# ZINC-AIR GRID ENERGY STORAGE

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**PROJECT TITLES:** Metal-Air Ionic Liquid Batteries;
Advanced Grid-Interoperable Power Electronics Enabling Scalability And Ultra-Low Cost
**PROGRAMS:** OPEN 2009; GRIDS
**AWARDS:** $5,133,150; $2,993,128
**PROJECT TEAMS:** *Arizona State University (Lead); Fluidic Energy (Lead)*
**PROJECT TERMS:** December 2009 – June 2012; October 2010 – March 2013

## TECHNICAL CHALLENGE

Advanced energy storage promises to play a key role in the modernization of our nation's electricity grid. While relatively little storage is deployed on today's grid, future grid development will likely require energy storage that not only enables the integration of increasing amounts of renewables, but also improves the grid's operating capabilities, enhances reliability, allows deferral of infrastructure investments and provides backup power during emergencies. Electrochemical energy storage (e.g. batteries) provides a significant opportunity to address these needs. Metal-air batteries are particularly attractive because a key component of the battery chemistry, oxygen, is available from the air and does not need to be carried in the battery cell, or recharged. However, metal-air batteries are prone to degradation, and historically have not had the ability to discharge and recharge over the large numbers of cycles required to deliver low-cost and extended lifetime energy storage.

## TECHNICAL OPPORTUNITY

One major issue for metal-air batteries is that the circulating air carries away evaporating liquids from the electrolyte, degrading battery performance over time. Another issue for the desirable, low-cost Zinc-air (Zn-air) battery is that zinc dendrites form on the anode as the battery is recharged, causing shorting. As a result, commercial Zn-air batteries have historically been limited to disposable (non-rechargeable), low power applications, such as hearing-aid batteries. Advances in materials science offer new opportunities for the design of electrodes and electrolytes that, applied to the Zn-air battery, address the issues that prevent recharging and long lifetime operation.

## INNOVATION DEMONSTRATION

With ARPA-E's support, Arizona State University, in partnership with Fluidic Energy, explored innovative approaches to transition nonrechargeable Zn-air battery chemistry into a rechargeable device. They focused on developing a battery design using an electrolyte based on ionic liquids. Ionic liquids are salts that are liquid at the battery operating temperature, delivering ionic conductance while maintaining substantial electrical insulation. The team developed chemistries that have negligible evaporation, are stable in the presence of oxygen, and do not absorb water over the cell operating voltages, and include additives that interact favorably with the Zn and air electrodes. In parallel, they experimented with carbon-nano-particle based air electrodes and nanostructured Zn electrodes, the latter including three-dimensional porous structures that address the problems of formation of Zn dendrites.

Figure 1: Fluidic unit installed in Honduras

As the team demonstrated the ability to cycle using their Zn-air battery designs, Fluidic Energy identified pathways to commercialization. A key issue in optimizing the battery performance was developing stringent control of operating parameters, such as rates of charge/discharge and depth of discharge, at the level of individual cells and modules. With ARPA-E's support, Fluidic Energy developed a prototype commercializable battery module, including the preliminary development of an advanced control system and integration of continuing improvements in the system of electrodes and electrolyte. Their system targeted kW-level power applications with delivery over 4 to 72 hours, requiring cost and performance competitiveness with traditional backup power based on diesel generators and/or lead-acid batteries.

## PATHWAY TO ECONOMIC IMPACT

In January 2016, Fluidic was recognized as one of the top 100 private firms positioned to solve tomorrow's global clean technology challenges with a 2015 Global Cleantech 100 award.

Additionally, since the conclusion of ARPA-E funding to the Fluidic team (in 2013), Fluidic has continued development of its commercial product, and reported the following progress, noting that the company's Zn-air battery and basis for its control system routines resulted directly from the ARPA-E-funded research projects:

As of September 2015, Fluidic had raised approximately $150 million in private sector capital, including a recent equity investment from Caterpillar, Inc., for commercialization of the ARPA-E-funded technologies. Fluidic has established its first markets in cell phone tower backup systems for developing regions, where reliable power delivery is essential. Fluidic's integrated smart controls, which provide remote monitoring, control and diagnostics of the complete energy storage system, have been important to successful commercialization in markets outside of the United States. The company is now working to transition their technology to broader rural electrification and microgrid applications. As of January 2016, Fluidic has installed more than 50,000 Zn-air battery cells, primarily in South East Asia and Latin America, reducing customer's operating costs while increasing reliability. As of January 2016, Fluidic also reports that the company is entering the rural electrification market, having been selected for 500-islanded renewable microgrids by the Indonesian government.

Fluidic's business model involves fabrication of the high-value components - the anode, cathode and electrolyte - in the United States. The components are then shipped for pick-and-place assembly near the point of sale.

## LONG-TERM IMPACTS

Fluidic's approach of leveraging its developed technology and cost position to deploy in long-duration energy storage markets, often in harsh environmental conditions with demanding operational requirements, has provided access to first markets. The results are beginning to provide the demonstration of effective operations that are needed to open up the long-duration storage market, which Fluidic estimates near-term to be valued at more than $25 billion. Such demonstrations are important for supporting entry into the conservative and more cost sensitive power grid systems in developed countries such as the United States.

In Fluidic's first applications, long-duration energy storage systems demonstrate the use of grid-scale storage for replacement of diesel generators, along with the associated $CO_2$ emissions. The results are indicative of the types of improvements in reliability of grid services and reduction of greenhouse gas emissions that are possible as battery energy storage continues to improve in cost and performance.

As an ancillary benefit, many tons of ionic liquids - chemistries developed under the ARPA-E programs - have been manufactured and deployed by Fluidic Energy; this may be the largest commercial deployment of ionic liquids in the world, and may provide a basis for other commercial developments based on these materials.

## INTELLECTUAL PROPERTY

As of February 2016, the Arizona State University and Fluidic Energy team's ARPA-E funded projects have generated 11 invention disclosures to ARPA-E, one pending U.S. Patent and Trademark Office patent application and eight patents issued by the PTO:

Arizona State University "*Metal-Air Low Temperature Ionic Liquid Cell*". (11/25/2014) US Patent No. 8895197. Washington, DC: U.S. Patent and Trademark Office.

Arizona State University "*Metal-Air Cell with Performance Enhancing Additive*". (11/10/2015) US Patent No. 9184478. Washington, DC: U.S. Patent and Trademark Office.

Arizona State University "*Aluminum-Based Metal-Air Batteries*". (1/12/2016) US Patent No. 9236643. Washington, DC: U.S. Patent and Trademark Office.

Fluidic, Inc. "*Ionic Liquid Containing Sulfonate Ions*". (6/3/2014) US Patent No. 8741491. Washington, DC: U.S. Patent and Trademark Office.

Fluidic, Inc. "*Metal-Air Cell Comprising an Electrolyte with a Room Temperature Ionic Liquid and Hygroscopic Additive*". (8/19/2014) US Patent No. 8808929. Washington, DC: U.S. Patent and Trademark Office.

Fluidic, Inc. "*Degenerate Doping of Metallic Anodes*". (5/12/2015) US Patent No. 9029027. Washington, DC: U.S. Patent and Trademark Office.

Fluidic, Inc. "*Metal-Air Cell with Ion Exchange Material*". (8/25/2015) US Patent No. 9118089. Washington, DC: U.S. Patent and Trademark Office.

Fluidic, Inc. "*Methods of Producing Sulfate Salts of Cations from Heteroatomic Compounds and Dialkyl Sulfates and Uses Thereof*". (9/29/2015) US Patent No. 9147919. Washington, DC: U.S. Patent and Trademark Office.