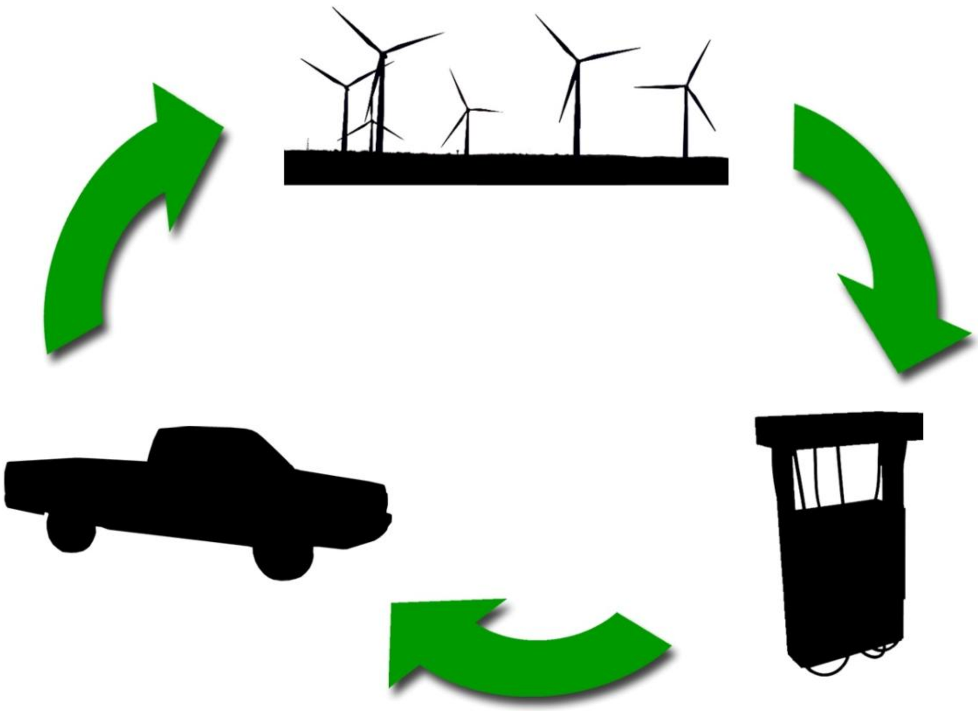
Refuelable Electric Vehicle

IPRO 313



Faculty and advisors: Francisco Ruiz, Denis Vasilescu, Ray DeBoth

Executive summary

In light of the global sustainability movement, several mainstream ideas and designs for low to zero carbon emission vehicles have been developed. In the case of all electric vehicles (EVs), Li-Ion batteries seem to be the favored technology due to their high energy density relative to competing energy storage technologies. Despite its superiority to other batteries, it still lacks the energy density to practically achieve comparable range to a fossil fuel powered car, and faces additional challenges in terms of refueling and infrastructure development. Therefore, technologies are needed to ease this demand and possibly supplement it. IPRO 313 has undertaken the task of using Zinc as an electrochemical fuel. The design is based on a Zinc-Air fuel cell developed by John F. Cooper of Lawrence Livermore National Laboratory (LLNL) [1]. The design allows the zinc to be provided as < 1 mm sized pellets in a saturated solution of KOH. Using Zinc as a fuel means that exhausted fuel, ZnO, can be recycled. The fact that the metal is recyclable lends this technology to requiring a minimum of new material to sustain the transportation infrastructure. Most importantly, in comparison to current refueling mechanisms, Cooper *et. al* showed that a battery can be refueled in less than 10 minutes [2] making it a good competitor in the current and emerging eco-friendly vehicle market of which the IPRO plans to build on. So far the IPRO has designed and constructed one prototype and conducted pressure drop experiments. The plans now are to improve the current ZAFC design and investigate the relationship between the electrolyte flow rate and the energy output. Once the single ZAFC has been tested and is providing the output needed, several more will be constructed and put together in an array to supplement the primary battery pack used to provide instantaneous power to the electric engine. Subsequently, the team will begin working on the staple of the project which is to design a mechanism which will refuel the ZAFC array by replacing the old electrolyte and zinc solution with a fresh electrolyte and zinc to all cells.

Purpose and objectives

The objectives of the project consist of both short term and long term goals which can be placed under three specific categories: fuel-cell, vehicle and media. Short term goals regarding the ZAFC are to finish ZAFC design and construction in order to investigate the relationship between electrolyte flow and specific energy. In the vehicle department, old components such as controllers, primary batteries, engine and transmission will be removed and replaced. In order to accomplish both of these categorical goals funds are required. Therefore, there will be a need to establish a media basis. This will include publicizing the team's progress via local and school newspapers, social networking sites (Facebook) and a personal website. In addition to that, the team will be targeting automotive manufacturers, electric car groups, and companies involved in the mining and processing of zinc. Primarily, we are looking for sponsorship from energy corporations and sustainability organizations. All these goals should be accomplished within the same period of time since all depend on each other.

Once the short term goals are accomplished the team will begin working on the long term goals. The ZAFC will be studied extensively in order to understand the flow behavior inside the cell and provide a better idea of features or mechanisms to include in the design in order to mitigate zinc agglomeration issues. Following that, several ZAFCs will be constructed and put together in an array to provide the primary battery with the required potential for proper charging. The array will then be attached to the primary batteries and a dummy load to simulate the draining and recharging the battery will undergo once it is used in the vehicle. Once all testing has checked out and the system proves to be working correctly, the batteries, both primary and secondary, will be hooked up to the vehicles electric engine.

Organization and Approach

In order to achieve the goals we have set for the project the IPRO has been split into three teams: the battery, car and financial/business team. Each team had a set of specific responsibilities which contributed to the progress of the team.

The battery team is mainly responsible for further improving the design based on prior experience from the results of the first prototype. The first prototype suffered from issues with leaks, low power under test load, low electrolyte flow, and zinc pellet agglomeration. Simple design improvements have been implemented to mitigate of the first three issues listed. The latter is what will occupy most of the team's time. In fact, Zinc agglomeration was also a problem that Cooper encountered while developing this type of cell. To further understand the kinetics and chemistry behaviors the team will perform both theoretical and experimental work. The team will first conduct simulations using a computational fluid dynamic (CFD) software package such as ANSYS or Comsol Multphysics™ as a means of understanding the characteristic flow of the system and elaborate on the previous pressure drop experiment conducted. After that, all ZAFC prototype constructed will be built with clear plates in the anode side in order to observe the cell functioning in real-time. By implementing this plate the team will gain more insight on the optimal electrolyte and air flow rates; the time evolution of zinc pellet agglomeration and be able to juxtapose simulation and experimental data. It will also help the team see what features one may want to include in the design to alleviate the zinc agglomeration problem. Once a ZAFC that provides the desired power and does not suffer from the initial problems encountered, several more cells (~20) will be constructed and set up in series to provide the required potential to charge the primary batteries followed by charging tests done on primary batteries hooked up to a dummy load.

The job of the car team was mainly an overhaul of the existing vehicles the team acquired from Argonne with the help of Fox Valley car club and Pioneering Conversions. Currently, one of the two Chevy S10s has undergone the overhaul procedure. This procedure includes removing old components that will be replaced with new ones such as the electric engine, manual transmission and controllers. Subsequently, a conversion kit is attached to the new electric engine to the new manual transmission. This same procedure will be repeated in the future on the second vehicle. Having a second vehicle will not only allow for more testing to be done in parallel but will also serve as a backup when the first vehicle is under maintenance.

Managing finances and team support was a task carried out by the financial team. The financial team is working with the Evan Venie (Associate director of Media relations) on publicity efforts. Evan is currently helping the team contact local columnists to attract the public's attention towards zinc/air technology but most importantly, possible sponsors. In addition to that, the web is also being used as a medium for publicity. A group on Facebook and website are both currently in the beginning stages of development. The Facebook group will serve as a way to recruit motivated students not only to sign up for the IPRO but to actively participate even if not enrolled. The website on the other hand will contain essential project information where useful knowledge can be shared between the team and EV enthusiasts. The group of business graduate students from the University of Chicago to publicize and assesses finances of the project.

Analysis and Findings

Analysis of the prototype after the experiment showed two things. First, zinc agglomeration was definitely a big issue in the cell. Much of the zinc had settled to the bottom of the cell hindering cell performance. Second, scanning electron microscope (SEM) images showed precipitate formation on the surface of the zinc particles and can be seen in figs. 1-3.

On the car side, after attaching the electric motor to the transmission there it was clear that some chassis modification had to be made. The electric motor mounts do not fall well with the existing mounts so there will have to be custom made mounts designed to securely attach the motor to the vehicle.

Conclusions and Recommendations

Overall the IPRO made important progress this semester. Two additional ZAFC prototypes were fabricated (fig. 4) with new features and clear plates to allow the team to further investigate electrolyte and zinc flow behavior. The car team was able to remove the old components and install the electric motor to the vehicle. Finally, a proposal was completed and submitted to the IIT Wagner Institute for Sustainable Energy Research (WISER). Next semester's work will consist of further testing and investigation of the new ZAFC prototype flow behavior. Once the ZAFC is characterized and is providing the required output it will be implemented into the vehicle to conduct experiments on battery drain and charging.

References

[1] Cooper, John F. "Powering Future Vehicles with the Refuelable Zinc/Air Battery." Science & Technology Review. October 1995. Pp 6-13.

[2] Cooper, John F., Krueger, Roger. "The Refuelable Zinc-Air Battery: Alternative Techniques for Zinc and Electrolyte Regeneration." LLNL Report. Lawrence Livermore National Laboratory. April 15, 1996.

[3] Vasilescu, Denis A., "Zinc-Air Fuel Cells and Vehicle Applications." MS Thesis, Illinois Institute of Technology. November 2010.

Appendix A: Analysis

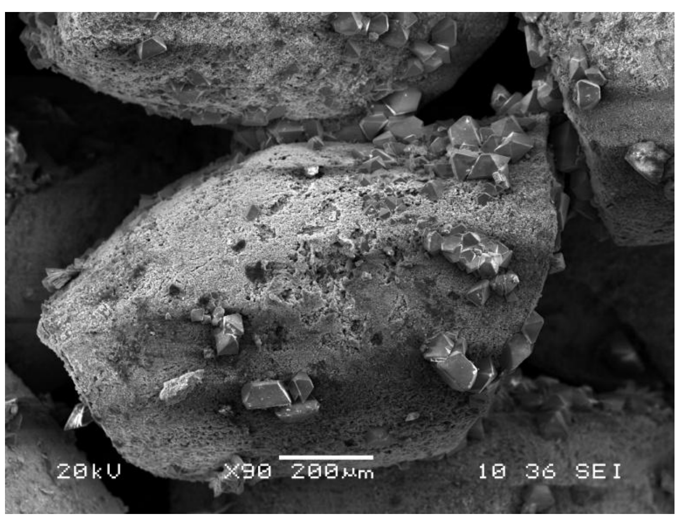


Figure 1: SEM image of an entire Zinc pellet

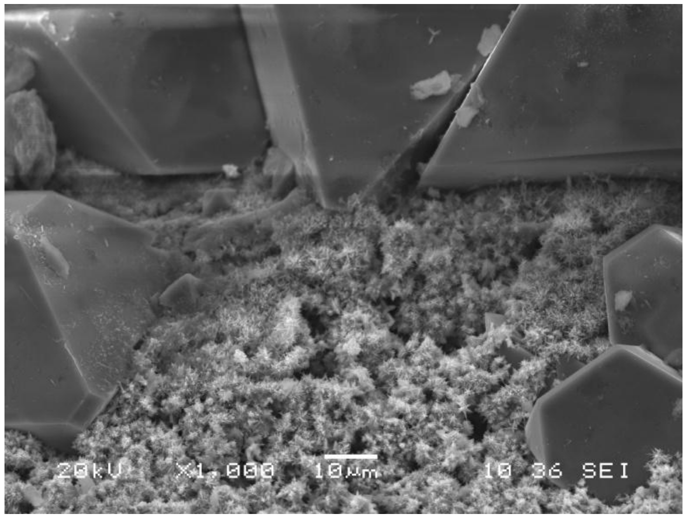


Figure 2: SEM images of magnified Zinc pellet.

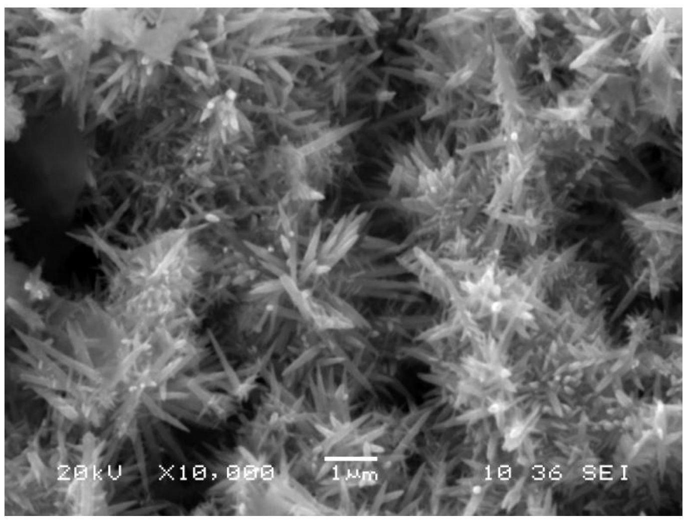


Figure 3: SEM image of dendrite formation on the surface of Zinc.

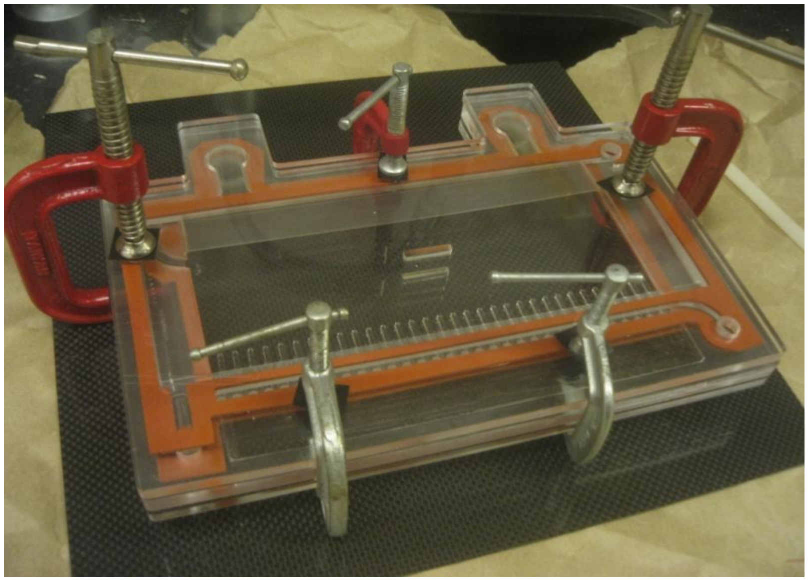


Figure 4: Construction of second Zinc Air fuel cell prototype

Figure 5: Installation of new electric engine and transmission.

Appendix B: Budget

Subsystem	Item	Material Cost Rate		Amount		Labor Cost Rate		Time		Quantity	Total Cost
12-Celled Zinc-Air Fuel Cell	Glass-filled Nylon Channel Plate	$0.56	/g	93	g	$100.00	/hr	1	hr	12	$1,824.96
	1/4" Acrylic Front Plate	$0.21	/in^2	72	in^2	$60.00	/hr	1	hr	12	$901.44
	1/4" Acrylic Back Plate	$0.21	/in^2	72	in^2	$60.00	/hr	1	hr	12	$901.44
	Cobalt Based Catalyzed Carbon Air Cathode	$0.05	/cm^2	151	cm^2					12	$90.78
	Copper Anode Current Collector	$0.54	/in^2	23.5	in^2					12	$152.77
	RTV Silicone Sealant	$1.60	/oz	1	oz					12	$19.20
Fluid Management System	Zinc Peristaltic Pump	$242.35		1						1	$242.35
	Electrolyte Centrifugal Pump	$314.48		1						1	$314.48
	Air Fan	$28.99		1						1	$28.99
	Hydrocyclone	$0.00		1						1	$0.00
	PVC Tubing	$10.95	/ft	12	ft					1	$131.40
Power Electronics	DC Brush Motor	$1,775.00		1						1	$1,775.00
	Motor Controller	$1,850.00		1						1	$1,850.00
	Hall Effect Accelerator Pedal	$140.00		1						1	$140.00
	Dashboard Display Module	$260.00		1						1	$260.00
Secondary Battery System	Lead-Acid Battery	$26.95		1						16	$431.20
	Charge Pump			1						1	$0.00
Fuel Supply	Zinc Pellets	$1.03	/lb	262	lb					1	$270.22
	Potasium Hydroxide	$27.90	/kg	7.12	kg					1	$198.62

	Water	$0.01	/gal	3.81	gal					1	$0.02
Total											$9,532.87

Table 1: Budget for supplies need for one vehicle

Appendix C: Team Members

Vladeilena Gaisina

Jose Miranda

Hector Garza Rodriguez

Kunlun Guo

Arjun Jalan

Taehoon Kim

Jose Miranda

Edgar Palacios

Samantha Leach

Ruth Shim

Omar Syed

Ran Xu

Charlie Ziman

Mirriyam Qureshi