Flow Battery Structures to Improve Performance and Reduce Manufacturing Cost

FARADAY TECHNOLOGY, INC.

CASE WESTERN RESERVE UNIVERSITY EST. 1826 think beyond the possible

U.S. DEPARTMENT OF ENERGY

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Goal

• Faraday, in collaboration with Case Western Reserve University aims to optimize the following:
– Increased reactant mass transfer while maintaining acceptable pressure drop,
– Reduced electrode cost (currently ~39% of total cell stack cost) by using thin metal substrates with engineered surfaces,
– Simplified cell manufacturing costs (currently ~10% of total cell stack cost) by reducing the parts count and integrating the electrode and bipolar plate components, and
– Enhancement in stack reproducibility by eliminating non-uniform felt type electrodes and maintaining a fixed membrane-plate separation.

Flow Battery – Introduction and Scope

• A flow battery, is a rechargeable battery that uses electrolytes moving ("flowing") through an electrochemical cell to convert chemical energy from the electrolyte into electricity (and vice versa when charging).
• The electrolytes are generally composed of ionized metal salts and stored in large external tanks. Like traditional batteries, cells are "stacked" together in a flow battery system to achieve the desired power output.

Flow Battery - Diagram

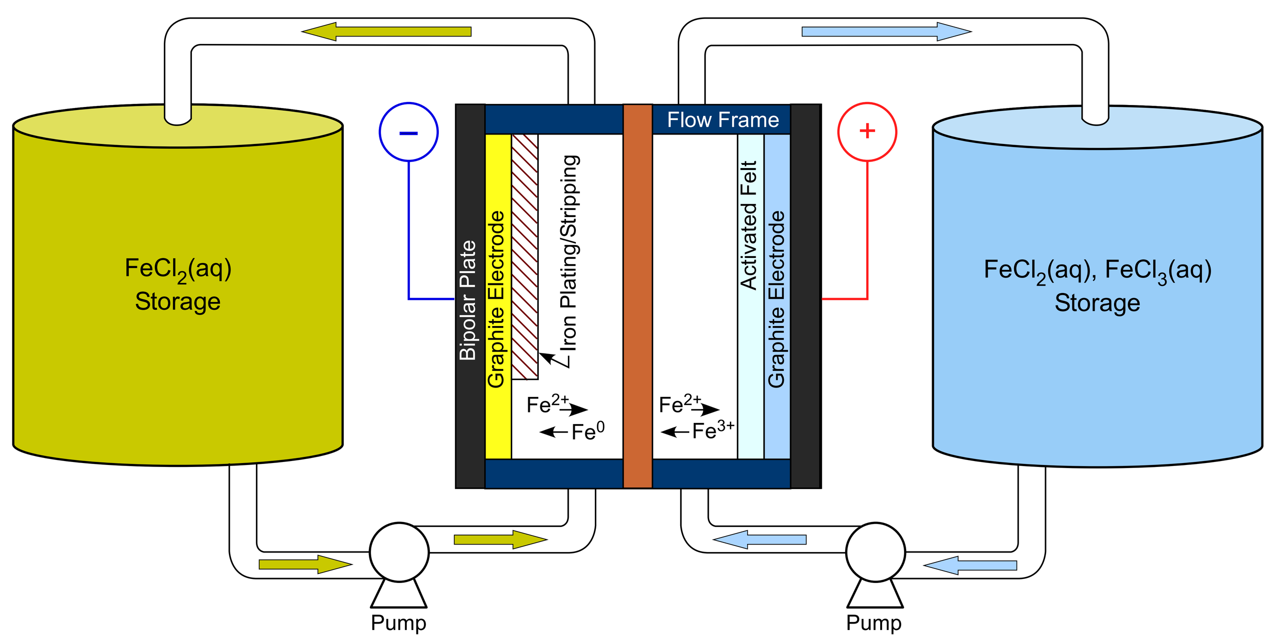
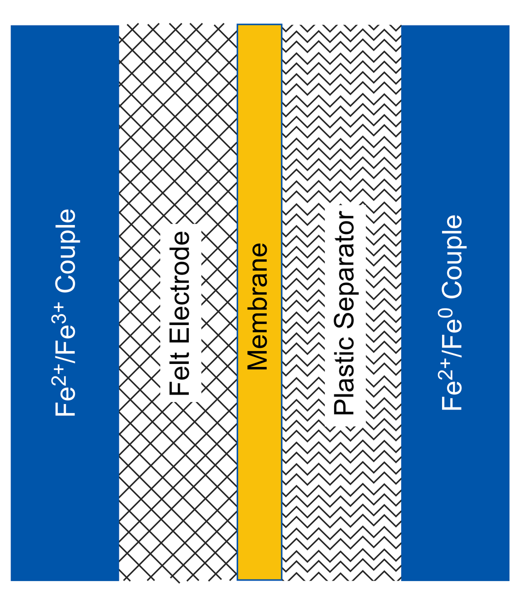


Diagram of an iron hybrid flow battery including system components and electrochemical reactions.

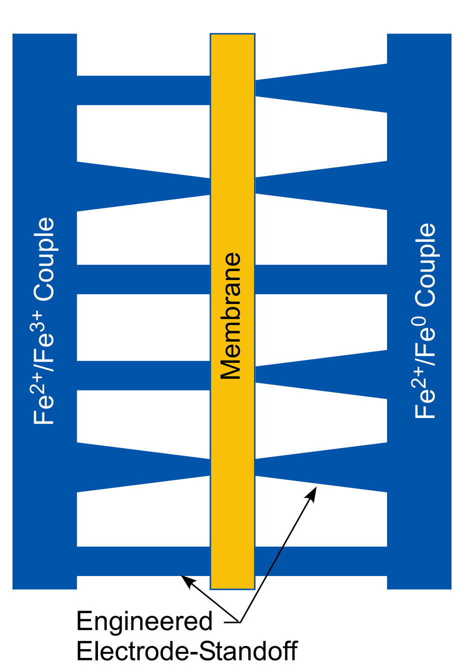
Current Technology and Its Limitations

• Traditional redox flow batteries are limited in their use due to non-uniform pressure drops and mass transfer limitations, as well as high manufacturing costs related to the felt material costs for the electrode and component alignment challenges during manufacturing.
• Traditional redox flow batteries use a bipolar plate that is separated from the membrane using a felt electrode (on the Fe^{2+}/Fe^{3+} redox side) and a plastic separator (on the Fe^{2+}/Fe^0 side).
• Disadvantages:
– Lower battery performance due to:
-- Undesirable pressure drops, and
-- Decreasing reactant mass transfer
– Increased manufacturing costs due to:
-- Difficulty in alignment during manufacturing, and
-- Additional material (felt) cost.

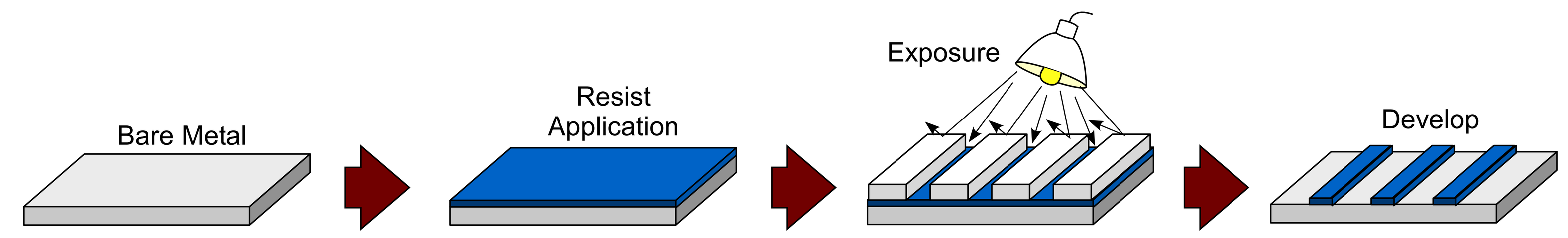


Faraday's Approach

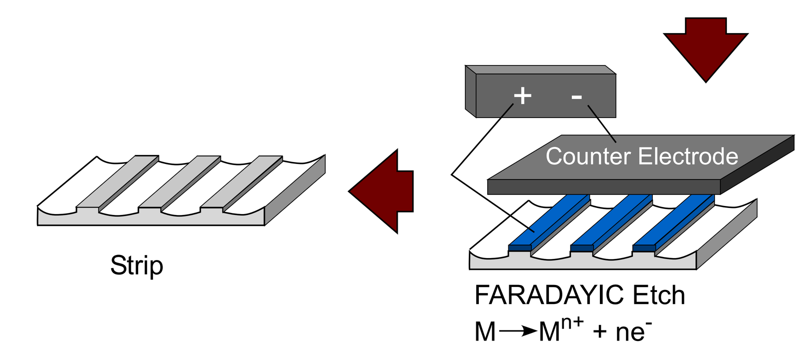
• Replace conventional bipolar plate components with thin metal substrates that have engineered electrode/bipolar plate structures and eliminate the separate non-uniform carbon felt electrodes
• The engineered structures utilize arrays of posts, pyramids and/or pillars on the bipolar plate surface to create uniform standoff between the plate and the membrane, on both sides of the membrane.
• Advantages
– Improved battery performance by:
-- Increasing mass transfer while maintaining acceptable pressure drops for both the Fe^{+2}/Fe^{+3} and Fe^{+2}/Fe^0 flow battery couples
-- Delivering a ~5x increase in current density compared to state of the art cells
• Decreased manufacturing costs by:
– Enhancing stack reproducibility by eliminating the need to align non-uniform felt type electrodes and maintaining a fixed membrane-plate separation
– Eliminating the need for the cost of the felt electrodes

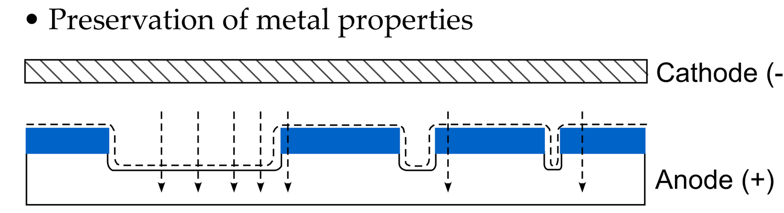


Approach: Through-Mask ElectroEtching



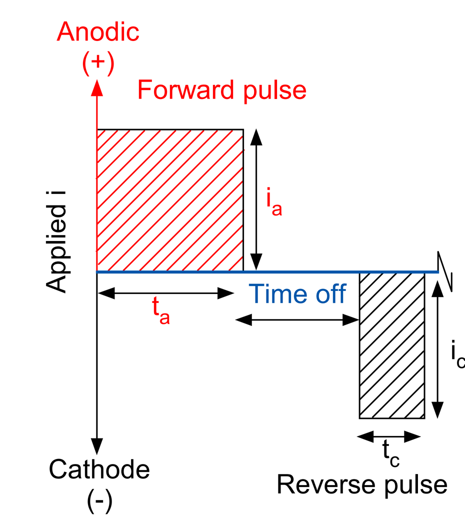
ADVANTAGES
• Anisotropic etch - Minimal undercut – with appropriate selection of pulse/pulse reverse parameters!
• Neutral salt solutions
• No recast or burrs
• No tool wear
• Preservation of metal properties

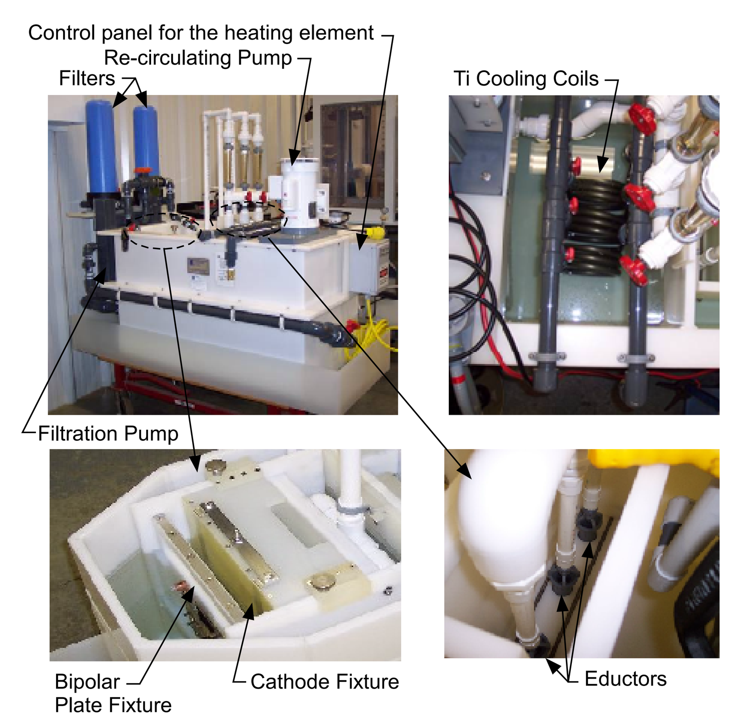




FARADAYIC^{SM} ElectroEtching Process

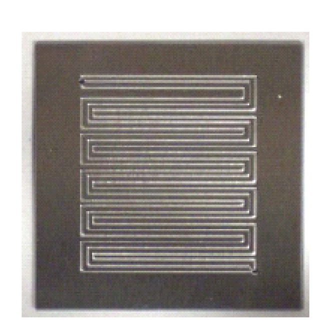
FARADAYIC^{SM} Waveform
• Electrochemical processing removes metal in a selective manner from the surface of the work piece by converting the metal into ions by means of an applied electric field.
• There are unlimited combinations of peak current densities, duty cycles, and frequencies to obtain a given etching rate. These additional parameters provide the potential for much greater process-product control vs. DC etching.



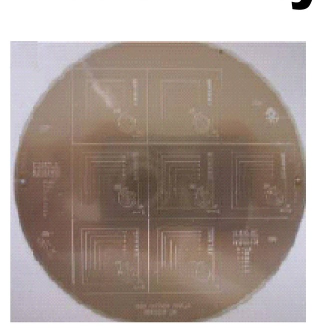


FARADAYIC® ElectroCell Geometry
• Based upon Faraday's electrochemical cell design that facilitates uniform flow across the surface of a flat substrate (US patent #7,553,401)
• Uniformity is the basic building block for establishing a robust, electrochemical manufacturing process.
• The unique patented cell geometry and flow scheme provides great uniformity across the plates, with a coefficient of variation across the sample of less than 4%.

Previous Accomplishments and Feasibility



Faraday has successfully shown feasibility of etching channels in the stainless steel bipolar plates for PEM fuel cells, using the FARADAYIC^{SM} process, under DOE contract DE-FG02-08ER85112. A uniformity of 97 % – 98 % was observed for an average channel depth of 0.40 mm.

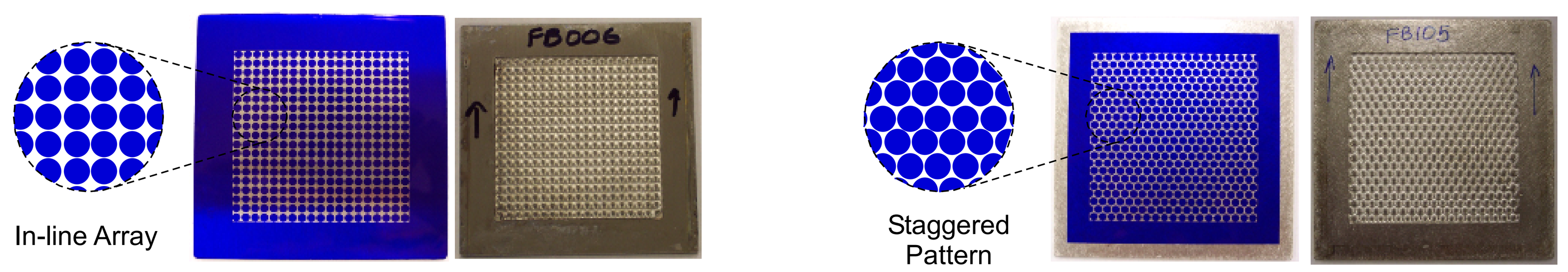


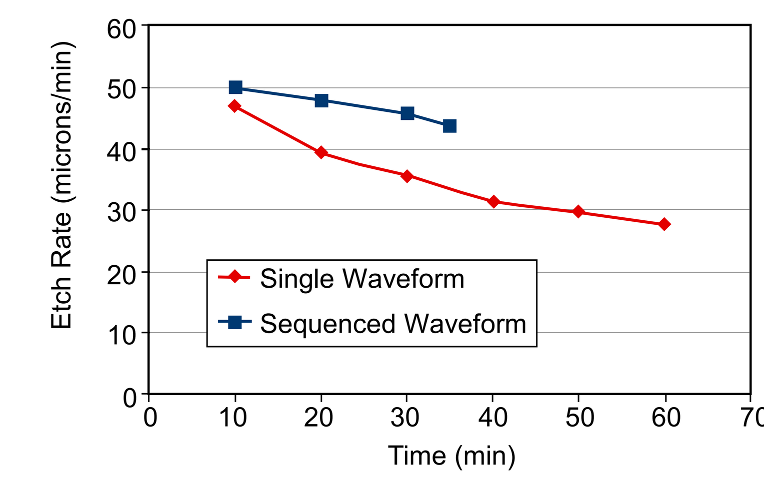
In on-going work funded by a commercial client, Faraday is adapting the FARADAYIC® Process for etching and polishing stainless steel HPLC chips in simple NaCl/$NaNO_3$ electrolytes. A 4" test template SS wafer with photoresist pattern was used for this design.

Related IP Status FARADAYIC^{SM} ElectroEtching and FARADAYIC® ElectroCell
• Method patents/patents pending
– US 6,221,235 (4-24-2001); 6,402,931 (6-11-2002)
– Two patents pending
• Apparatus patents/patents pending
– US 7,553,401 (6-30-2009); 7,947,161 (5-24-2011); 8,226,804 (7-24-2012)
– One patent pending

Current Results

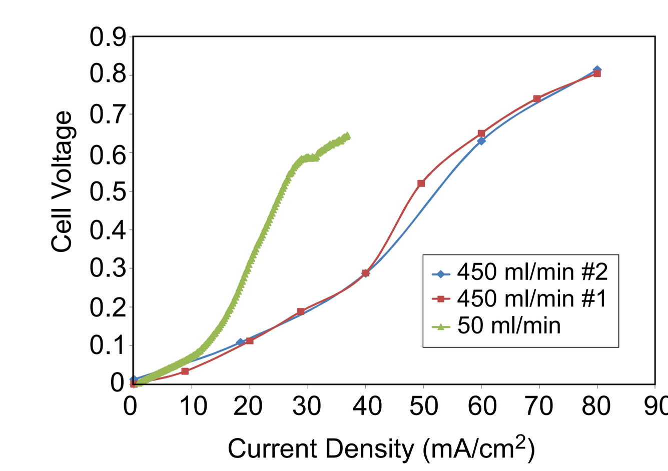
Through mask electro-etching of stainless steel plates using FARADAYIC® conditions



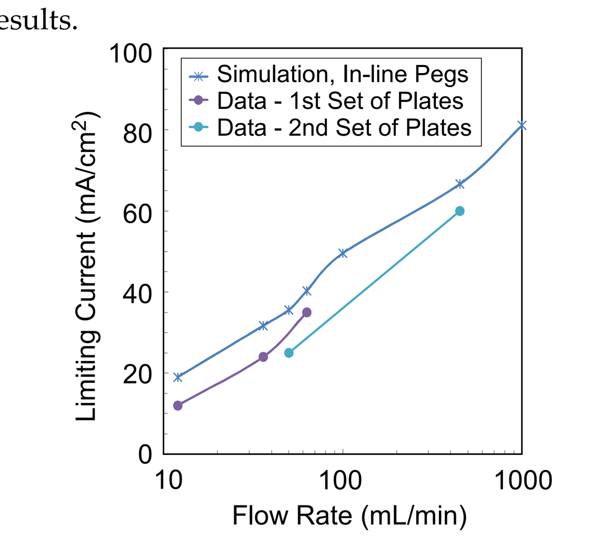


Enhancing the etching process by reducing the etch time per plate using sequential FARADAYIC® conditions. (Etch depth ~ 1500 mm)

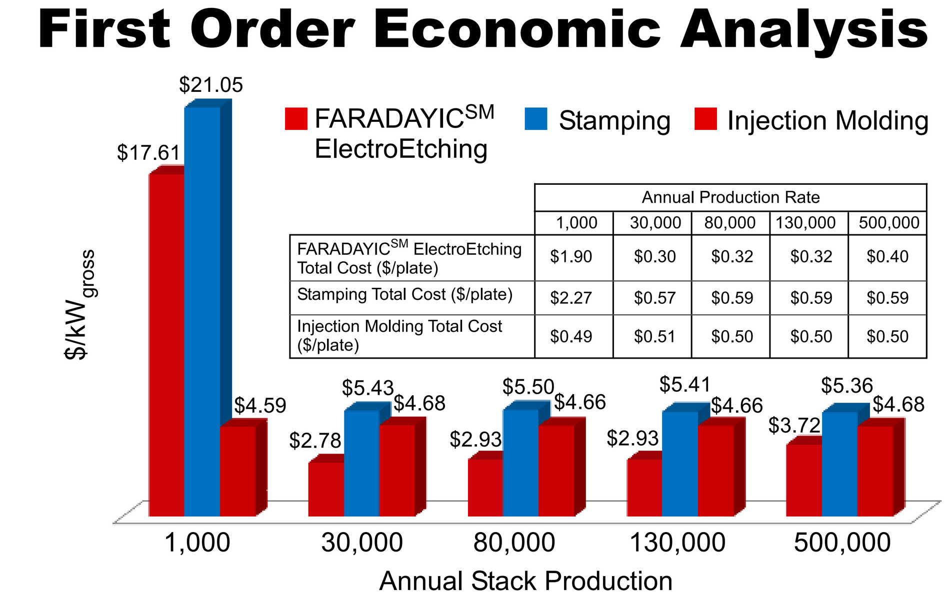
Polarization experiments performed by Case Western Reserve University on in line array show an enhancement in limiting current density with the increase in the flow rate.



Additional Computational Fluid Dynamic (CFD) predictions agree well with the experimental results.



First Order Economic Analysis



	Annual Production Rate				
	1,000	30,000	80,000	130,000	500,000
FARADAYIC^{SM} ElectroEtching Total Cost (\$/plate)	\$1.90	\$0.30	\$0.32	\$0.32	\$0.40
Stamping Total Cost (\$/plate)	\$2.27	\$0.57	\$0.59	\$0.59	\$0.59
Injection Molding Total Cost (\$/plate)	\$0.49	\$0.51	\$0.50	\$0.50	\$0.50

Achievements and Future Work

• Potential for decreasing the manufacturing time using FARADAYIC^{SM} sequential process.
• Achieved etching of different features and patterns using the FARADAYIC^{SM} ElectroEtching Process.
• First order economic analysis shows that FARADAYIC^{SM} ElectroEtching is competitive with other component forming processes
• Continued modeling efforts to find the optimum feature size and shape to enhance the limiting current density in the flow batteries.

Acknowledgements

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References

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