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LLNL-TR-745682

SULI Final Report

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February 2, 2018

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

Abstract

This project looks at alternative water sources, specifically in the field of desalination and selective ion removal through capacitive deionization (CDI). It project aims to both scale up the desalination capabilities of CDI cells as well as determine the selectivity of CDI for particular ions. My task is to design and build cells that have reproducible performance and characterize the materials for building these cells. The scientific methods I've learned through my work in CDI and the data mining and analysis tools I've become familiar with through CAES will be important catalysts in my future success in a graduate program. The purpose of this presentation is to give a standard of practice for my current method of building of capacitive deionization cells. Parts 1 and 2 will be discussed in which the electrodes are prepared, and the cell is built.

CDI Cell SOP

Erica Clevenger

12/21/17

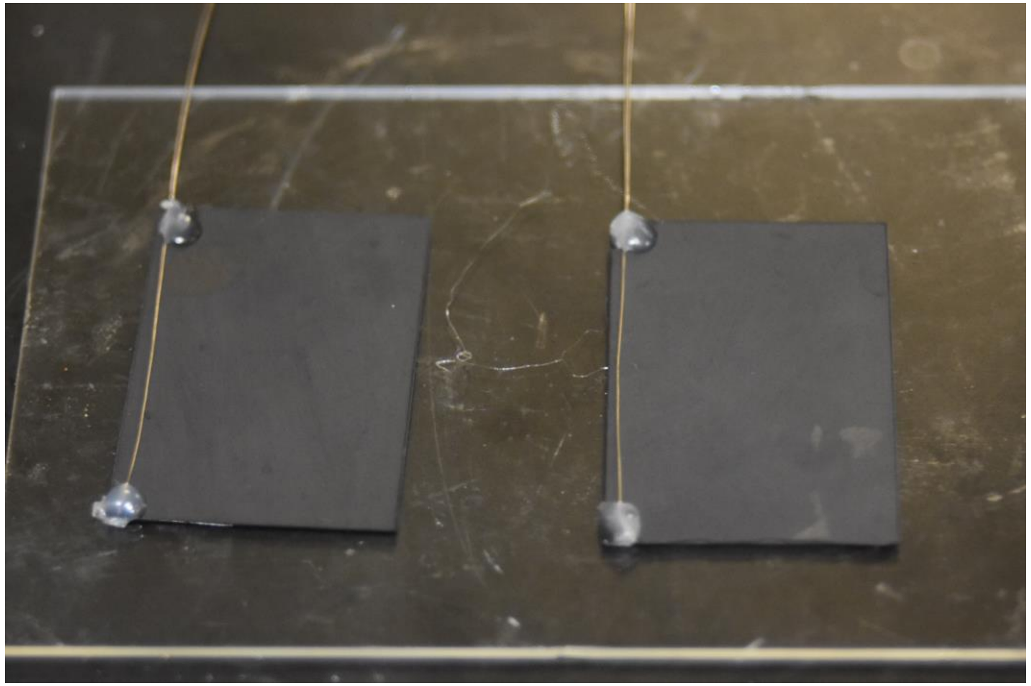
Part 1: Preparing the Electrode

Things you will need

- At least 2 electrodes (2x3 or 4x6)
- Nickel wire
- Hot glue gun (turn on)
- Nickel paint or paste
- Sylgard
- Glass slide
- Hot plate (on->set->120°C->set)

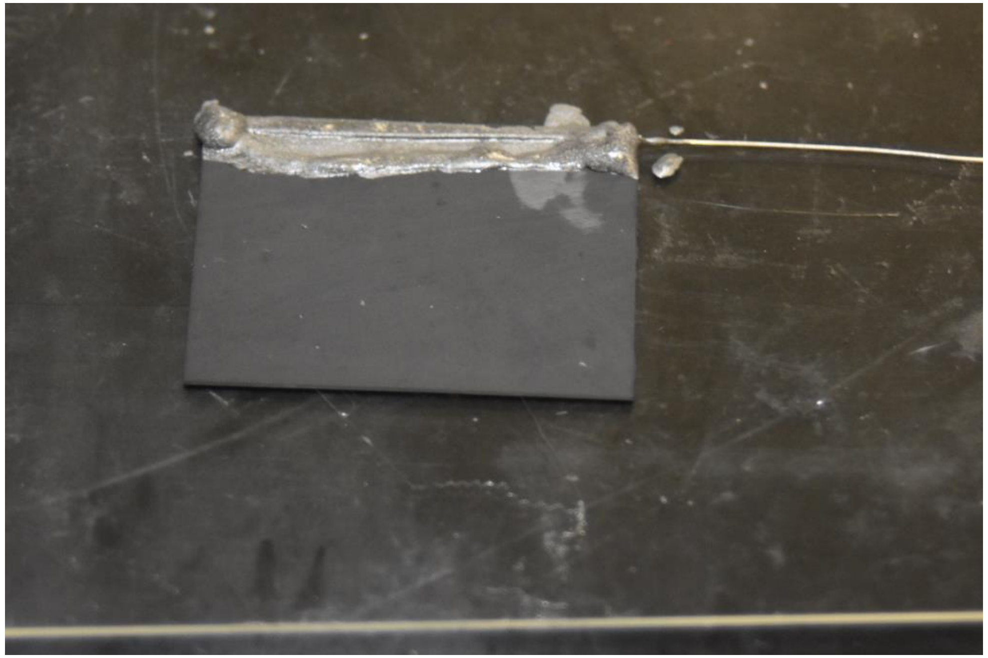
Step 1: Adhere wire to electrode

- Use a dollop of hot glue to adhere wire to electrode one side at a time
- Cut away excess glue if necessary



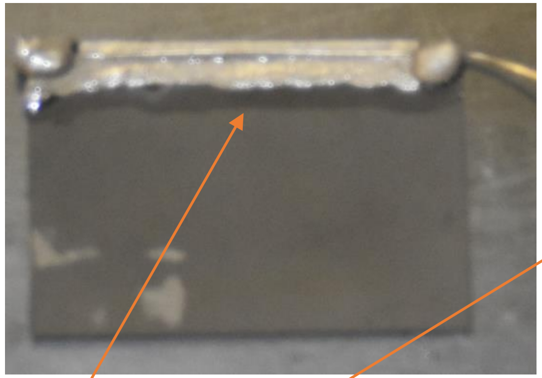
Step 2: Nickel Paint

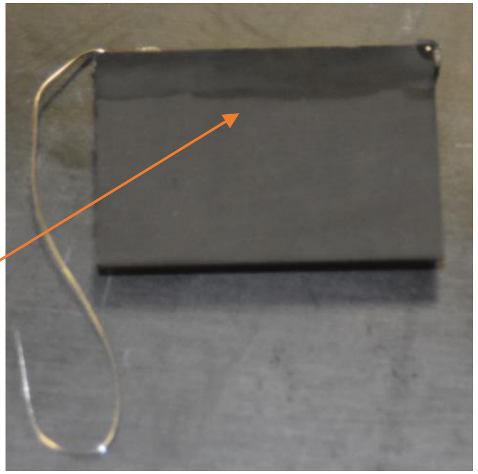
- Paint the Nickle paint on the side of electrode with the wire
- Place electrode on hot plate for around 30s to dry

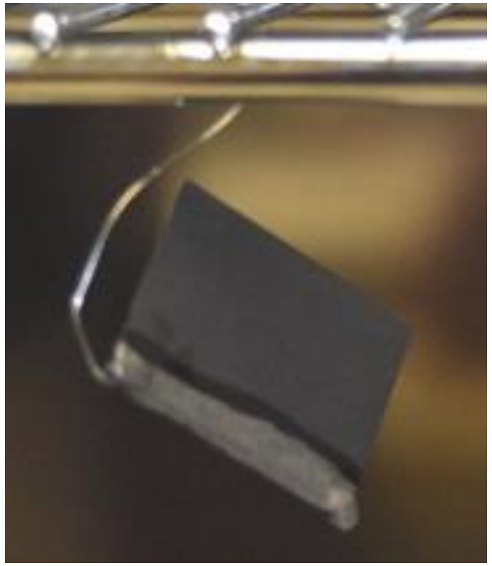


Step 3: Sylgard

- Weigh 10 parts A & 1 part B of Sylgard
- Mix together
- Paint Sylgard on both sides of electrode so that it goes just past the nickel paint
- Hang to dry in oven (Sylgard side down) overnight before using
- Store in water







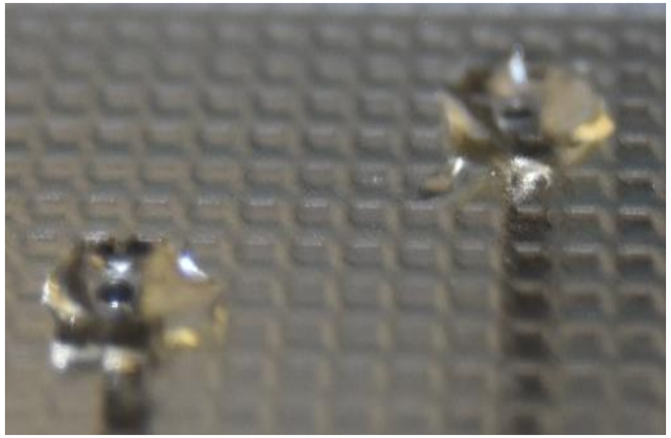
Part 2: Building the Cell

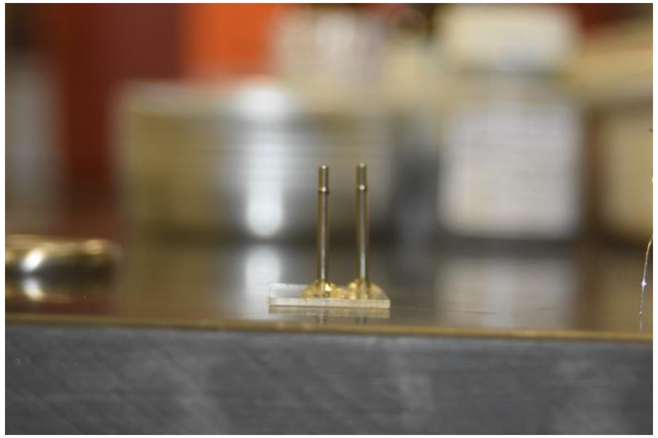
Things you will need

- UV Cure epoxy
- Thermal Cure epoxy (Stylcast 1266 Pt. A & Pt. B)
- Hot glue gun
- Tubulations x4
- Header plate x2
- Seperator (plastic mesh)
- Mold (metal)
- Prepared electrodes x2

Step 1: Prepare header plates

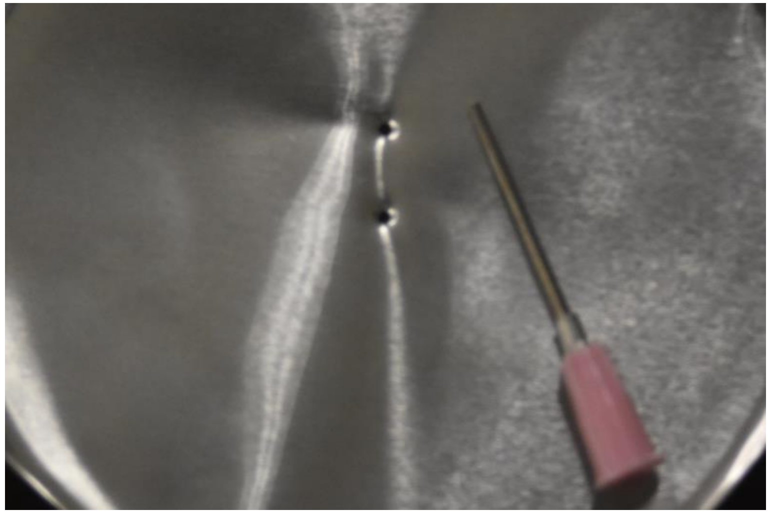
- Turn on UV light and hot glue gun
- Poke tubulations into header plate so that they are nearly flush with the bottom side of header plate (rough side)
- Apply UV epoxy around tubulation ports and stick under UV light for ~ 30s to cure





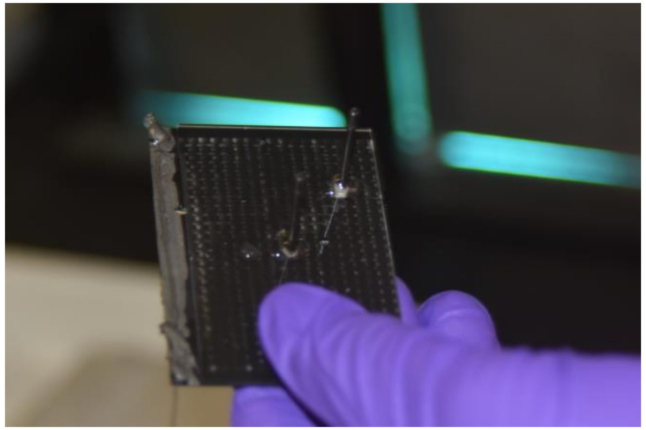
Step 2: Prepare Mold

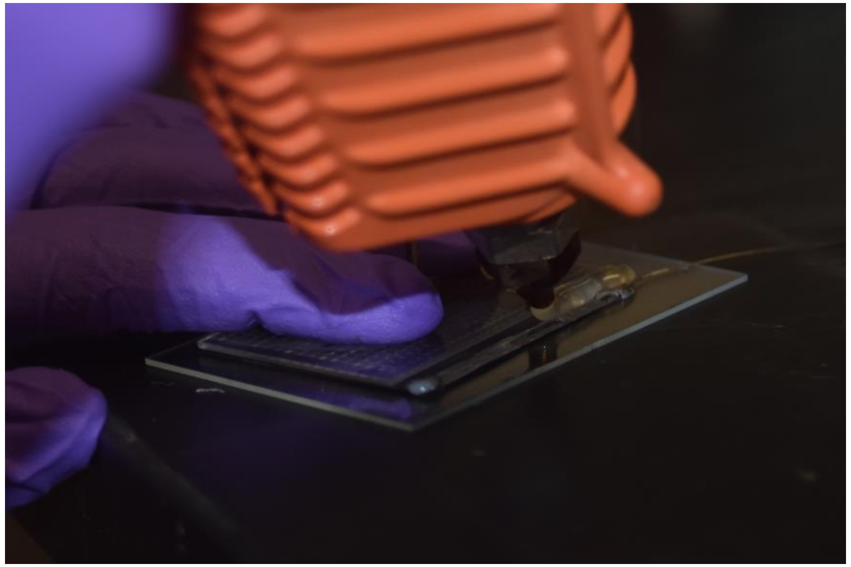
- Press header plate with tubulations into mold to make an indent
- Use syringe adaptor or other tool to poke holes where the tubulation ports are marked
- The purpose of this step is to create holes so that the tubulations can be inserted into them later and the cell mold can be filled with expoxy

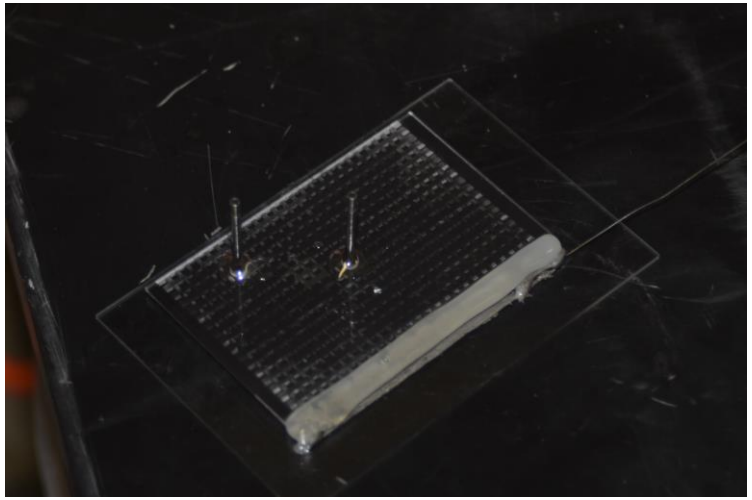


Step 3: Seal side of cell with hot glue

- Hot glue protruding side of electrode (side with wire/glue) to header plate (ridge side)



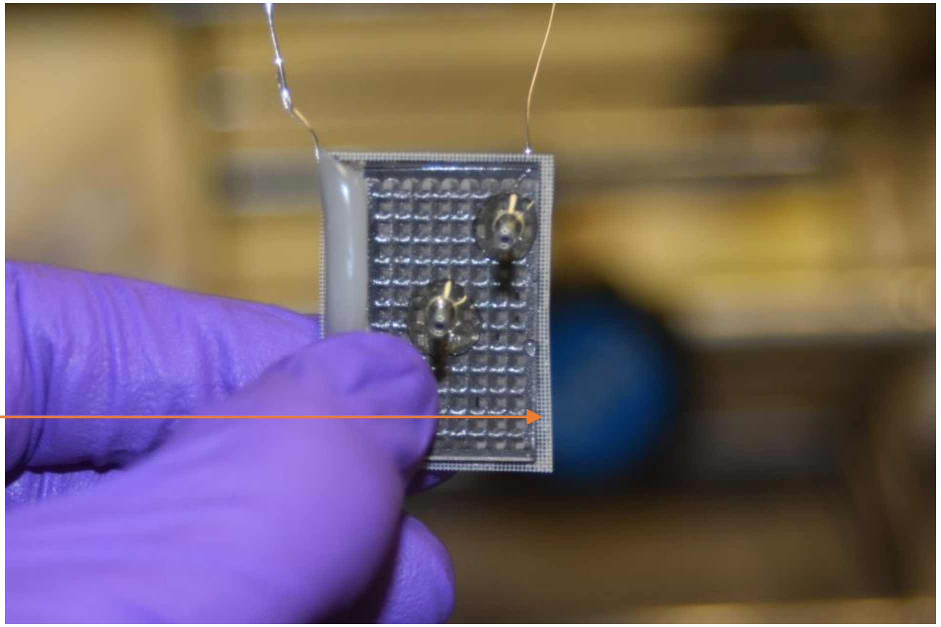


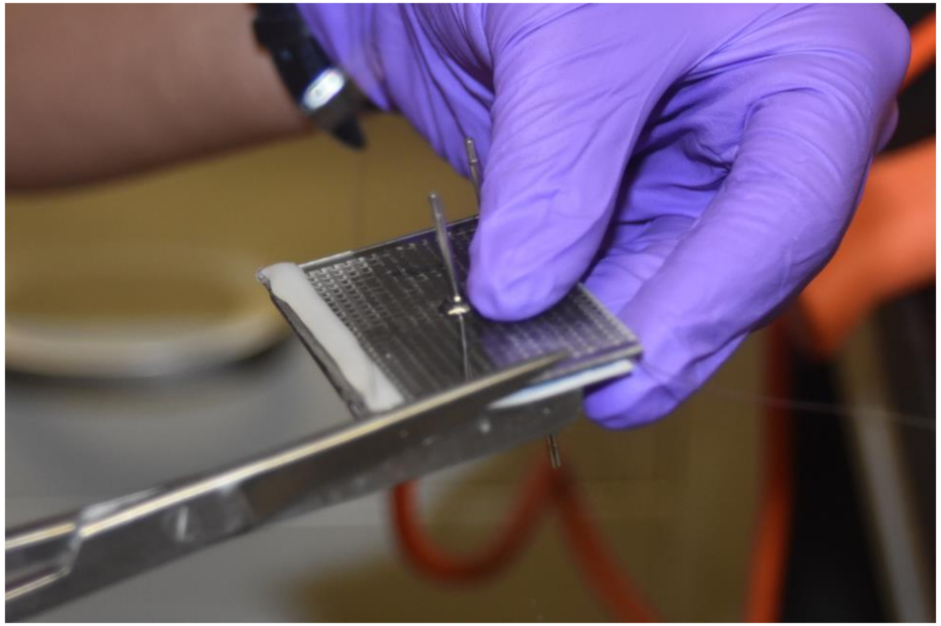


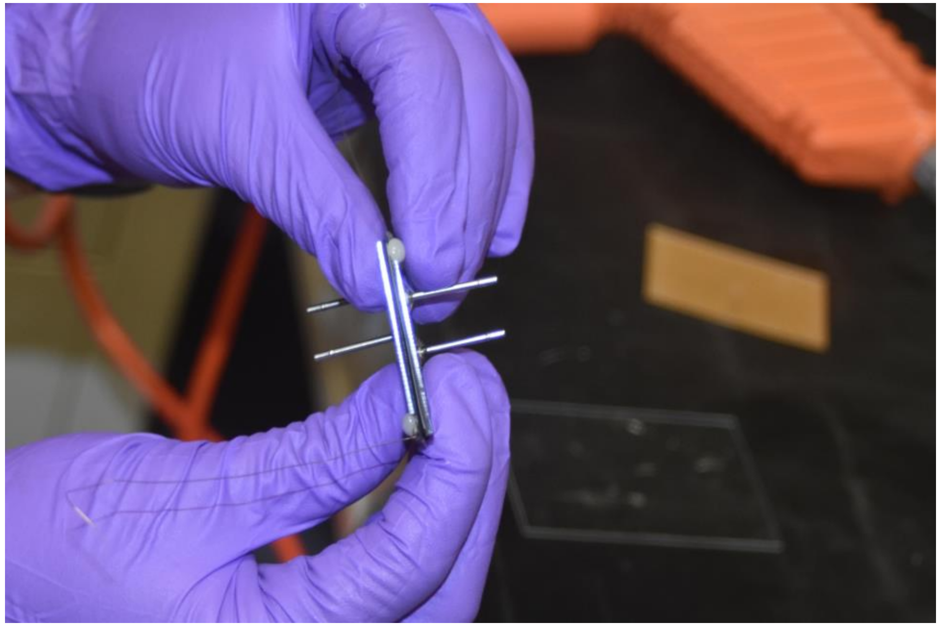
- Do this for each side (two times) separately

Step 4: Separator

- Cut separator to approximate size of cell -> a hair larger is best
- Trim if necessary
- Place in between electrodes (wet)

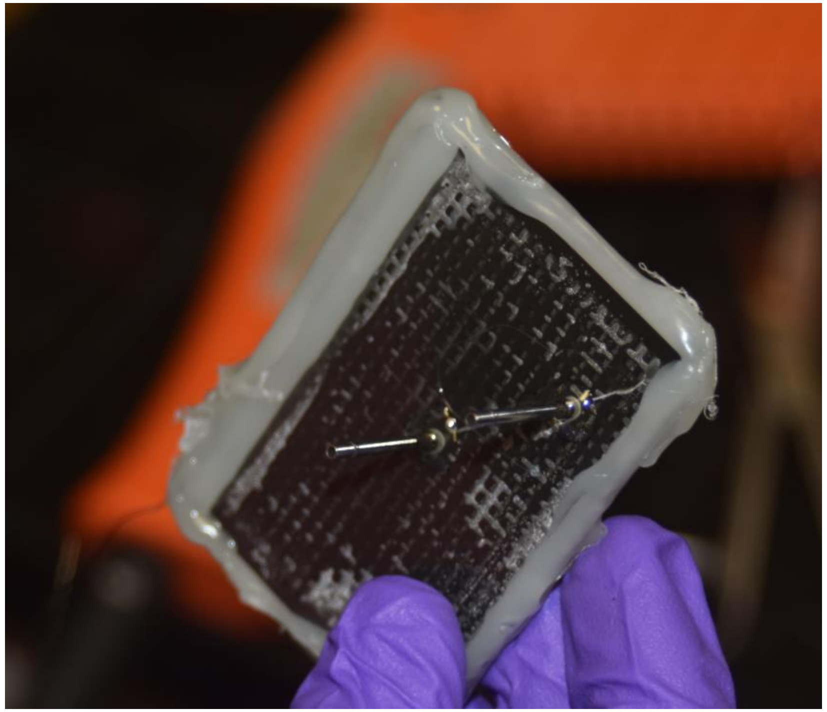






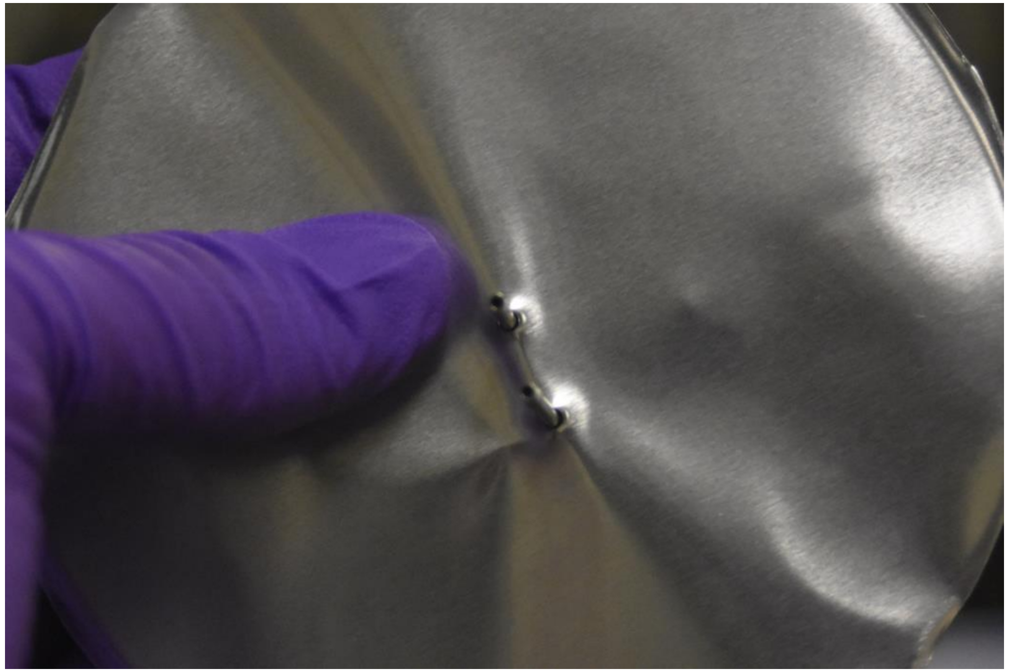
Step 5: Finish sealing off cell

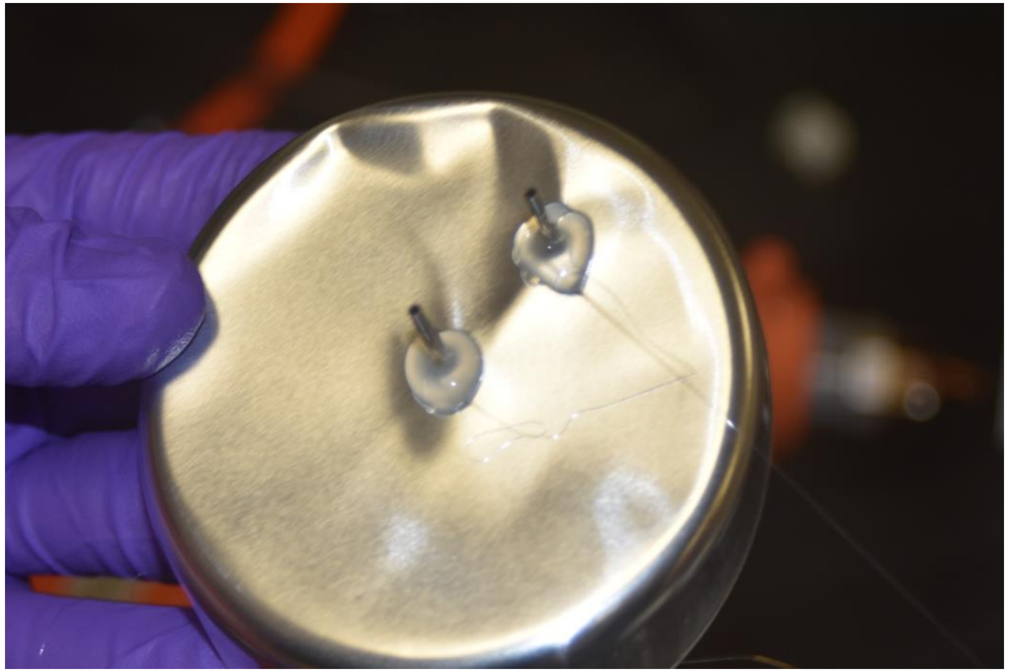
- Use hot glue to carefully seal off all sides of the cell, hold each side tightly as you glue to prevent spaces
- Look for and seal off any holes



Step 6: Place cell in mold

- Carefully put tubulations through the holes in the mold so that the cell is just raised from the bottom
- Seal off holes around tubulations with hot glue





Step 7: Pour thermal cure epoxy

- Pour thermal cure epoxy into the mold starting on the side and letting the epoxy run under the cell to prevent any air pockets beneath the cell
- Pour more epoxy until the cell is completely covered and the level of epoxy is higher than any hot glue
- Leave out overnight to cure
  - DO NOT put in oven, this will cause the hot glue to melt and bubbles to form
- Turn off all equipment (UV light/hot glue gun)

Erica Clevenger

Peer Review

December 20, 2017

Nuclear Air-Brayton Combined Cycle Power Conversion Design, Physical Performance Estimation and Economic Assessment, Charalampos Andreades

Andreades set out with a clear objective of assessing the viability of a Nuclear Air-Brayton Combined Cycle Power Conversion (NACC) Design as technique for renewable energy generation. He began with an overview of the technology and introduction to the main heat sources used in the study, and Mk1 FHR. While he discussed the technology in depth, a few more visual aids would have been useful. The only visual aid provided lacked some finer details. For example, no visual aid was provided for a steam cycle (instead we are shown just a box with the words steam cycle inside.) There is also a box labeled generator with no apparent explanation as to what that means.

The supporting evidence includes NACC design and performance under ambient conditions, NACC off-nominal and transient performance, NACC ramp rate calculation, Mk1 FHR cost estimation, and supplementary configurations. Andreades organized the information well and each subject lead well into the following information. Again, there was somewhat a lack of figures, however, the tables and graphical data were useful for comparison of different methods in the analysis.

Andreades ended with a conclusion describing the market and potential impact of this technology. He also gave some final cost estimates and profitability measures to demonstrate the economic viability of the operation. Overall the presentation was through and well researched. My only question would have been whether this would still be a viable option if the air is heated to under the auto ignition temperature of natural gas (less than 600°C)? Andreades was not available to comment.

Erica Clevenger

Michael Stadermann, Tom Buscheck

Lawrence Livermore National Laboratory

Research Project Report, December 20th, 2017

Capacitive Deionization and Air Earth Battery

During my internship at Lawrence Livermore National Laboratory I worked on two distinct projects in the Physical and Life Sciences Directorate. The first, is a detailed study looking into the feasibility of an advanced adiabatic compressed air energy storage system (CAES), a method for renewable energy storage, called the Air Earth Battery. As a member, I gather relevant scientific literature related to existing and future CAES and underground natural gas storage facilities. I also created multiple plant simulations using Aspen plus software and created economic analyses of potential systems. Furthermore, I have collaborated with two other members of this project in order to create a feasibility study for one of these simulations thereby setting the ground work for expansion and future studies. The second project looks at alternative water sources, specifically in the field of desalination and selective ion removal through capacitive deionization (CDI). This project aims to both scale up the desalination capabilities of CDI cells as well as determine the selectivity of CDI for particular ions. My task is to design and build cells that have reproducible performance and characterize the materials for building these cells. I apply techniques such as cyclic voltammetry and electrochemical impedance spectroscopy to characterize cells in addition to simpler techniques which use tools such as a scanning electron microscope, pH meters, ion selective electrodes and conductivity sensors. Through each of these projects, I was able to explore and come up with innovative ideas and solutions to complex problems.

My research into the feasibility of the Air earth battery began with a review of relevant literature regarding compressed air energy storage. This is a type of storage system that could work in conjunction with intermittent renewable energy. For example, when solar energy is being collected it isn't always needed to be transferred immediately to the grid. Conversely there are times when the grid needs more energy where solar is not producing enough. i.e. it is cloudy outside. The basic premise of a CAES system is that it would store energy during times of excess energy for use when there is more demand. How it works is the system uses excess energy to compress air to high pressures and store it. Once the energy is needed it can be expanded in a turbine to produce power. The approach that is take with the Air Earth Battery is to not only compress and store the air, but also store the heat of compression to make a nearly adiabatic system. There are currently two working compressed air energy storage systems in the world. On is in Huntorf, Germany and the other is in McClintock, Alabama. Literature on these two sites provided the bulk of data that I unearthed. The main difference between these systems and the Air earth battery, however, is that when these systems are put to work, they compress and cool the air. This turns the heat from the compressed air into wasted energy. The Air Earth battery seeks to use this heat rather than waste it and therefore improve the efficiency of the process.

For my project, I built multiple simulation systems using Aspen Plus® software. These simulations included several different configurations for the Air Earth Battery including changes to the number of stages of reheat, turbines, different working gases and added natural gas boosting capabilities. One configuration is pictured below. In this configuration ambient air enters the low-

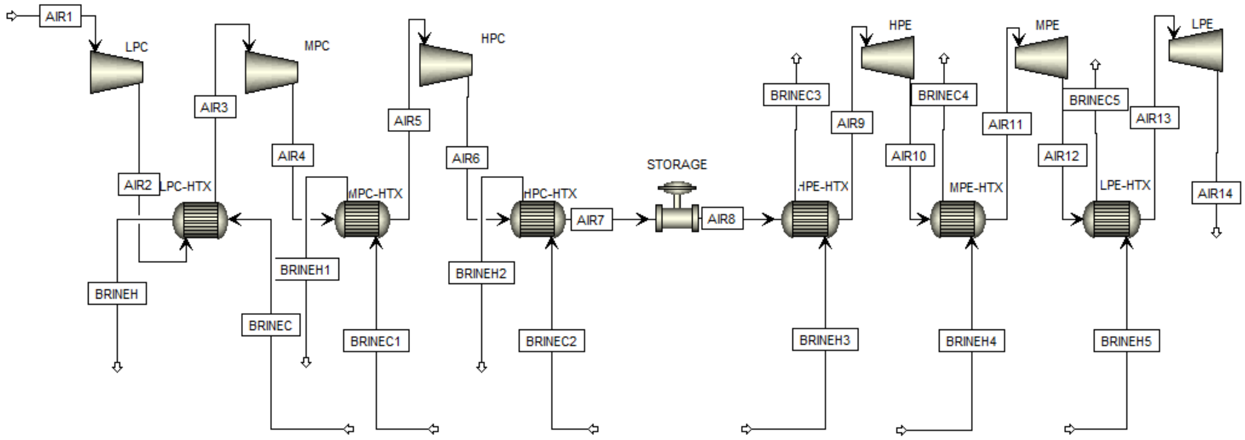
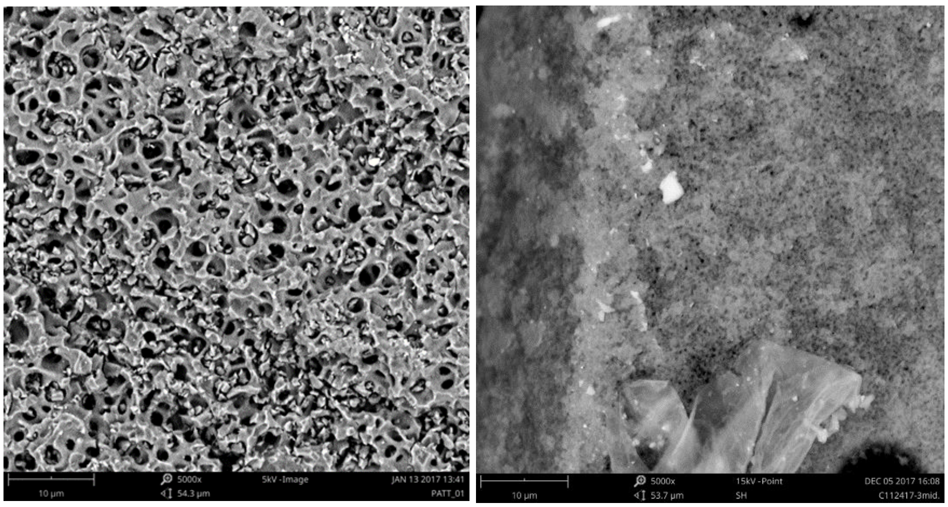


Figure 1: Aspen base simulation

pressure compressor and is compressed to approximately 5 bar. At this time the air is nearly 240°C and will head to the heat exchanger to heat brine and be sent to the next compressor. This continues until the air is at 180 bar. It will then be sent into storage until it is needed. The hot brine will be stored either underground or in some kind of insulated container. Once the energy is needed, the brine will be used to heat the air again before it is sent to a turbine and so forth. Using this method, we can create a nearly adiabatic renewable energy storage system. Excess energy from the grid can be bought at low prices, stored and sold at higher prices in order to make this system economically viable. It can also be paired with a solar plant or a nuclear plant. Other simulations included the addition of a natural gas turbine to boost plant peaking power. This is the power needed at peak demand times. Additionally, I modeled a simple steam bottoming cycle that could be used to extract any remaining heat (energy) from the exhaust of this system.

The second project I took on during my time at Lawrence Livermore National Laboratory involved water treatment in the form of desalination. I performed research on a method known as capacitive deionization (CDI) in which electrical potential is applied over two electrodes that extract ions from the water. We use a flow through model in which the activated carbon has sufficient porosity to allow for water to pass directly through it rather than around it like most conventional CDI cells. Initially I worked on calibrating and writing standards of practice for some analytical tools in the lab that didn't have clear directions and but were essential to the project. These tools included conductivity sensors, pH meters, and an ion-meter. Each of these is useful for characterization of treated and untreated water used for deionization. I also spent time characterizing electrodes and separators for the cells. This included use of tools such as cyclic voltammetry, electrochemical impedance spectroscopy, a scanning electron microscope and some simple measurements. The characterization of carbon material using the scanning electron microscope was particularly useful for determining what effect different activation techniques had on the porosity and structure of the material. I looked at the carbon before and after it was activated. When carbon is activated it is placed in a furnace in a stack. One of my tasks was to look at carbon slices from different levels in the stack in order to determine if it's placement had any effect on its structure. I found that the samples I analyzed that were cured at room temperature did not have the same pore structure as cells that were cured at higher temperatures. (see photos) However, some earlier room temperature cures fared much better in their pore structures. I was unable to investigate as to why this was however our strategy going forward will be to build a database of SEM images of carbon cured using different methods. This will help determine what curing techniques are affecting pore morphology. It is ideal to have good pore morphology in order to promote a flow through model with enough surface area to extract ions from the water. The two images below are at the same magnification but are drastically different. Each of these samples was cured at room temperature but in different batches. It will be important to next determine why the structure is so different. There were also significant differences between the position of the carbon material in the stack when it was cured.



Figures 2 & 3: Scanning electron microscope images of activated carbon

I spent the majority of my time building and testing cells in order to come up with a more efficient and robust model. In these cells, water passes through a header plate, the activated carbon sheet, a separator, another carbon sheet and through the last header plate. Leaks plagued the initial model because an epoxy could not be found that would effectively prevent water from coming out. Some epoxies could do this but they themselves would wick into the cell and dam the electrode. This model was highly time consuming to make and was plagued with leaking issues. My solution was to use hot glue to dam the cell from epoxy and then submerge the cell in epoxy that would prevent the water from leaking. This method proved to be robust although not significantly less time consuming. Once a proper mold can be found that cells can be placed in, this method will become much more efficient.

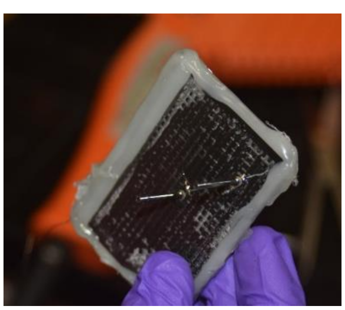


Figure 4: CDI Cell

During my time at Lawrence Livermore Laboratory my research allowed me to work on a number of projects and diverse tasks. My time spent on the Air Earth battery allowed for the determination of economic viability of the project as well as useful simulations which generated mass and energy balances for different configurations. I used many tools and scientific methods to characterize materials and cells during my project on CDI. It was found that the type of cure and location of carbon in the furnace played a role in the pore structure of the final activated carbon product. Furthermore, I found a more robust way to create CDI cells and prevent leakage. The scientific methods I've learned through my work in CDI and the data mining and analysis tools I've become familiar with through CAES will be important catalysts in my future success in a graduate program.