Refuelable Electric Car (IPRO 313) Spring 2010 Final Report

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CZAR-CAR: REVOLUTIONIZING THE WAY YOU DRIVE!

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Executive Summary

[…INSERT SUMMARY HERE…]

Team Purpose and Objectives

Team Vision:

To become and be recognized as a unified, efficient, and skilled team capable of confidently approaching, analyzing, and solving a multi-faceted technical problem with a global impact.

Team Mission:

To make significant strides toward creating a working prototype of a refuelable electric vehicle using a zinc air battery and to raise public awareness of the potential of this technology.

Team Objectives:

1. To construct and thoroughly test a single zinc-air fuel cell unit according to applicable standards and procedures.
2. To improve on the existing zinc-air fuel cell design based on the results of testing the first unit.
3. To check existing systems on board vehicles donated by Argonne National Labs next semester.
4. To replace systems that are out of order or unsuitable for use in a zinc-air powered system.
5. To spend idle periods in designing a system for refueling the prototype vehicle that is cost-effective, safe, and comparable in ease of use to current gasoline fueling systems.
6. To raise awareness and support of the project through publicity, directed toward potential corporate and non-profit sponsors, as well as the public.
7. Act ethically and legally, respect intellectual property rights, and verify the safety of the product throughout development and testing.

Project Background

Modern industrial society is highly dependent on the transportation of products and of people. The automobile is a preferred form of transportation for both individuals and businesses, as it can go virtually anywhere at any time. Private automobiles are valued by individuals for convenient, efficient transportation. Tons of goods are transported by trucks across the North American continent daily, making them indispensable to commerce. Buses relieve congestion in downtown areas of large cities, while providing city-dwellers with convenient transportation options.

All these vehicles are major consumers of gasoline fuels derived from crude oil. However, the global supply of crude oil is dwindling and is unlikely to support currently industrialized society, much less the industrialization of developing countries, for much longer. Furthermore, the internal combustion engines used by most vehicles spew hundreds of tons of pollutants into the atmosphere in the United States alone. Worldwide, this amounts to a staggering amount of carbon monoxide, nitrous oxides, volatile organic compounds (VOC's) and other pollutants exhausted into the atmosphere by the global fleet of vehicles. Even without touching on the controversial issue of global climate change, the impact on air quality and health is impossible to ignore. The United States must put considerable resources into regulating and monitoring air quality, to ensure the safety of its citizens. To further add to the detriment of internal combustion vehicles, the United States' national security is placed at risk due to a dependence on foreign oil because of an insufficient domestic supply.

Clearly, an alternative is desperately needed, which is why research into a number of alternative fuel options is currently being performed by every major automobile manufacturer. Biofuel-powered cars, hydrogen fuel-cell powered cars, and plug in hybrid-electric vehicles (PHEV), as well as fully-electric cars, are being considered as the successor for traditional internal combustion engine vehicles. However, each of these options has its own fatal flaw.

Biofuels must be eliminated first, chiefly because they do not solve the emissions problem, although they may reduce it temporarily or slow it down. Other concerns with biofuels include the amount of land needed to cultivate the biomass of which they are produced, and the possible impact of this on food production and on the environment if more land must be cleared to accommodate growing biomass for both fuel and food. There is also at this time a very limited infrastructure for processing, producing, and distributing biofuels, except as an addition to gasoline. Overall, this option does not solve all the problems, and still requires significant capital investment. It is not prudent to put that capital into a technology that offers such limited improvements on its predecessor when there are other options.

Hydrogen fuel cells can seem like an attractive option, at first. However, there are several concerns that disqualify them as a solution. Safety is a major concern: hydrogen is a highly volatile gas, and furthermore, it is difficult to contain due to its small molecular weight. The task of designing a hydrogen infrastructure that is safe and easy for the consumer to use is a daunting one. Another major concern is the production of hydrogen: the most energy- and cost-efficient way to produce hydrogen at this time is from hydrocarbon fuels, particularly natural gas, with a byproduct of many of the emissions that alternative fuel technology is attempting to eliminate. Although fuel cell technology is a definite improvement over internal combustion engines—fuel cells have a higher efficiency—they are still not a viable alternative energy source at this time.

Plug in hybrid vehicles are yet another popular solution—and a logical progression from hybrid vehicles of today. There are estimates that plug in hybrid vehicles could eliminate up to 90% of current fuel consumption. While this is clearly an improvement on current technology, plug in hybrid technology is still ultimately dependent on gasoline for trips longer than one battery charge. The technology is a step in the right direction—

electric vehicles have been shown to be more efficient than internal combustion engines, even if they are ultimately charging from electricity produced from fossil fuels. Still, they are at most an intermediate step and an extension of the impending deadline enforced by the dwindling oil supply.

Fully electric vehicles (EV's) are the next step up from PHEV's. They run entirely off the electric grid, producing no emissions of their own. As mentioned above, running vehicles off the electric grid is more efficient than having each run off its own combustion reaction. Meridian International Research found in a 2007 report that electric vehicles were the only possible alternative to gasoline-powered vehicles.

The main question facing the electric vehicle market is, what kind of battery will it use? Lithium-ion (LiIon) batteries are a public favorite, but this could be due to familiarity—LiIon batteries power most portable consumer electronics devices. A LiIon battery to power an automobile must be one hundred times larger than a laptop computer battery. This, compared with global reserves of lithium, was shown in a Meridian report to be too scarce a resource to power cars around the world. Nickel-metal hydride batteries (NiMH) and sodium nickel chloride (NaNiCl) batteries are another alternative, but they are heavy, and the nickel supply is only a little less limited than the lithium supply. Both of these options also suffer from a recharge time unacceptable to the average consumer; a problem that has yet to be resolved.

Another alternative is the Zinc-air battery. It is an economical choice because there are no particularly rare or expensive components—zinc is one of the more abundant metals, and the fourth most abundantly mined. The product of the reaction, zinc oxide, is also readily recyclable back into zinc for reuse; this is actually cheaper than using new zinc!

There are several types of Zinc-air batteries—while the rechargeable battery is an option as it is with LiIon and NiMH batteries, the Zinc-air battery can also be used as a reconstructable or refuelable battery. The reconstructable option involves removing the battery and replacing parts consumed by the battery reaction. The refuelable option involves resupplying the battery with a slurry of zinc and electrolyte. Rechargeable zinc-air batteries have recently been significantly improved through the research efforts of ReVolt Technology, currently based in Switzerland; this has eliminated a prior barrier of low cycle life. The company endeavors to market them as a more energetic alternative to LiIon batteries for consumer electronics. Reconstructable batteries have been demonstrated by Electric Fuel, Ltd., based in Israel, which has worked with several organizations and government agencies, to create a zinc-air powered shuttle bus that used replaceable zinc-air cassettes. The technology was fully operational, but the cost involved in recycling the cassettes was prohibitive for most applications. The third option is the refuelable battery, invented and tested by John F. Cooper from Lawrence Livermore National Laboratory (LLNL) in Livermore, CA. A unique battery hardware design allows the zinc to be provided as <1mm sized pellets in a saturated solution of potassium hydroxide (KOH). The slurry of pellets in electrolyte can then be supplied without moving the battery hardware.

For automotive applications, this quality of the zinc-air refuelable battery is very important. Cooper showed that a battery can be refueled in less than 10 minutes, comparable to the amount of time spent by a consumer at a gas station today. The battery has sufficient energy density for the range per tank to be comparable to current values as well. The fact that the metal is recyclable means that after an initial investment, a minimum of new material would be required on a regular basis to sustain the transportation infrastructure.

The battery is also a good choice ethically. It is clean, safe, and environmentally friendly by virtue of having no toxic components and producing no emissions. It also contains no reactive materials—there is virtually no risk of fire or explosion, as there is with current gasoline usage and with hydrogen gas. There is one danger, and that is that potassium hydroxide is a corrosive substance. This will be an important consideration during design of refueling systems to avoid human contact with the chemical, which could cause chemical burns.

The battery is also an ethical choice on a social level—the abundance of the materials involved worldwide means this technology is accessible to developing countries as well as to industrialized countries. Intellectual property rights would of course need to be considered on an international level for this to occur legally and fairly, with due respect to the patent-holders.

The zinc-air technology is brimming with potential, but seems to have largely been overlooked in the public search for solutions to the gasoline problem. Consumer gasoline prices spiked to $4/gallon in some areas of the nation over the summer of 2008, as compared to around $1.30 in 1998. Prices of consumer goods have risen as well, sometimes as much as doubling, on products including food, toiletries, clothing, and school supplies; life's necessities. The public is paying the price for a continued reliance on oil. The public is also paying in healthcare costs and in lives due to poor air quality, particularly in cities. Ultimately, dependence on oil is costing in quality of life, and that is the most valuable thing.

The goal of the IPRO project is to demonstrate the potential of the zinc-air technology in a public way. The team will solicit the help of interested sponsors, including but not limited to, energy companies, automotive manufacturers, local electric car groups, government offices, transportation services (CTA, etc), and Power Air Corporation, the company that currently holds the rights to the ZARB technology. The team will also solicit help from interested individuals—John F. Cooper, the inventor and patent-holder of the ZARB technology, has expressed excitement for the project, as have several other individuals.

In the last semester, the first semester of this project, the team set the direction of the project and laid groundwork in the form of theoretical calculations, designs, and publicity. They consulted with electric car interest groups in the area, initiated and maintained contact with potential sponsors, performed research using books and internet sources, and reverse-engineered a ZARB cell when it became clear it could not be readily purchased externally.

This team will make use of the support solicited by the previous team and the existing plans and designs to begin work on creating and testing prototypes. Several iterations may be necessary and the final prototype will not be ready this semester, but significant strides can be made. Simultaneously, the team will work on designing a safe, efficient, and easy-to-use refueling system that is as similar as possible to gas pumps. Lastly, the team will continue use every possible opportunity to publicize the project and its potential, including news media.

This project's scope prohibits having a single sponsor, but it is supported by donations from Exelon Corp., IIT's Wagner Institute for Sustainable Energy Research (WISER), and Argonne National Laboratories. It is also supported by expertise and time donated by Pioneer Conversions, the Fox Valley Electric Automobile Association, and many individuals on and off the IIT campus. The project is still actively looking for more sponsors and more support.

** See Appendices A, B, C, and D for more documentation **

Organization and Approach

Team Structure

The team is organized into three teams, the Car Team, the Battery Team, and the Promotional Team. These teams were used at the advice of returning team members and due to a logical breakdown in tasks resulting from such a structure.

The teams have equal authority and there are no official leaders—decisions will be reached by consensus. This team structure was selected because no student at this point has significantly more familiarity with any part of the project to make educated decisions alone. Furthermore, electing a single leader would detract from the responsibility that rests with *every* team member.

Some team members felt their interests (at least for the time being) lay in more than one team; they were encouraged to take part in the activities of all the teams that interested them. Furthermore, it was recognized that a fluidity in the team structure was necessary to make best use of everyone's talents during all stages of the project.

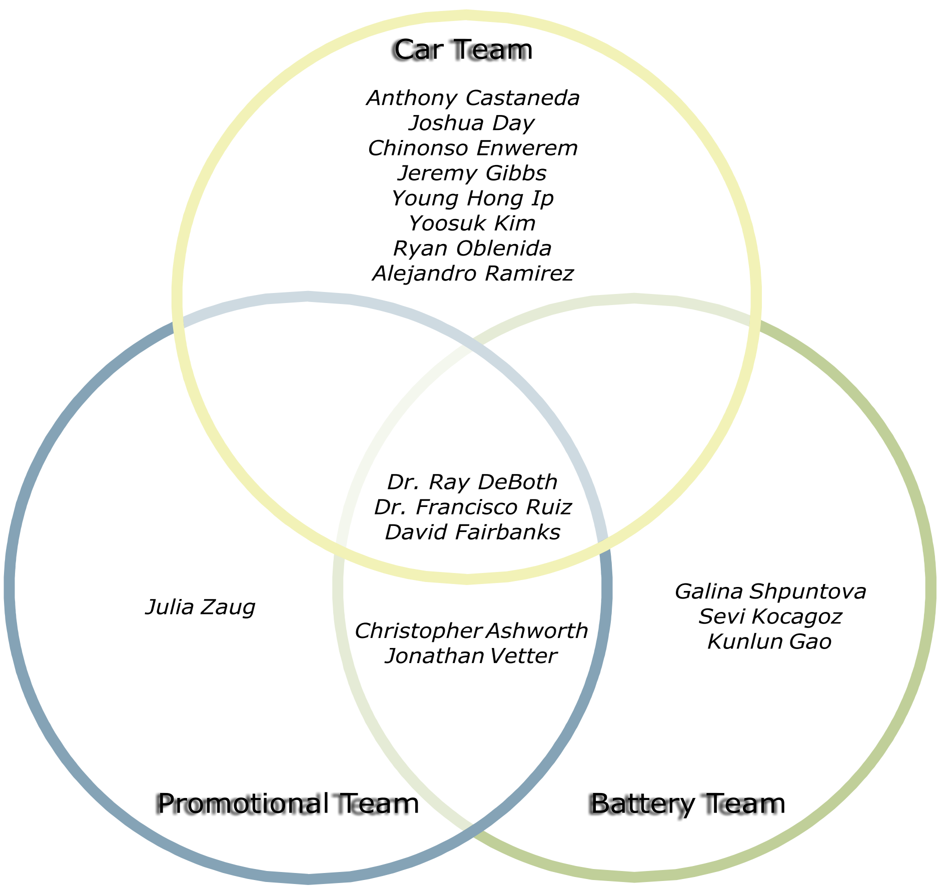

Figure 1: Team Organization

Major Tasks

Tasks were best organized with respect to the groups responsible for executing them.

Car Team

1. Examine and test all components in donated vehicles
2. Order any replacement parts as necessary
3. Remove broken components and install replacement parts

Battery Team

1. Finalize cell design from last semester
2. Manufacture single cell
3. Create and execute testing plan for single cell
4. Use conclusions to create alternative designs
5. Test alternative designs and select optimal design

Publicity Team

1. Identify funding opportunities with approaching deadlines
2. Publish articles in IIT media (TechNews, IIT magazine, etc.)
3. Contact IIT Media Relations Office and Chicago news media

Analysis and Findings

Car Team

The car team focused on the repair of an electric vehicle (EV). Many challenges have been encountered along the way due to the complexity of the vehicle. With two trucks donated from Argonne, the team began their work without any knowledge or documentation of the electrical system in the vehicles with a goal of repair at least one of the two cars.

The team quickly learned that the vehicles were converted by a professional company, which was later contact but unwilling to release documentation of the vehicles. By investigation, both trucks contain the same 3-phase AC induction motor, motor controller, and the original braking and accessory systems. The battery pack and battery monitors differ, one containing nickel-metal-hydride (NiMH) batteries and the other lead-acid batteries.

The first concern of the team was the battery packs. The team realized that the NiMH batteries were in very poor condition. After some research on battery behavior, a series of tests were performed and confirmed that they needed replacing. Several batteries were considered as replacements including batteries from the Toyota Prius and from Saft technologies. Through our contacts at Pioneer Conversions, a set of Saft batteries were found but the cost-analysis pack did not legitimize the purchase of this battery pack. Fortunately, the team discovered that the lead-acid batteries were in working condition.

Another obstacle for this team was the lack of documentation of the vehicle. The electronic systems such as the motor controller are complex devices with various safety and communication devices. Certainly analyzing these devices were heavily time-consuming. The group divided to investigate certain subsystems. The motor controller, battery monitor system, charging circuits, and voltage converters were analyzed by specific individuals. Basic schematics were made and documented on PSIM (a circuit simulation program) for future reference and further analysis. The safety system in the battery monitor system was a major difficulty. Due to the nature of the system, the car was unable to be in the drive mode because of error conditions. Without the proper documentation, the battery monitor system caused major difficulties in testing the vehicle.

The team has decided to design a simple DC system to replace the AC system. At the same time, the battery management system will be replaced so that the battery can be safely monitored and so that the motor and controller can also be tested. The DC system is a popular system for electrical vehicle enthusiast and the S-10 vehicle is a popular choice for many. The system will therefore be a well-established design that will be simpler and less costly. There are a variety of components that are commercially available. Since the popularity of these systems is high, the future team will be able to find resources and assistance more easily in comparison to the AC system. The future system is likely to contain a Warp motor, Warp controller, and Paktrakr battery monitor system. The system has not been finalized, but we are researching to determine the most effective way to design the vehicle.

Battery Team

The progress of the battery team this semester was generally in beginning the manufacture and testing of battery cells. The design devised in the previous semester had to be modified for several major reasons. Available manufacturing processes included SLS (Selective Laser Sintering) or milling out of a solid piece of material. SLS would be faster and less expensive but produce a porous nylon material; it was also subject to a size limitation of about 8x11 inches. Milling could produce a part out of a wider range of materials, but would be more expensive due to a higher demand on the machinist's time. After considering these alternatives, the team decided to choose SLS manufacture for the first prototype, perhaps opting for milling on a later design if necessary or desirable.

As a result of this manufacturing choice, the battery had to be redesigned to accommodate the new dimensions. The battery design consisted of three essentially flat plates with channels to guide the reactant flow and hold the reactants. Changes in the design mainly involved changing the relative sizes of channels and compartments to accommodate the manufacturing method selected. In addition, several improvements were made, including the addition of threaded connectors on the front and back plates of the battery. Threads are fairly universal and would allow the connectors or battery plates to be changed independently of each other—the battery plates could be manufactured without changing the connectors and the connectors could be changed separately, as long as they retained the threads on one side.

Another part of the battery team focused on selecting and ordering peripheral systems and supplies, including pumps, piping, reactants, containers, and data acquisition devices. These were off-the-shelf components including a desktop fountain pump and a computer cooling fan. It was important to acquire these supplies before the battery manufacture was complete so that the experimental setup would be prepared for the battery.

Everyone in the group spent the first few weeks working on designing a testing plan for the battery cell. In large part, this plan was based on the testing performed on a similar battery model at Argonne National Labs in April 2001. This procedure was based on the guidelines established by the US Advanced Battery Consortium, but eliminated tests that involved degradation with recharge, since the battery was refueled.

Once the battery cell was manufactured, the battery team set about trying to assemble it. Sealing the battery against KOH solution penetration was a major concern; one that was addressed by sealing each plate with superglue. Some connection problems were also detected. Essentially, this first prototype highlighted several issues in the design that needed to be corrected. The battery team consulted with the rest of the IPRO group and decided that having a new battery manufactured would be beneficial to further testing. Manufacture of the second prototype and assembly of batteries is still in progress.

Promotions Team

[Not yet received…]

Conclusions and Recommendations

[To be completed…]