Adaptive Process Controls and Ultrasonics for High Temperature PEM MEA Manufacture

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Wednesday, May 15, 2013

MN005

Overview

Timeline

- Project start date: 9/01/08
- Project end date: 9/30/13
- Percent complete: 95%

Budget

- Total project funding: $2,508,186
  - DOE share: $1,611,129
  - Contractor share: $897,057
- Funding received in FY12: $270,813
- Funding for FY13: $61,083

Barriers Addressed

- A. Lack of High-Volume Membrane Electrode Assembly (MEA) Production
- F. Low Levels of Quality Control and Inflexible Processes

Partners

- RPI CATS - Project Lead
- ASU - Subcontractor
- BASF Fuel Cell - Collaborator
- PMD - Collaborator
- UltraCell - Collaborator
- NREL - Collaborator
- Ballard - Collaborator

Relevance

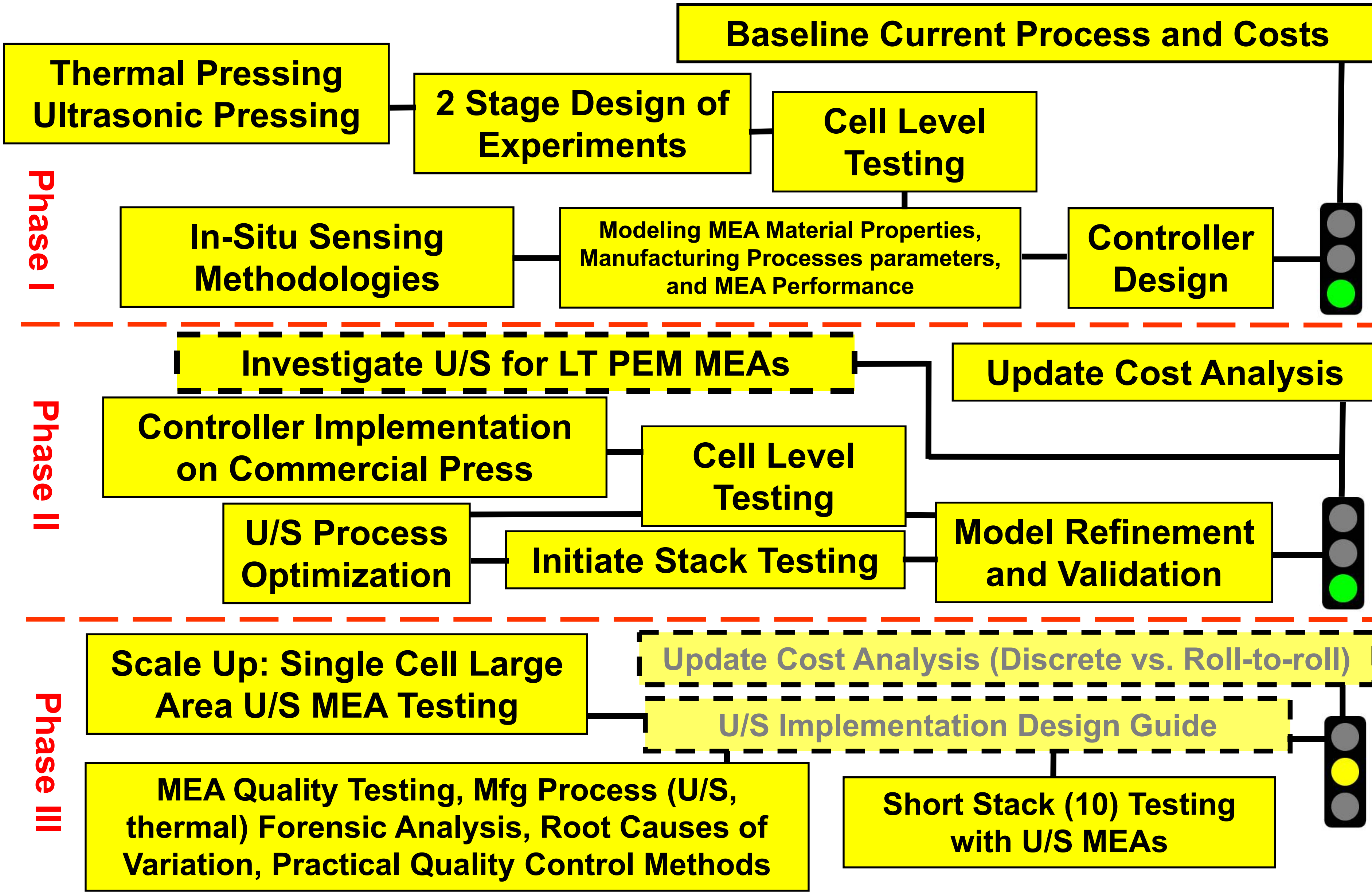
Situation and Objectives

- Situation: In spite of the fact that there are variations in MEA component material properties, industry uses the same manufacturing process parameters for each one fabricated. This results in variations in MEA properties and performance, and the potential for stack failures and re-work, and reduced durability.
- We need to develop a deeper understanding of the relationships among MEA material properties, manufacturing processes parameters, and MEA performance (3Ps).
- The high level objectives of the proposed work are to enable cost effective, high volume manufacture of **high temperature (160-180°C) PEM MEAs** by:

Specific Objective	Barrier Addressed
1. Significantly reducing MEA pressing cycle time through the development of novel, robust ultrasonic (U/S) bonding processes (also demonstrate for low temperature (<100°C) PEM MEAs)	A. Lack of High-Volume MEA Production
2. Achieving greater manufacturing uniformity and performance through (a) an investigation into the causes of excessive variation in ultrasonically and thermally bonded MEAs using more diagnostics applied during the entire fabrication and cell build process and (b) development of rapid, yet simple quality control measurement techniques for use by industry.	F. Low Levels of Quality Control and Inflexible Processes

Technical Approach

Project Plan



Phase I

Task	Description	Results/Conclusions	Completion
1.0	Baseline and Analysis of Current Process	Initial cost model developed	100%
2.0	Comparison of Current and Proposed MEA Pressing Processes	Hardware, tooling, and protocol for thermally and U/S bonding of MEAs achieved	100%
3.0	Baseline Process Testing	Performance of thermally and U/S bonded MEAs quantified and shown equivalent to commercial product	100%
4.0	Model Development	Combined dynamic/FEA model demonstrated	100%
5.0	Development of In-situ Sensing Techniques	Adaptive process control via in-situ AC impedance measurement demonstrated	100%
6.0	Controller Development	Control performed manually	100%
7.0	Phase I program review	Go Decision	100%

Phase II

Task	Description	Results/Conclusions	Completion
8.0	APC Implementation	Convergence of AC real impedance (1 kHz) to small value signifies complete bonding $\rightarrow$ 30 to 7 sec reduction in sealing time	100%
8.1	APC for Ultrasonics	Acoustic signal sensing inconclusive, but U/S process robustness and speed lessen need for APC anyway	100%
9.0	Evaluation of MEA Performance	Five-cell stack testing for 50 cm^2 cells demonstrated	100%
9.1	Evaluation of Larger Scale Ultrasonically Sealed MEAs	140 cm^2 cell and hardware designs successfully demonstrated and experimental testing is on-going.	100%
9.2	Ultrasonic Sealing Process Optimization	2 sec bonding time; post heat treatment is the dominant process parameter	100%
9.3	Heat Treatment Process Optimization	Heat treatment time can be reduced by 50% at higher temperature	100%
9.4	Evaluate Feasibility of Ultrasonic Sealing and APC for Low Temperature MEAs	For 10 cm^2 size using optimal conditions, U/S bonding showed 94% cycle time and 98% energy reduction compared to thermal bonding. O_2 performance same, but air slightly degraded.	100%
9.5	Durability Testing of Ultrasonically Sealed MEAs	Ultrasonically sealed MEAs with optimized process parameters exhibited no cell voltage degradation and minimal Δcell internal resistance during the 200 hour tests	100%
10.0	Updated Cost Analysis	Conservatively, cost reductions of 29% for APC, and 90% for U/S bonding	100%
11.0	Phase II program review	Go Decision	100%

Phase III

Task	Description	Status	Completion
12.0	Short Stack Testing	Completed	100%
13.0	Testing of High Temperature MEAs with Larger Active Area	Completed	100%
14.0	Quality Testing of Thermally and Ultrasonically Bonded High Temperature MEAs	Completed	100%
15.0	Expanded Cost Analysis	In progress	75%
16.0	Ultrasonic Bonding Implementation Design Guidelines	In progress	75%
17.0	Phase III Program Review	Expected in Spring 2013	0%

Blue shading indicates tasks performed during FY2012 and covered in Accomplishments & Progress section

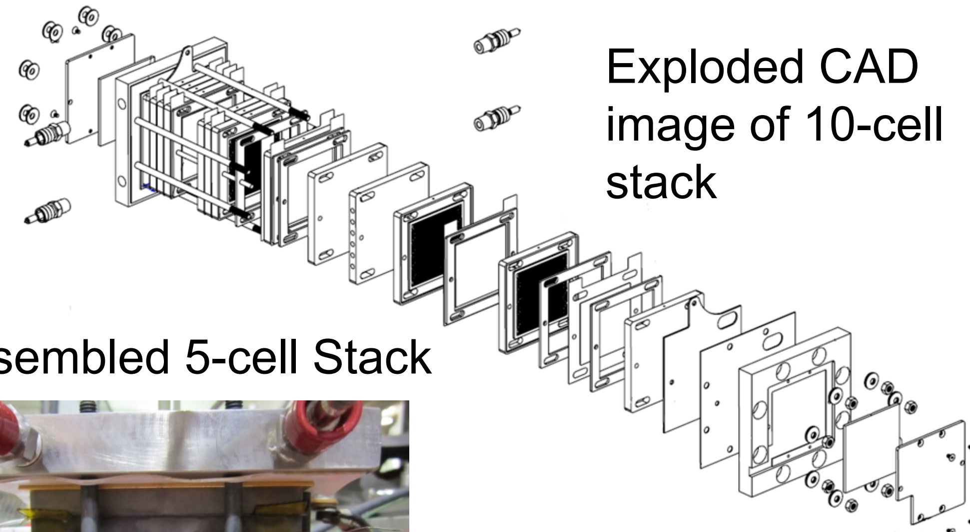
Short Stack Testing (Task 12.0)

Normal Test Procedures:

- 2-hour warm up
- 13-hour conditioning cycle
- Air and oxygen polarization curves

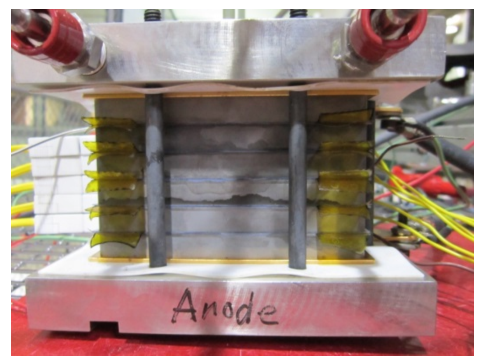
When possible:

- 200-hour endurance cycle
- Air and oxygen polarization curves



Exploded CAD image of 10-cell stack

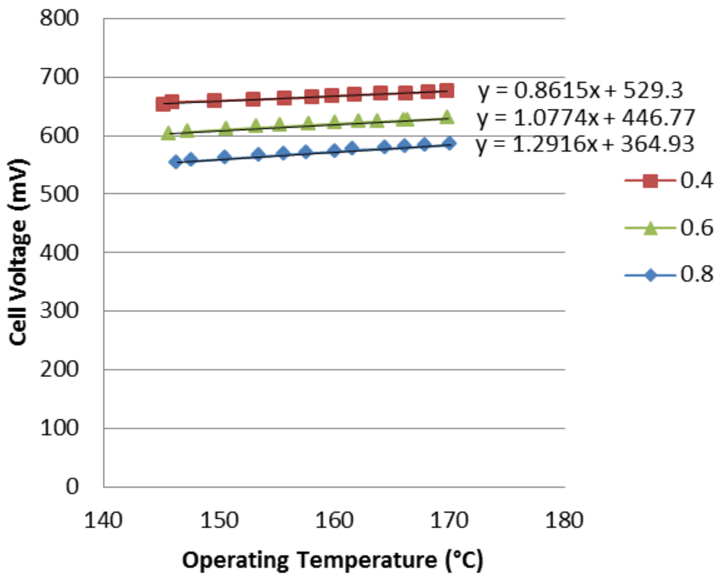
Assembled 5-cell Stack

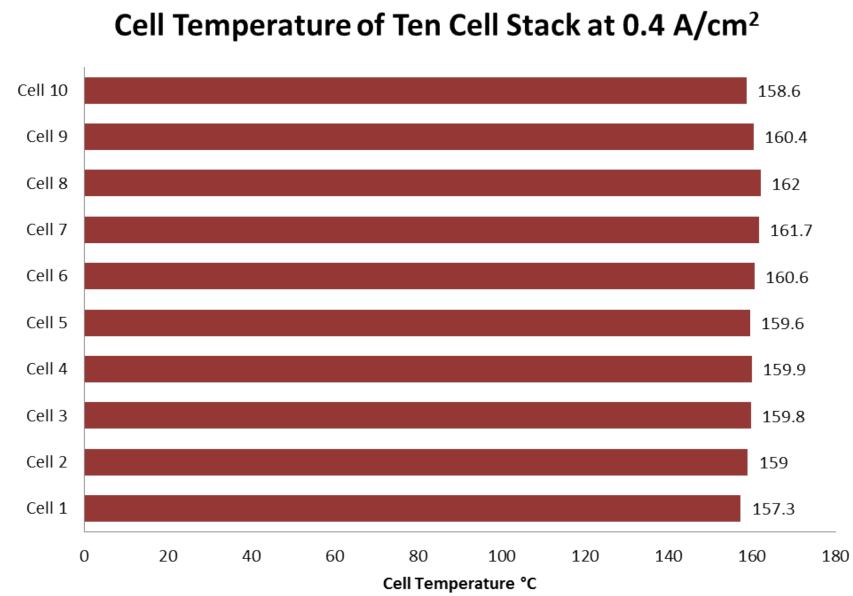


Insulated Stack Case

Dedicated Test Stand

Stack Inter-cell Temperature Distribution & Sensitivity (Task 12.0)



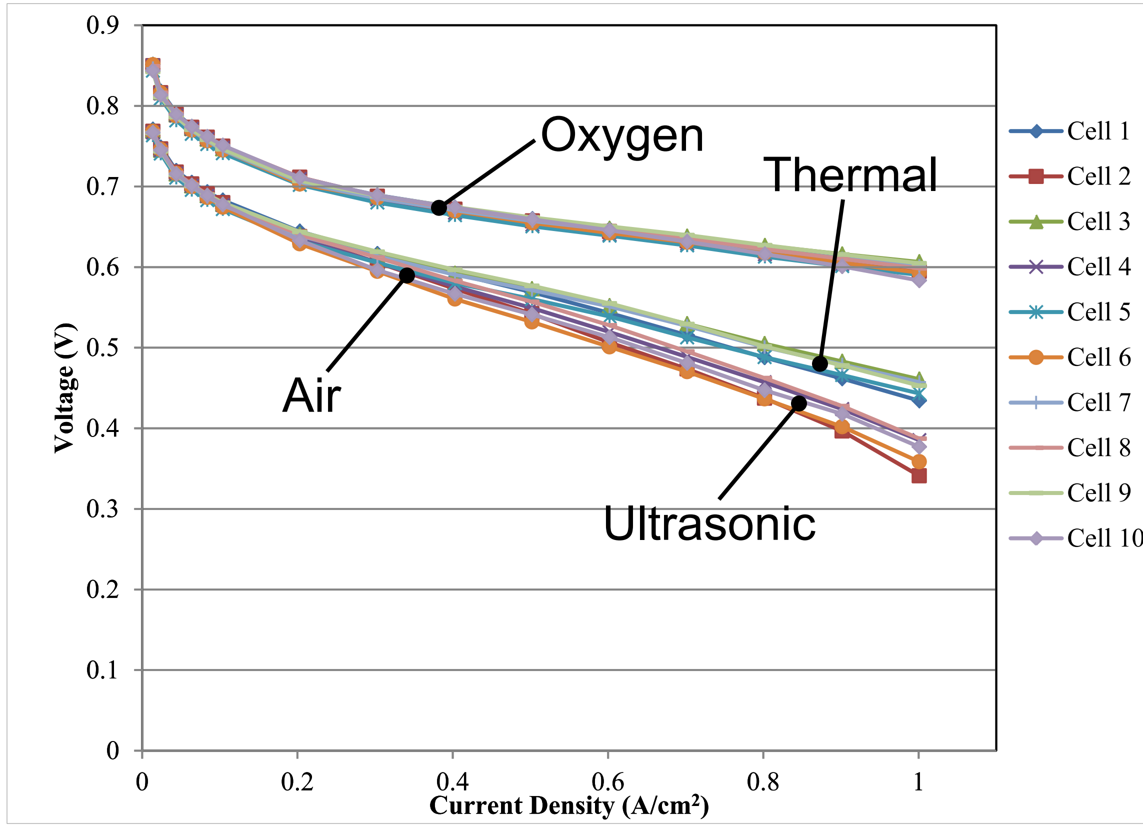


- Current was held constant while temperature was varied.
- Range chosen was ±10°C about 160°C operating point
- Approximately 1 mV/°C change

- Cell 1 is the bottom of the stack and in contact with the cathode current collector
- Average stack temperature is 159.9°C
- No correlation between temperature distribution and differences in cell performance

10-Cell Stack Performance (Task 12.0)

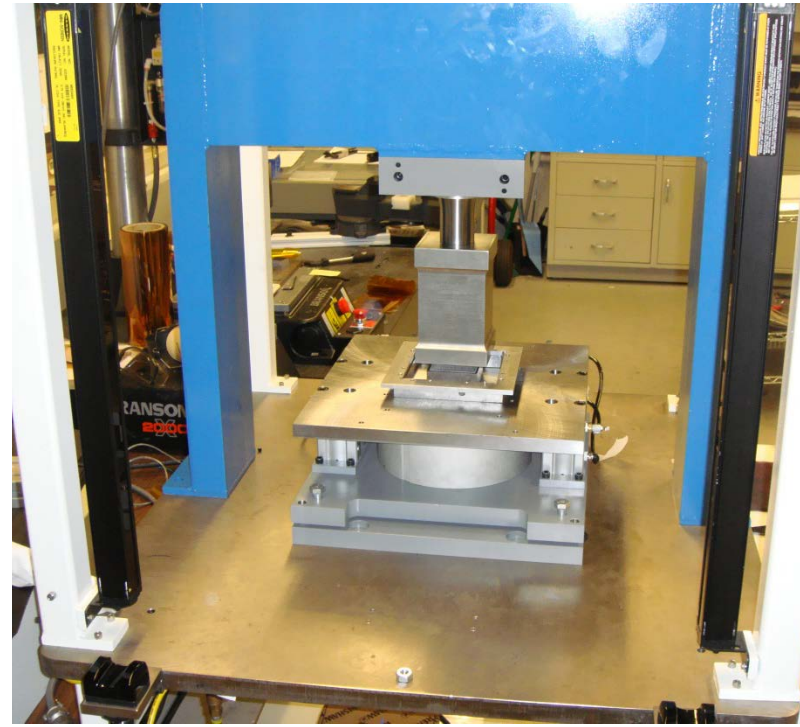
- Mixed stack consists of 5 ultrasonically pressed MEAs (Cells 2,4,6,8,10) and 5 thermally pressed MEAs (Cells 1,3,5,7,9)
- Actual post lamination thickness compression for mixed stack:
  - Ultrasonic = 17%
  - Thermal = 35%
- Clear difference in performance on air, but not O_2.

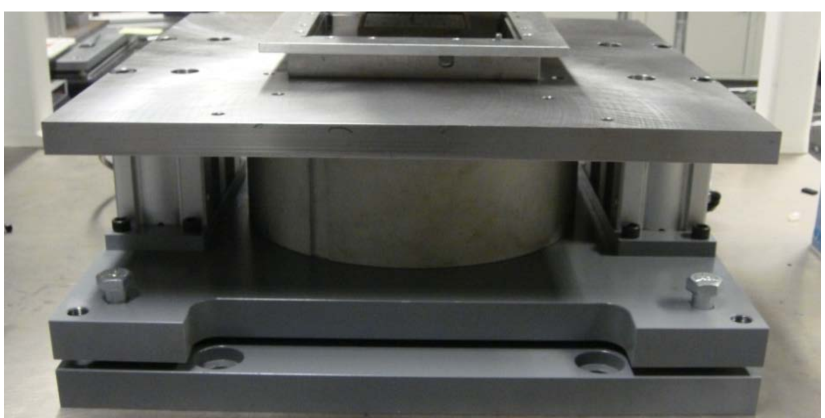


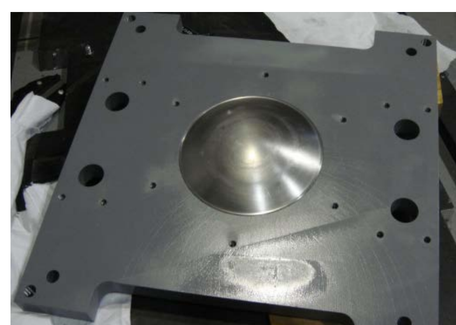
Same thickness gasketing used for ultrasonic and thermal MEAs. Hence, poorer ultrasonic MEA performance on air is attributable to higher in-stack compression, which results in higher mass transport losses.

15 kHz Ultrasonic Welder (Task 13.0)

- H-Frame permits higher loads and lamination of larger areas
- Ultrasonic horn and driver are on fixed mount to H-frame (top)
- Master and guide cylinders support “anvil” (bottom)
- Anvil and cylinders are gimbaled for alignment to ultrasonic horn



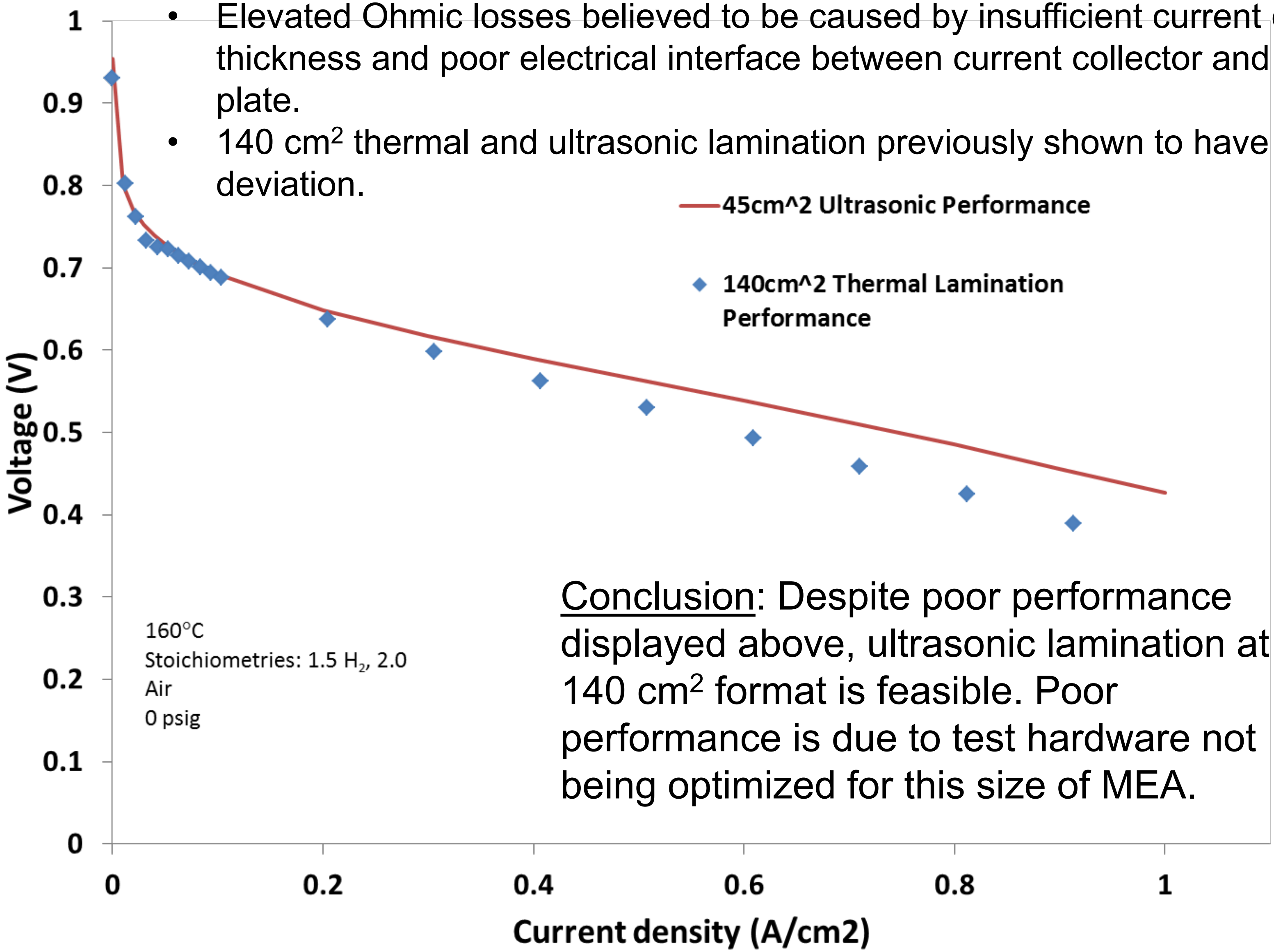




Accomplishments & Progress

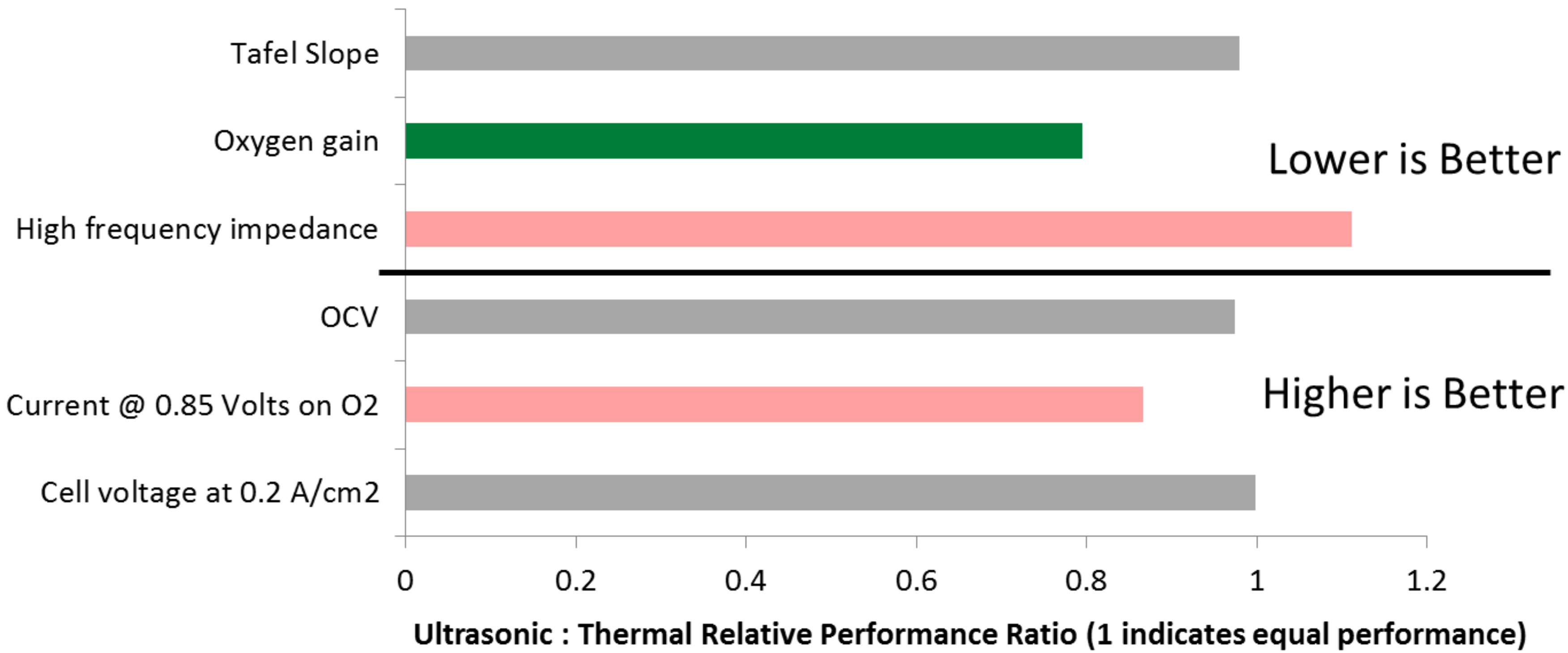
140 cm^2 Performance (Task 13.0)

- Elevated Ohmic losses believed to be caused by insufficient current collector thickness and poor electrical interface between current collector and bipolar plate.
- 140 cm^2 thermal and ultrasonic lamination previously shown to have negligible deviation.



Conclusion: Despite poor performance displayed above, ultrasonic lamination at 140 cm^2 format is feasible. Poor performance is due to test hardware not being optimized for this size of MEA.

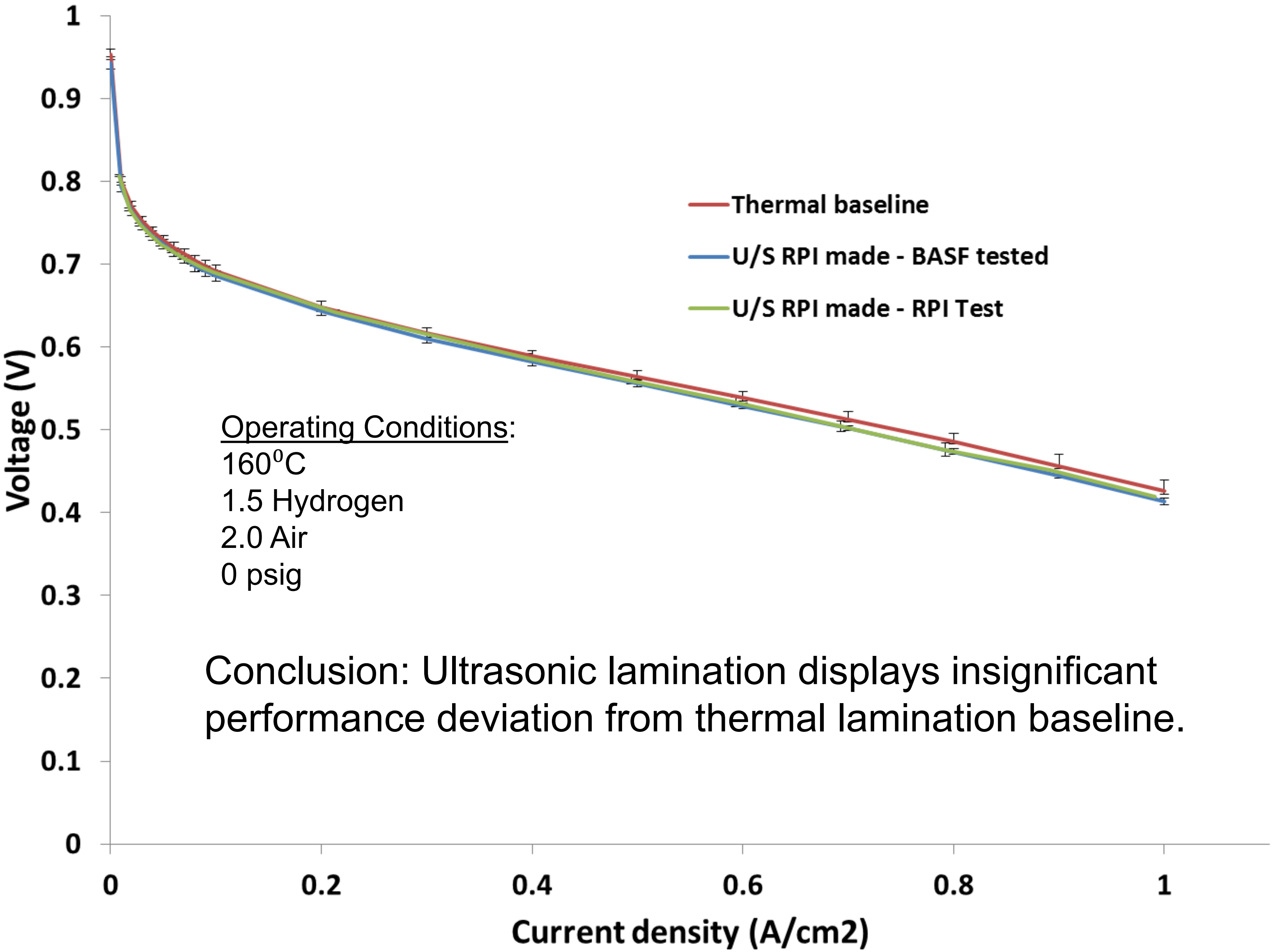
Ultrasonic vs. Thermal Performance (Task 14.0)



Bonding conditions:
Thermal bonding: 25% compression at 140°C for 30 seconds
Ultrasonic bonding: 20 kHz, 5 kJ & 414 kPa (60 psi) in 2 seconds
Average based on 8 ultrasonic and 5 thermally bonded MEAs
Data obtained on 45 cm^2 hardware

Operating Conditions
160^{0}C
1.5 Hydrogen
2.0 Air
0 psig

Ultrasonic vs. Thermal Performance (Task 14.0)

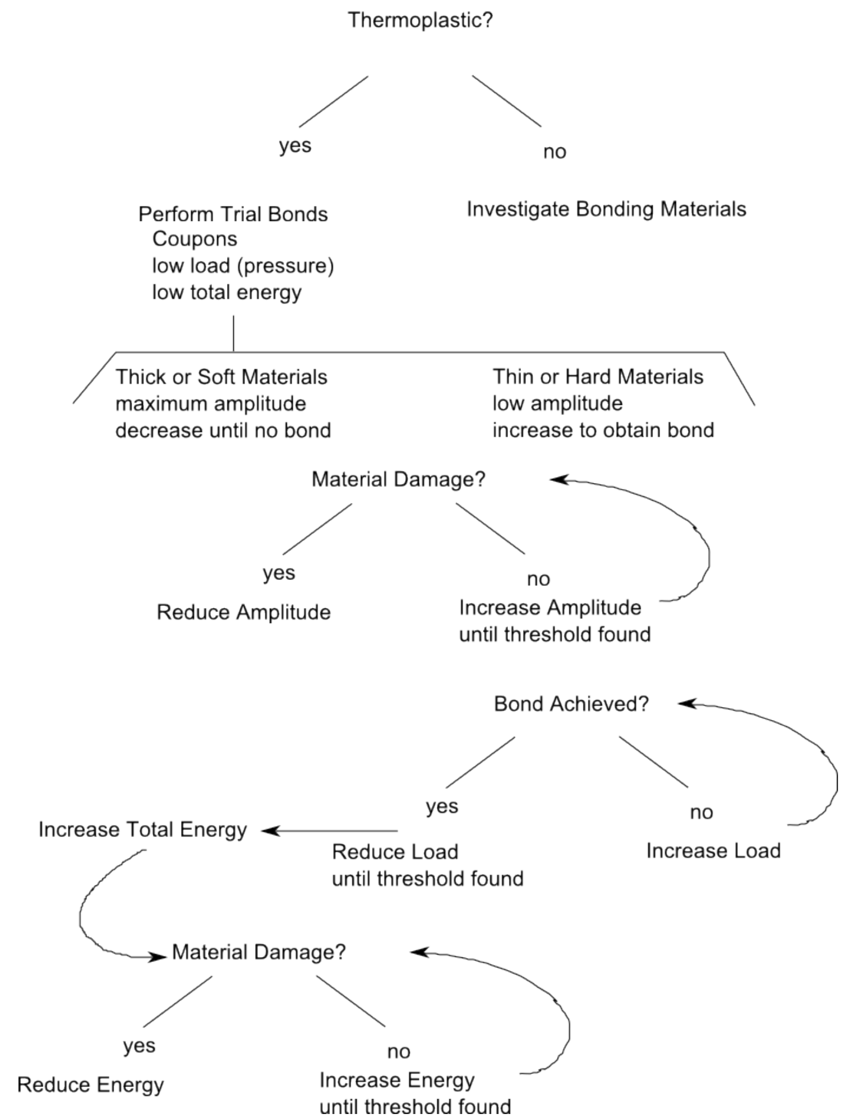


Conclusion: Ultrasonic lamination displays insignificant performance deviation from thermal lamination baseline.

Accomplishments & Progress

Ultrasonic Bonding Implementation Design Guidelines (Task 16.0)

- Successful lamination can be achieved with various controls
  - Amplitude
  - Pressure (load)
  - Energy (power x time)
- Minimal disturbance is desired
  - Minimize impact on materials
- Preliminary experimentation to determine operating space
  - achieve a bond
- Follow with focused design of experiments
  - including measurements of cell performance and detection of component performance



Collaborations

- BASF Fuel Cell
  - Supply high temperature membrane and electrodes for all testing
  - Benefit directly from thermal bonding, ultrasonic bonding, and heat treatment findings
  - Royalty-free license agreement for use of MEA ultrasonics bonding patent in high temperature MEA applications (pending)
- NREL
  - Performance testing and assessment of thermally and ultrasonically bonded low temperature MEAs
- Progressive Machine & Design (PMD)
  - Working with PMD to continuously improve and ugprade BASF's manufacturing line
- Ballard Power Systems
  - Tested ultrasonically welded MEAs using Ballard low temperature membrane and GDE

Future Work

- Finish cost analysis and compare discrete manufacturing and roll-to-roll manufacturing approaches
- Finish design guidelines for ultrasonic tooling and process to bond high- and low-temperature PEM MEAs.

Project Summary

Task 12.0 – Short Stack Testing

- Stack architecture has minimal effect on MEA performance and can be used to efficiently test multiple MEAs simultaneously.
- Performance differences between equal mix of thermally and ultrasonically bonded 45 cm^2 MEAs in 10-cell stack on O_2 are negligible, indicating that their impedances are similar. Poorer performance of ultrasonic MEAs is a result of higher in-stack compression, which leads to higher mass transport losses.

Task 13.0 – Testing MEAs with Larger Active Areas

- Despite poor performance as compared to manufacturer's baseline data, ultrasonic lamination at larger format (140 cm^2) format is feasible. Poor performance is due to inadequate test hardware.

Task 14.0 – Quality Testing of Thermally and Ultrasonically Bonded High Temperature MEAs

- Ultrasonic lamination displays insignificant performance deviation from thermal lamination baseline

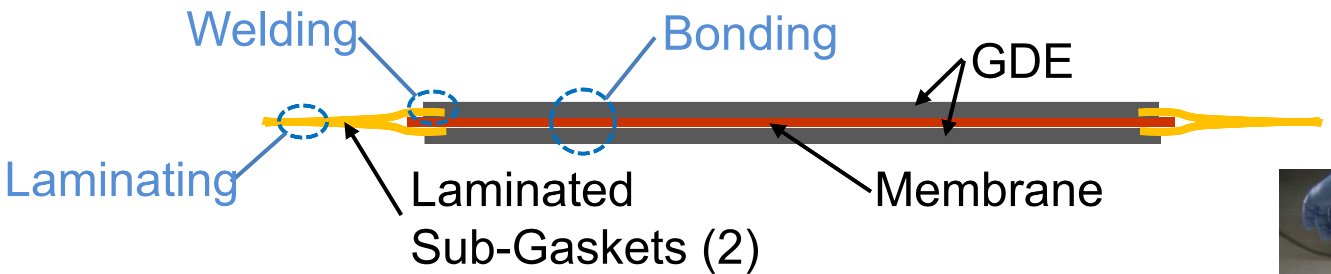
Task 16.0 - Ultrasonic Bonding Implementation Design Guidelines

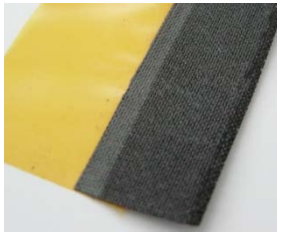
- A general set of process design guidelines has been established for implementing ultrasonic bonding in PEMFC MEA manufacturing.

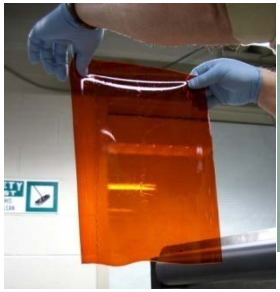
Technical Backup Slides

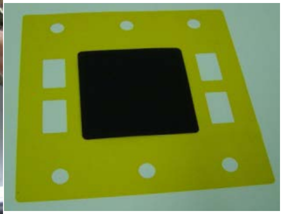
MEA and Thermal Pressing Details

- 5-layer MEA Architecture

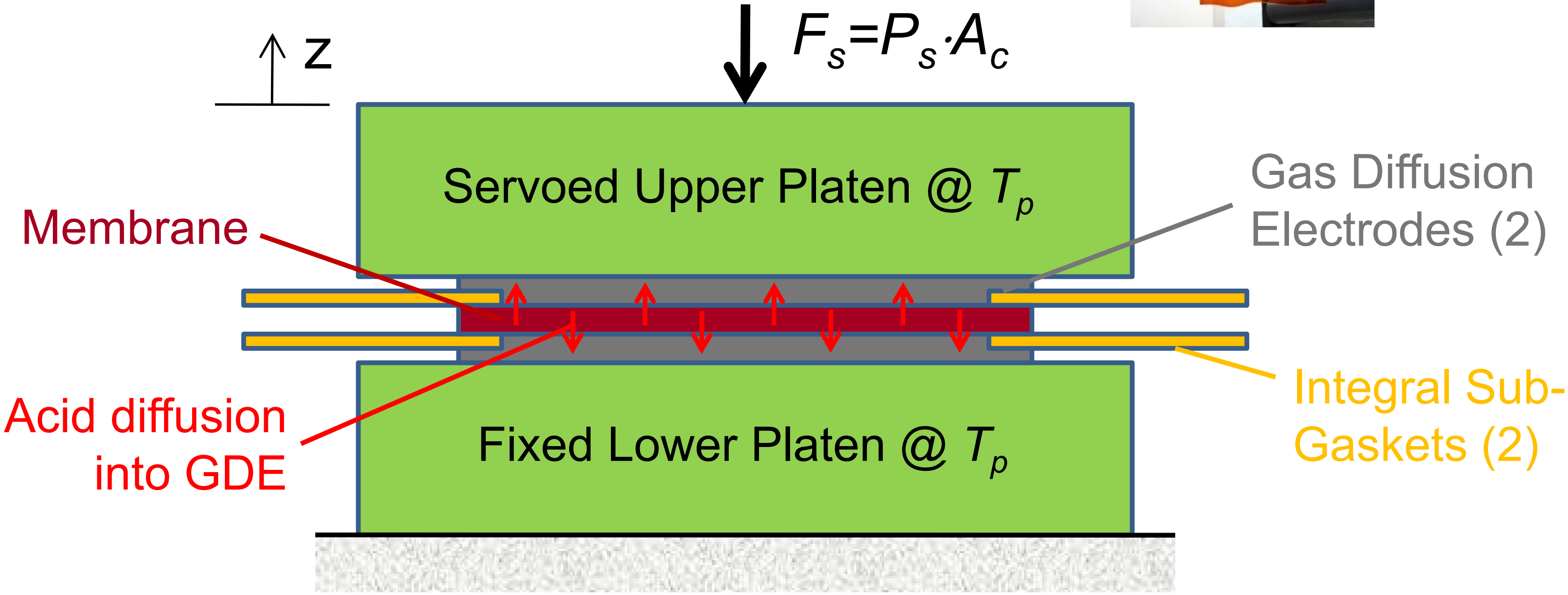




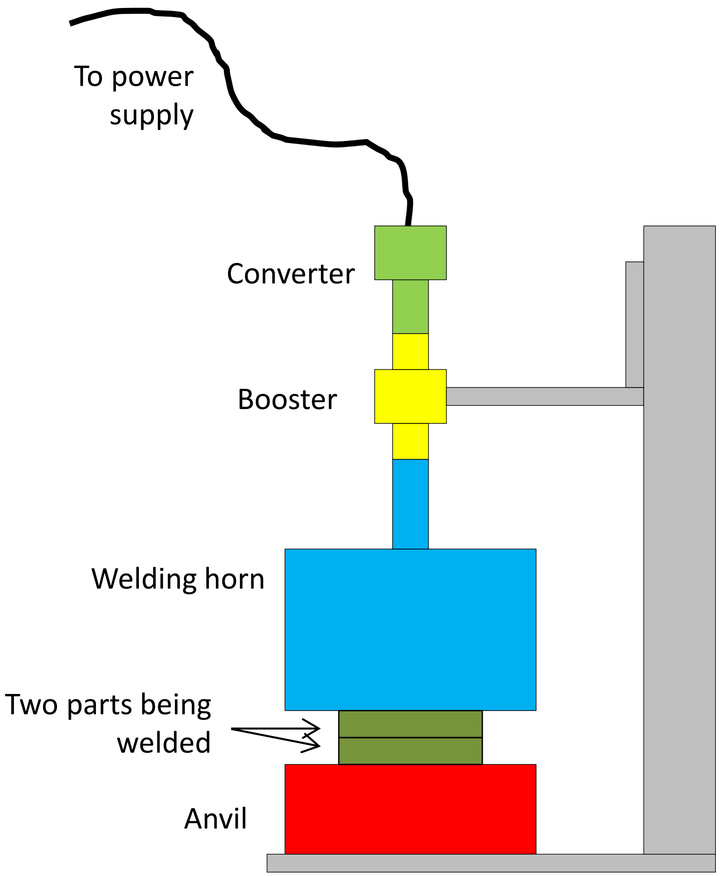




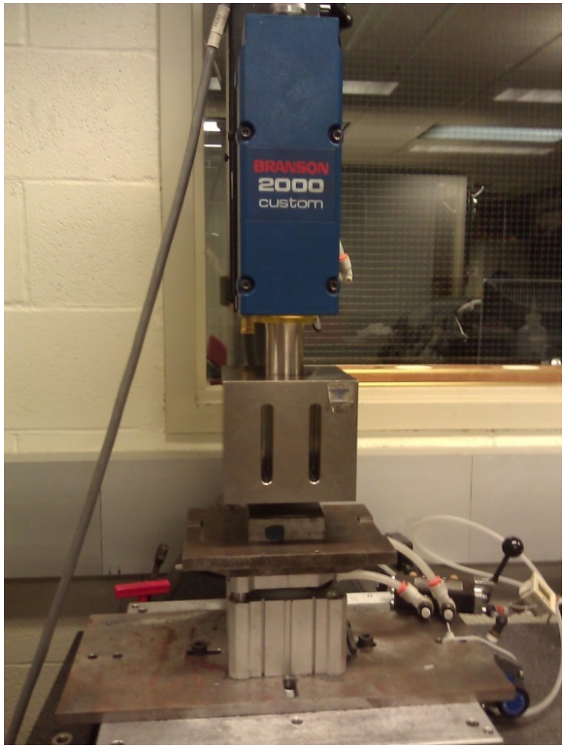
- Thermal Bonding Procedure



Ultrasonic Bonding Details



Schematic of ultrasonic welder and workpiece



Branson 20 kHz ultrasonic welder retrofitted for MEA bonding