IPRO 313 Final Report (first draft)

CZAR CAR

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Executive Summary

In the current market for electric cars the ability to easily and quickly re-charge the battery is paramount. Our project's goal is reinventing the current automobile infrastructure to eliminate pollution but still maintain the current system. By using zinc pellets our electric car will be able to charge in less than ten minutes, as opposed to the current hybrid and full electric cars which take hours. Current refueling stations can easily be converted to zinc stations, not disturbing the structure in place today. Other sources of electric power, such as Hydrogen fuel, require significant amounts of power to synthesis the fuel its self increasing its price and decreasing its availability. Zinc is easily refined and is highly abundant. Also the waste product produced by the chemical reaction can be converted completely to usable zinc fuel.

Purpose and Objectives

Our objective is to create a working prototype of a refuelable electric vehicle based on a Zinc-Air battery that is comparable to current consumer vehicles in performance and fuel delivery. We will select and acquire a vehicle for conversion either from an internal combustion engine or from an existing electrical drive. Design and build a Zinc-Air prototype battery of sufficient voltage and power to drive the vehicle selected. Design a system for refueling the prototype vehicle that is cost-effective, safe, and comparable in ease to the existing refueling infrastructure. Also we will raise awareness and support of the project through publicity specifically directed toward potential corporate and non-profit sponsors, and the public. Acting ethically and legally, respecting intellectual property rights, and verifying the safety of the product throughout development and testing will be followed.

Organization and Approach

The team plans on making a small prototype of Zinc-Air fuel cell. In order to achieve this, the battery sub-team will order the materials required to make one at an IIT facility. Calculations are being done to calculate the quantity of Zinc, Potassium Hydroxide (electrolyte) and casing material needed. For testing purposes the team will start with a Five-cell battery. It is not sufficient for driving the automobile but fairly enough to perform uphill, downhill, course route and drag tests. It has been concluded from the cost analysis done that approximately 50% of the cost goes into making the Air cathode. The team plans on getting one from an outside source. As a plan B, even the Air cathode might be made at the college facility. Security of the battery is also an important factor. So, while the construction of the battery is going on, the car sub-team plans on making a casing for the battery. Materials will be selected based on the material properties. The properties include high corrosion resistance, high impact resistance, high ductility and low density.

We have chosen to construct an electric vehicle. Contrary to gas powered vehicles, electric vehicles produce no emissions, reducing the strain on the environment and the nation's dependence on foreign oil. President Barrack Obama has made a push for electric vehicle development. The type of fuel source will be the Zinc-Air battery. These batteries run on Zinc pellets. Zinc is abundant, readily found in nature, and inexpensive. A vehicle utilizing the Zinc-Air battery will take approximately 10 minutes to refuel and run for approximately 300 miles (depending on the tank's capacity). This provides a great advantage over other electric vehicles which have a more limited range and the usually require 4 to 6 hours to recharge.

The choice of the automobile to be used was the most vital decision. The automobile will be from an American manufacturer. As a first step the team narrowed the options down to either a sedan or a compact truck. A sedan would appeal to consumers from family ride perspective while a compact truck will give more space to work with the Zinc-Air fuel cell batteries. From the above two options, the team decided to go with a compact truck. There were quite a few reasons behind this. To begin with, the ease of space was an essential factor. In a sedan there was a lot of fabrication need in making cases to hold the batteries. The trailer of the truck works as a read- made bed where the batteries could be placed. There is also space under the trailer to put more batteries. The drag co-efficient on a compact truck is fairly large, but to overcome this more batteries can be added to the additional bed space.

Amongst compact trucks, the team had a couple of options. The Ford Ranger was a good model to work with. Very similar was Chevrolet S10. The team decided to work with Chevrolet S10. A pickup truck provides the ideal prototype vehicle. Compared to a car, a minute amount of altering must be done to a pickup in order to house the electric motor, batteries, and additional components. A car does not have a large truck space; however, a pickup has a large bed in comparison. This bed will provide an excellent place to house the battery components of the electrical system. A pickup truck provides the ideal prototype vehicle. Compared to a car, a minute amount of altering must be done to a pickup in order to house the electric motor, batteries, and additional components. A car does not have a large truck space; however, a pickup has a large bed in comparison. This bed will provide an excellent place to house the battery components of the electrical system. For the prototype, a compact pickup provides the most efficient, cost-effective option with the benefits of the pickup design. Compared to other pickups, compact pickups have the lowest drag coefficient, making it more aerodynamic. Also, compact pickups weigh the least. The combination of low weight and drag coefficient reduces the amount of batteries and fuel required to power the vehicle.

An excellent pickup of choice for a Zinc-Air battery powered electric vehicle would be the Chevy S-10. For this project, the vehicle must be converted from an internal combustion engine to an electric motor. The most popular compact pickup truck conversion on the market is the Chevy S-10. In fact, easy to install conversation kits have been developed specifically for the S-10. Plus, the S-10 is longer, has better drag coefficient, and weighs less than the second best pickup for this prototype, the Ford Ranger. S-10 is over 17 feet long with a drag coefficient of 0.44 and weighs 3077 pounds (curb weight), while the Ranger is about 15.5 feet long with a drag coefficient of 0.49 and weighs 3437 pounds (curb weight). Again, the combination of a lower weight and a lower drag coefficient reduces the amount of batteries and fuel required. Also the addition length provides more space.

In the design of this electric vehicle, the Zinc-Air batteries act similar to a generator. The Zinc-Air batteries will constantly produce power to recharge the secondary battery unit. The secondary battery unit is the source of power that directly drives the electric motor. Why not use the Zinc-Air battery to run the electric motor? The Zinc-Air battery produces power at a constant rate and does not respond to the periodic power spikes experienced while driving, such as accelerating and driving up hills. The purpose of the secondary battery unit is to output the required power to the electric motor. In standard electric car conversations, lead-acid batteries fulfill this requirement. However, lead-acid batteries add too much weight to the vehicle. A heavier vehicle needs more Zinc-Air batteries to run, space that we don't have. The answer to this problem is to use $LiFe(PO_4)$ battery. This battery is lighter than lead-acid batteries. For our prototype battery, we have decided to go with Lithium Iron Phosphate ($LiFePO_4$) rather than the more tradition Li-Ion batters, lithium cobalt oxide and lithium-manganese oxide. We chose this type of battery because of several key advantages such as improved safety through higher resistance to thermal runaway, longer cycle and calendar life, higher current or peak-power rating, and use of iron and phosphate which have lower environmental impact than cobalt.

4. Analysis and Findings
5. Conclusions and Recommendations

Appendix

Specific Task Analysis:

The Czar Car IPRO team was sub-divided into three groups for efficient communication. Below is a summary for each sub-group, discussing specific tasks performed by each member.

Car Team

The car team began researching the power requirements for different types of vehicles at highway cruising speed. In addition, the working room in the vehicle was considered. Parts availability and electric conversion information were also important factors. Consumer appeal was considered as a high priority. The decision was made to use a small size pickup truck as it provided the ideal balance of all of the above criteria.

Both an in-house conversion and sourcing a previously converted electric vehicle were considered. It was decided to search for a converted vehicle due to time constraints, as there were other resource allocations that were considered higher priority. We met with local electric car enthusiast clubs and businesses to learn more about the conversion process and the current state of battery electric vehicles. Two custom electric vehicle conversions based on the Chevrolet S-10 located at the nearby Argonne National laboratory facility were assessed and decided upon as the base platform for continuing project. Mechanical work on the truck will be performed mainly by students at the IIT SAE garage.

Additionally, an initial plan for the electrical system was developed. Calculations were done showing the requirement of an auxiliary battery to augment the fuel cell for acceleration power and regenerative braking capability. Several capacitor and electrochemical battery solutions were analyzed, including lead-acid, nickel-based chemistries, supercapacitors and lithium-ion. It was shown that for our particular power and energy requirements, lithium-ion batteries offered the best solution. Specifically, the high life cycle and safety of lithium iron phosphate ($LiFePO_4$) anode chemistry was considered as our top selection.

We are currently assessing the electrical systems of the trucks located at the Argonne facility. Possible steps forward include either converting the system to DC or using the existing AC motor with additional electronics. We will be working with Dr. Emadi of IIT concerning the power electronics subsystem.

Promotional\Sponsorship Team

Firstly, out team performed preliminary research on possible funding sources, as well as different companies and organizations in our area of interest (electrical car applications). Next a website was made to promote the awareness of Czar Car and for a reference for interested individuals or organizations. A proposal was written for WISER and submitted, we are still awaiting response. A meeting was set up with the president of IIT, Mr. John Anderson, to personally introduce him to the Czar Car and get some suggestions and advice for the advancement of the Czar Car idea. A proposal to Exelon and the NCIAA were also written, we again are still awaiting response. The Department of Energy, in Chicago, was contacted as well as American Science and Technology for information on government grants.

Battery Team

The battery team began by performing an analysis of the chemical processes occurring in the battery. They met with Dr. Vijay Ramani to discuss and thoroughly understand the operation of the battery. Using data provided by the car team, the appropriate amounts and flowrates of the reactants for the whole battery were determined to be 50 kg/hr of zinc and 4.76 L/s (12.23 kg/hr) of oxygen, and therefore 22.6 L/s of air (100.3 kg/hr). For one cell (of which there are 150 in the full battery), about 0.7% of this is required. The geometry required to support the functioning of the battery were also examined and discussed. This created the basis for further division within the battery subteam.

Using papers and presentations published by Cooper et. al., as well as other publicly available information sources on this zinc-air battery design, one member of the battery team reverse-engineered a model of the battery enclosure in Autodesk Inventor. The enclosure is essentially a flat plate with flow paths and cavities milled into it on both sides; it defines the battery geometry. He then used this model in a computational fluid dynamics software to analyze the flow rates required in the battery, and from this verified the sizing of all orifices in the battery enclosure.

Selection of materials for the zinc-air battery required careful consideration of a number of factors, including strength, durability, corrosion resistance, cost, availability, and ease of manufacturing. By examining papers by Cooper et. al. and comparing with material safety data sheets (MSDS) on KOH, it was determined that a plastic was the only option for the battery enclosure, as most metals corrode rapidly in its presence. Although it was by no means the ideal choice, polycarbonate was the selected option because its disadvantages could be compensated by the design of the battery casing. Extremely thin sections, which cannot be manufactured from polycarbonate, were avoided in the design, and thin, flexible gaskets were integrated to compensate for slight deformation of the material and prevent leakage between plates.

The current collector on the anode side presented further complications. The purpose of the current collector implies that it must be a good electric conductor, which consequently implies a metal. Analysis of available data on the electrochemistry of copper, aluminum, and iron, as well as more expensive metals, showed that the best way to determine a good current-collector material is to test different materials in a prototype; however, copper was found to be likely candidate and a good material with which to begin testing. The requirements for the testing procedure were determined and recorded for future application.

The selection of the air cathode was of pivotal importance to the battery design as well. From preliminary research based on Cooper's papers, it was determined that the necessary product was a gas diffusion electrode, consisting of Teflon-bonded carbon black supporting a cobalt porphyrin catalyst (from Cooper 1998). The product is available commercially; the vendor of this product was Electric-Fuel, Ltd. The battery team contacted this company for a price quote and found it reasonable for production of a prototype.

The full list of all materials necessary to manufacture a battery cell for testing was submitted for purchasing. Polycarbonate for the frame did not need to be purchased as it is expected to be provided by the manufacturer, presumably the IIT machine shop.

A final task of the battery team was to find and analyze competing technologies. In the midst of this project, a project based in Germany was discovered, which is utilizing a redox-flow battery for electric vehicle applications. The redox couple used in this design is vanadium, and the product is commonly referred to as a Vanadium Redox Battery (VRB). The battery technology has been in existence for some time, and has been primarily used in large-scale designs (e.g:-wind energy storage, auxiliary power source). However, Fraunhofer ICT—the German group currently working on advancing the technology—has recently made a press release about the application for VRBs on a smaller scale (namely in electric vehicles). The prior restriction in the application of VRBs in automobiles was their limited energy density. Upon extensive research, it proved impossible to find specific information on the battery's design and specifications for electric vehicle applications. This development appears to be very recent, and perhaps in due time more information will be available publicly with regards to the design, upon which a more comprehensive comparison with the zinc-air battery can be performed.