students and community members on the different potential impacts related to use of PHEVs and EVs.

Integrated Systems Analysis and Synthesis of a Decision Support Tool.

The described research activities are planned to contribute to a multidisciplinary effort to develop a triple bottom line project systems decision support tool (see Figure 1) that can be used for decision making at several different levels. Metrics will be developed to combine and integrate social value considerations, environmental impacts, and economic values in the decision making tool. The ideal tool will have value for individuals who are considering EVs and PHEVs, for organizations such as K-State, and for companies that supply power, solar panels, charge stations, and power electronic products. This part of the research will approach the development of decision support tools from an interdisciplinary perspective that integrates science and engineering, including economics, psychology, public inputs, and life cycle assessment methods using a synergistic, systems approach.

Expected Outcomes

It is expected that the results of this project will benefit society in several ways. First, the research results will contribute to the knowledge of how to achieve electrical grid and mini-grid efficiency, voltage stability and reliability in systems as solar power is incorporated at greater levels into the national energy mix. Second, the decision support tools and a public education program will help advance market penetration of EVs, PHEVs, and charge stations. Additionally, the project will provide multidisciplinary team experiences working to advance the development of solar powered charge stations for many students at Kansas State University. Also, the project will enable many engineering graduates to be better prepared to work on solar energy, charge station, and battery projects.

Progress

Student Projects Completed

For the past three years, NSF supported undergraduate students have participated in visioning efforts to investigate the potential feasibility of using parking lots as locations to produce electric power, charge plug-in electric vehicles, store energy in batteries, and enjoy the benefits of shaded parking. This group project has provided a good triple bottom line exercise because the shade and convenience have social value, the reduction in greenhouse gas emissions and tail pipe emissions have environmental value and there are important economic issues as well.

Relevant LCA Studies in the Literature

Many independent groups from different regions have already conducted thirteen LCAs of various solar panel systems, including monocrystallized silicon and concentrated photovoltaics (which boasts higher efficiency). A literature search did not find any LCAs for electric vehicle charging stations.

One aspect of the planned research is to compare stations charged by solar versus those charged by current mix of resources in the United States and in Kansas, as well as solely with wind, coal, and natural gas. Many LCAs have been conducted for wind turbines, as well, thus this work will be combined with a basic structural framework for the charge station in order to evaluate charge stations powered by different types of fuel. The result will be a screening level LCA to direct further efforts of the research team.

Published LCA studies have resulted in greenhouse gas emission calculations that differ based on location, electricity grid, methodology of calculation, and solar panel array design. For the United States, literature values from 2006 and 2008 calculated that photovoltaic (PV) panels using monocrystallized silicon at 14% efficiency would emit life-cycle emissions of 39 g CO_2-eq./kWh, whereas cadmium telluride photovoltaics (CdTe PVs) emit 13 g CO_2-eq./kWh, the lowest seen in the literature (Fthenakis et al., 2011). A study of the Amonix 7700 panels stationed in Phoenix, AZ, which uses high-concentration photovoltaic cells (HCPV), calculated that over a 30-year lifespan, 27 g CO_2-eq./kWh would be emitted. If the III-V cells were replaced after the 30 years, the system’s lifespan would extend from 30 to 50 years. Since cell replacement does not add significantly to the lifetime emissions, the study predicted emissions of 16 g CO_2-eq./kWh over a 50-year lifespan. These values are significantly smaller than those for coal and natural gas (Fthenakis et al., 2007; Skone et al., 2011; Spath and Mann, 2000).

A sustainability firm based in Oregon noted that life-cycle GHG emissions were “40 – 55 grams per kilowatt-hour of generation capacity for standard silicon panels and 25 - 32 grams per kilowatt-hour for the newer thin-film technologies” (Good Company, 2008).

The time taken for the solar panels to recoup the energy input during its production process is called the energy payback time. For the United States, this appears to be about four years ("LCA of Silicon PV Panels").

Some of the finite resources depleted in the manufacture of solar panels include quartz, silicon carbide, silica, aluminum, fossil fuels (in transportation and refinement process, primarily from electricity use), and copper (wires).

The most significant waterborne effluents from the manufacture of various solar panels appear to be fluoride and chlorine (Alsema et al., 1995). The aforementioned Amonix system is expected to consume 26 liters of water per MWh, or 106,000 kg total over its 30-year operation (Fthenakis et al., 2011).

Life cycle air emissions reported by the various LCA studies of solar panels include solvents and alcohols, fluorine, chlorine, lead, and sulfur dioxides, though it was reported that air emissions are routed through control equipment and regulated under an air permit (Good Company, 2008).

These pollutants are emitted during the material extraction and production phases only. While the panels are in use, there are virtually no water or air emissions, which makes solar power favorable to traditional energy sources over the lifetime of the solar panels.

Solid waste attributed to solar panels is primarily generated during the material extraction and production phases as well. Assuming that the general solar panel production process has been unchanged since 1995, a Dutch study lists silicon dioxide, contaminated silica, calcium fluoride, and titanium oxides as solid waste (Alsema et al., 1995).

Funding

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Conclusions

Life cycle assessment shows that solar energy has lower greenhouse gas emissions compared to coal and natural gas. There are air quality benefits associated with the electrification of transportation. Further research is needed to develop the decision support tools.

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Figure 1: Architecture for decision support tool.