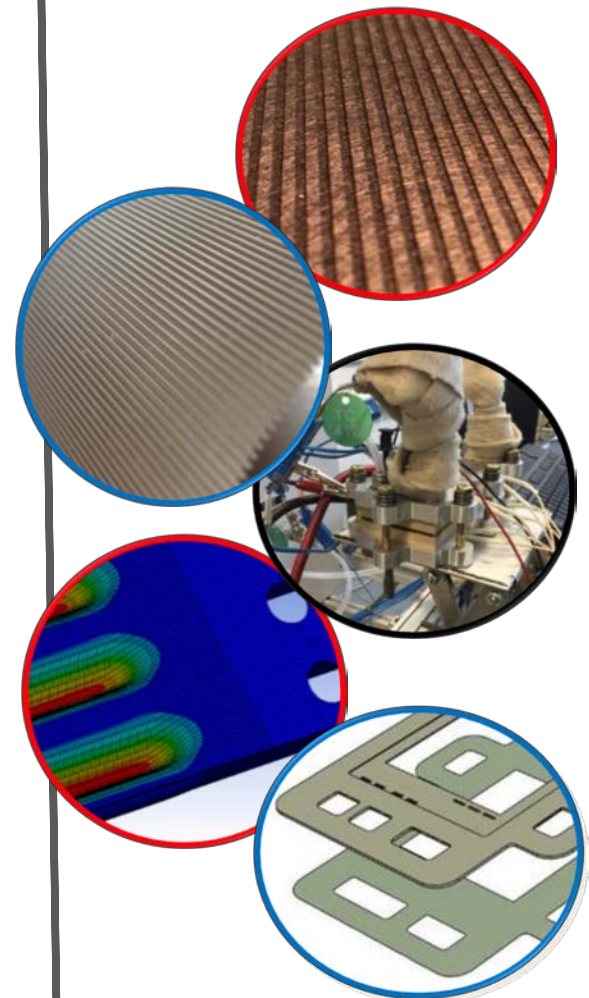
FY17 SBIR I Release 2: Over-Molded Plate for Reduced Cost and Mass PEM Fuel Cells



PI: Daniel O'Connell
Presenter: Jon Owejan

Team: Peter Borglum, Steve Goebel, Brian Litteer, Jon Seinkowski

American Fuel Cell LLC

June 13, 2018

Project ID FC177

This presentation does not contain any proprietary, confidential, or otherwise restricted information

American Fuel Cell

ESCL
Energy Storage & Conversion
Laboratory at Alfred State

Overview

Timeline

Project start date: June 2017

Project end date: April 2018

Percent complete: 100%

Barriers

Cost

Performance

Budget

Total project funding: $150K

Partners

SUNY Alfred

Relevance

Objective: Demonstrate a low cost and mass plate architecture capable of enabling a diffusion substrate that is compatible with roll-to-roll manufacturing while meeting benchmark automotive fuel cell performance.

- ***Meet or exceed DOE 2020 target for plate cost of \$3/kW$_{net}$***
- ***Meet or exceed DOE 2020 target for plate mass of 0.4 kg/kW$_{net}$***

Characteristic	Units	Status	2020 Target
Plate cost[a]	\$/kW	4[b,c]	3
Plate weight	kg/kW	<0.4[c,d]	0.4
Plate H_2 permeation coefficient[e]	Std $cm^3/(sec\ cm^2\ Pa)$ @ 80°C, 3 atm 100% RH	$<2 \times 10^{6}$[f]	1.3×10^{-14}
Corrosion anode[g]	$\mu A/cm^2$	no active peak[h]	1 and no active peak
Corrosion cathode[i]	$\mu A/cm^2$	<0.1	1
Electrical conductivity	S/cm	>100[j]	100
Areal specific resistance[k]	Ohm cm^2	0.006[h]	0.01
Flexural strength[l]	MPa	>34 (carbon plate)	25
Forming elongation[m]	See note m	20-40[n]	See note m

Background:

Many fuel cell manufacturers require a stiff diffusion layer substrate for support across channel span

– Not compatible with continuous roll-to-roll coating

Current production methods for gas flow channels limit span to 0.5 mm

– Stamping, molding, and embossing constrain dimension

Current stamped bipolar plates require 3 mil stainless foil for mechanical strength

– Thinner foils would save cost and mass

Discontinuous manufacturing and individual part handling slow BBP throughput

– Minimizing capital equipment cost while increasing rate of manufacture will reduce cost

Approach

Sept. 2017

Demonstrate manufacture of microchannels with viable forming methods

Nov. 2017

Develop stackable architecture around fine pitch flow field

Mar. 2018

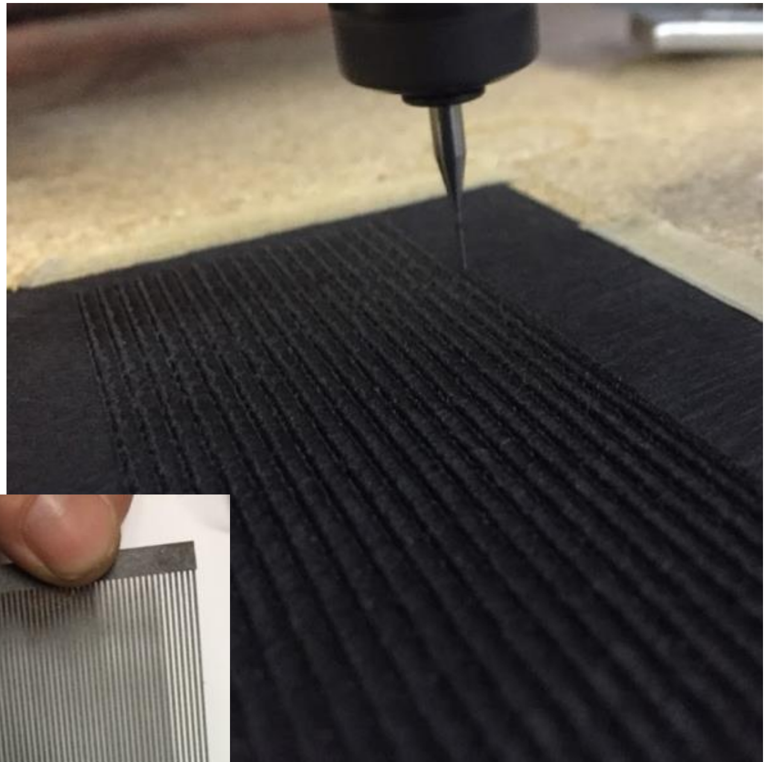
Manufacture small scale prototypes and validate performance

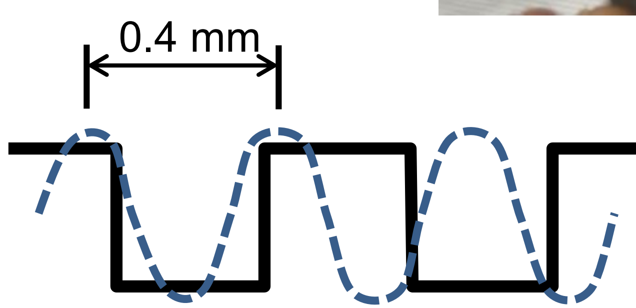
Scale-up design and manufacturing processes for 300 cm^2 short stack (Phase II)

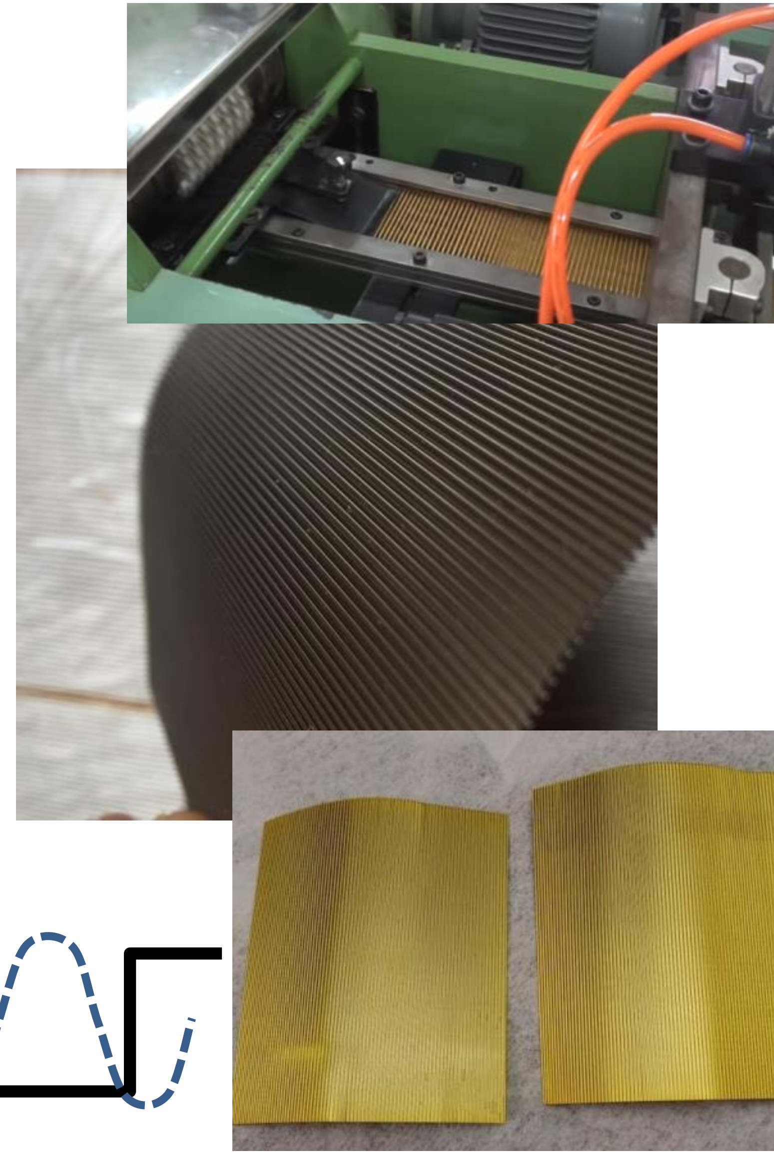
Customer Discovery and Business Development

Accomplishments: Finer Pitch Gas Flow Channel Manufacturing

Forming channels in GDL and corrugating thin foils results in narrow spans



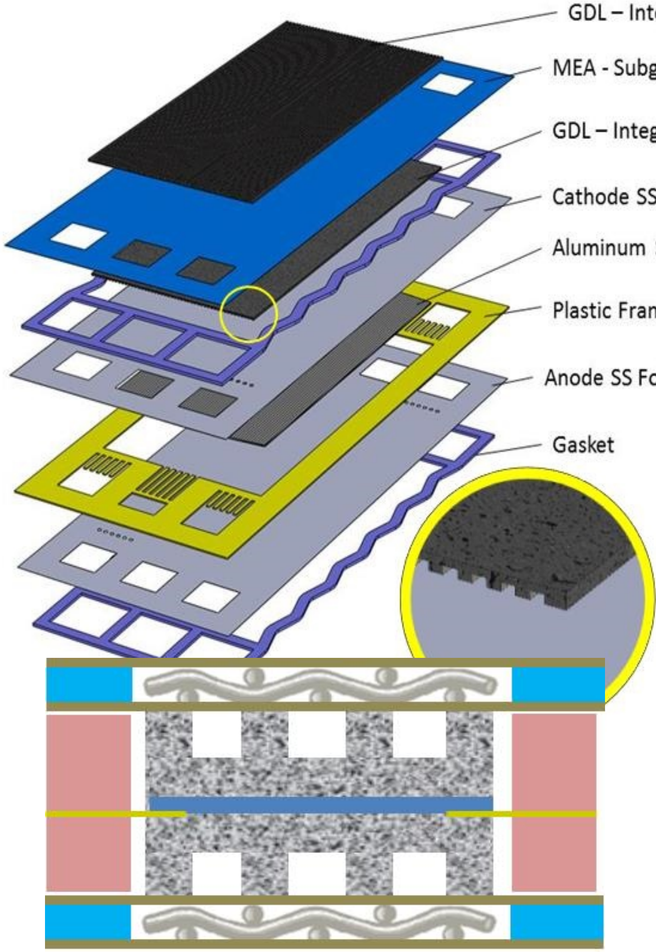




Accomplishments: Small-Scale Demonstration of BPP Architectures

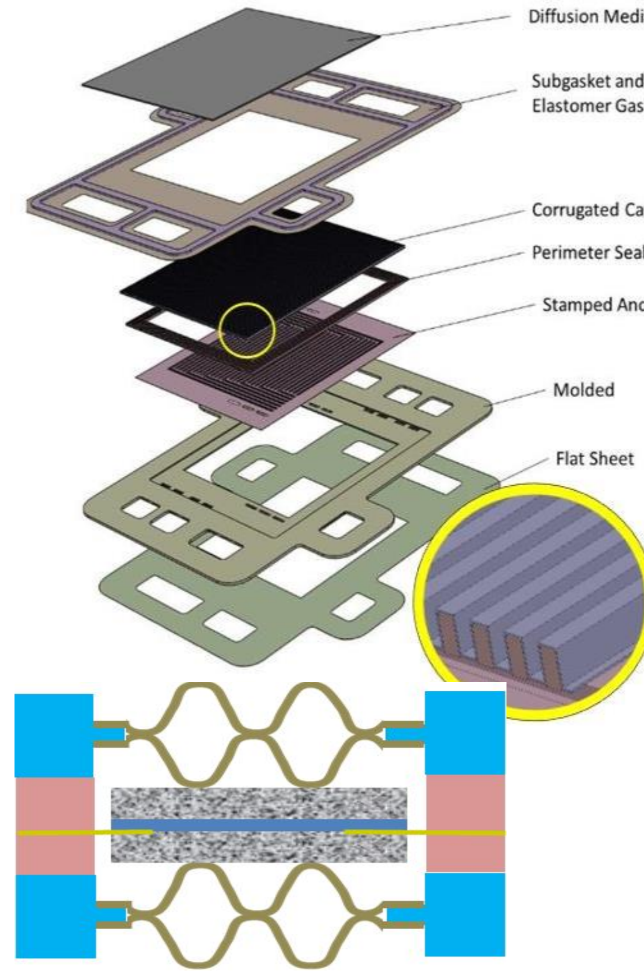
Enables prototype evaluation of BPP features and assembly, used for ex situ and in situ testing

Laminate Structure with Integrated GDL Channels



GDL channels decrease bend radius and enable 1 mil SS foil with BPP manufactured in a continuous lamination process.

Corrugated Flow Field with Plastic Frame



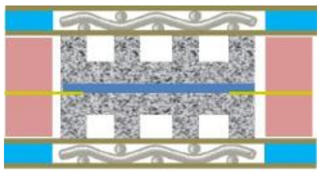
Narrow channels enable low cost GDL, plastic frame reduces SS content. Lowers shunt current through coolant.

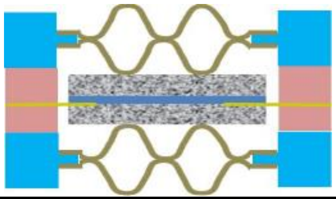
Accomplishments: Design Benefits Compared to Current Stamped SS BPPs

Desirable attributes for next-gen fuel cells identified, laminated concept selected for development focus

✓ - Positive benefit relative to state-of-the-art

○ - No change relative to state-of-the-art

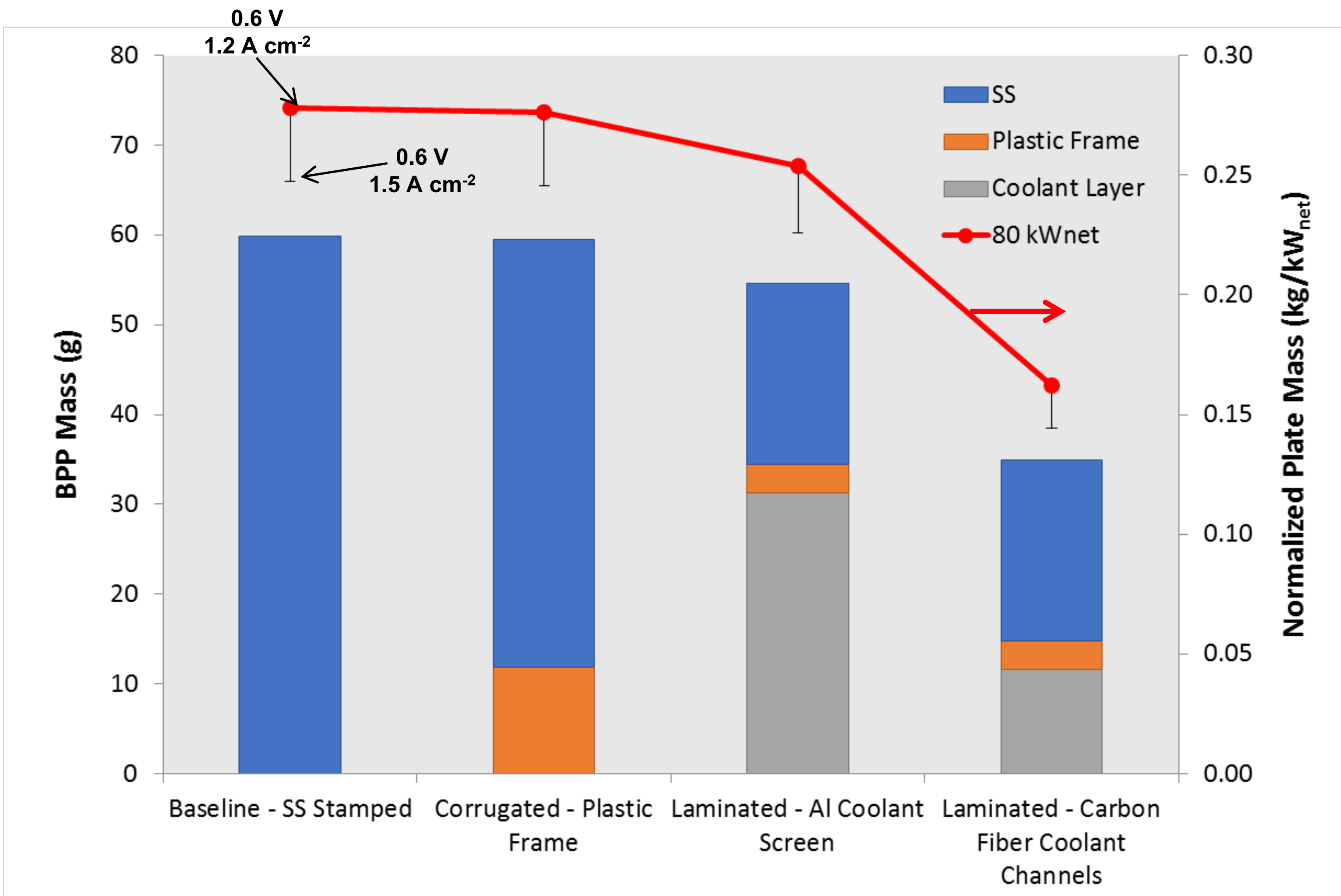




Attribute	Laminated with GDL Channels	Corrugated with Plastic Frame
Utilize Existing Manufacture Methods	✓	✓
Fine Pitch	✓	✓
Enables 1 mil SS Foil	✓	○
R2R Manufacturing of Plates	✓	○
Enables R2R Processing of UEA	✓	✓
Reduced SS	✓	✓
Reduced Mass	✓	○
Reduced Shunt Current	○	✓
Improved Gas Transport	✓	✓
Enables SS Coating Prior to Forming (Carbon)	✓	○
Increased GDL-Plate Contact Area (lower resistance)	✓	○
Increased Membrane-Plate dT (water transport)	✓	○

Accomplishments: BPP Mass Reduction

Laminated architecture exceeds DOE 2020 mass target by 2x (0.16 kg/kW_{net})



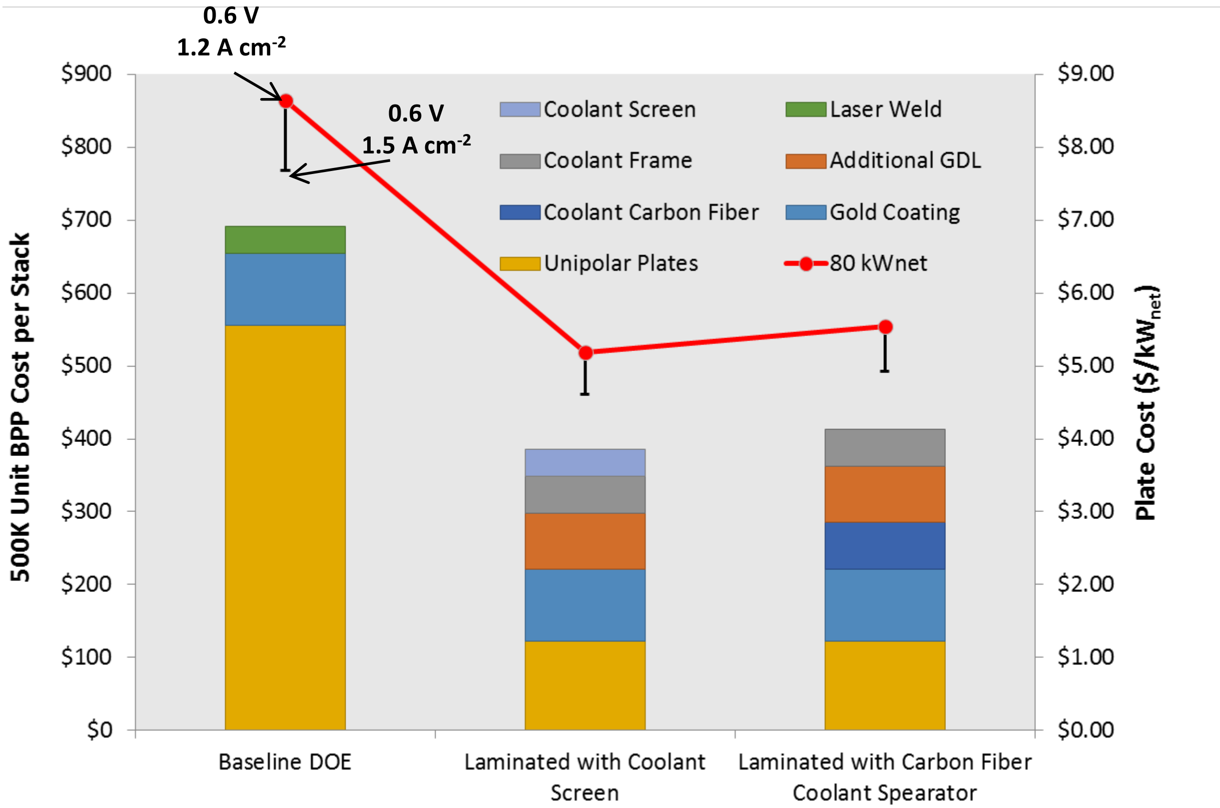
Accomplishments: BPP Cost Reduction

Laminated architecture approaches cost target ($4.80 $/kW$_{net}$, 40 % reduction relative to 3 mil stamped BPPs)

BPP Stack Cost

	Baseline DOE	Laminated with Coolant Screen	Laminated with Carbon Fiber Coolant Separator
Unipolar Plates	$555	$122	$122
Gold Coating	$99	$99	$99
Laser Weld	$37	$-	$-
Coolant Screen	$-	$36	$-
Coolant Carbon Fiber	$-	$-	$64
Additional GDL	$-	$77	$77
Coolant Frame	$-	$51	$51
Assembly	$-	$30	$30
Total per Stack	$691	$415	$443
For 80 kW$_{net}$	$8.64	$5.19	$5.54

(0.6 V, 1.2 A cm^2)



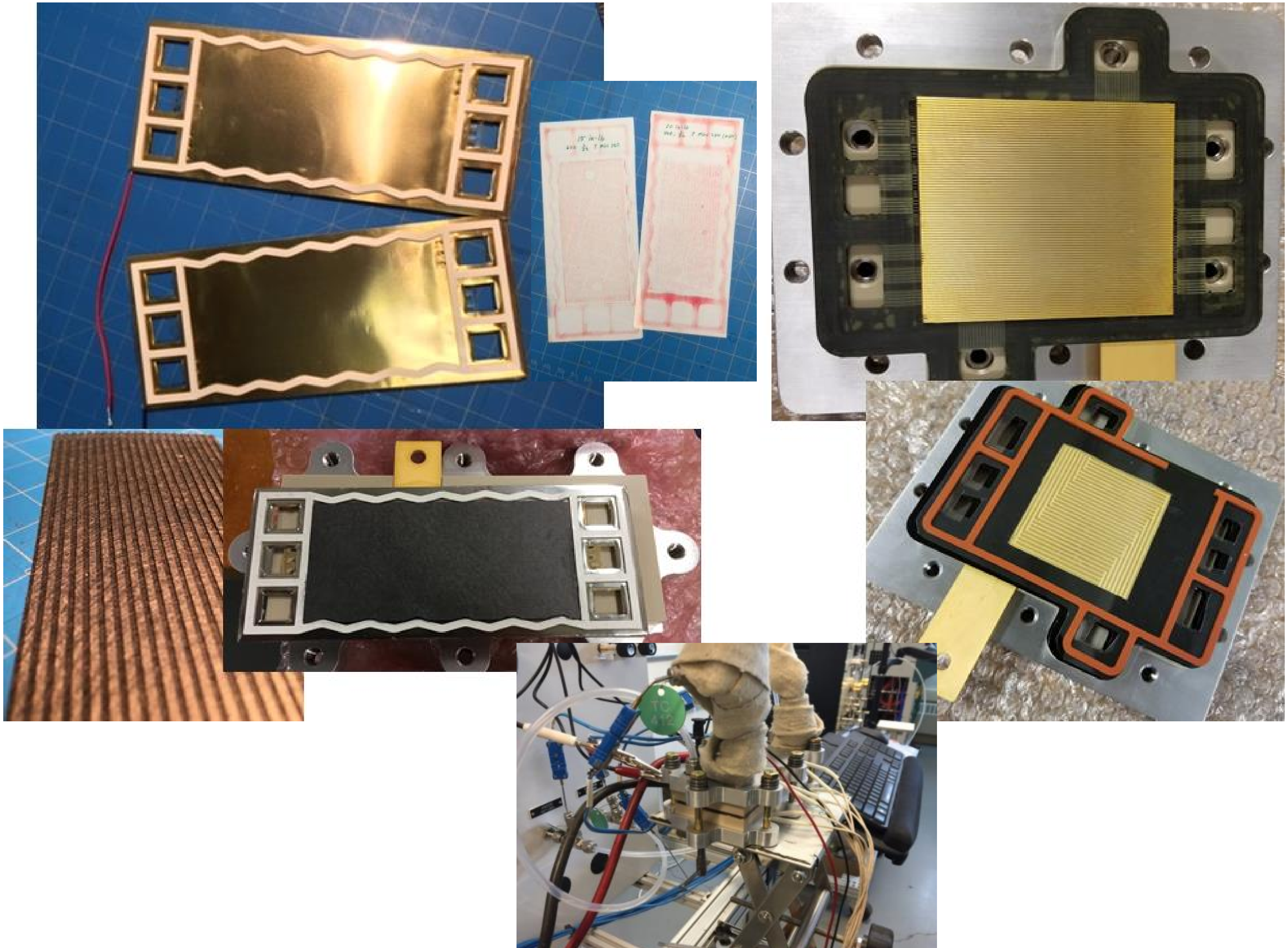
Projections for 500K stacks per year. Model follows DOE baseline BPP costs[1, 2] for stamped SS, then expanded to analyze new concept. Cost estimates include additional carbon fiber for channel ribs. Carbon plate coating would provide further cost reduction. Additional savings in UEA processing (R2R enabled) and stack assembly not captured.

[1]Brian D. James et. al, "Mass Production Cost Estimation of Direct H2 PEM Fuel Cell Systems for Transportation Applications: 2016 Update" (link), September 2016

[2]Brian D. James et. al, "Bipolar Plate Cost and Issues at High Production Rate" (link), February 2017

Accomplishments: BPP Prototype Development

50 cm^2 parts are repeating BPPs that include all features required for scale-up

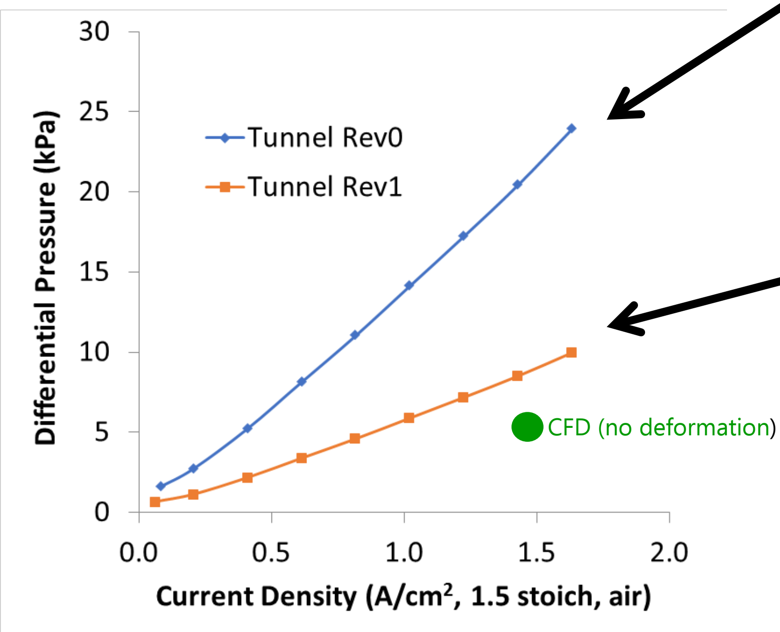


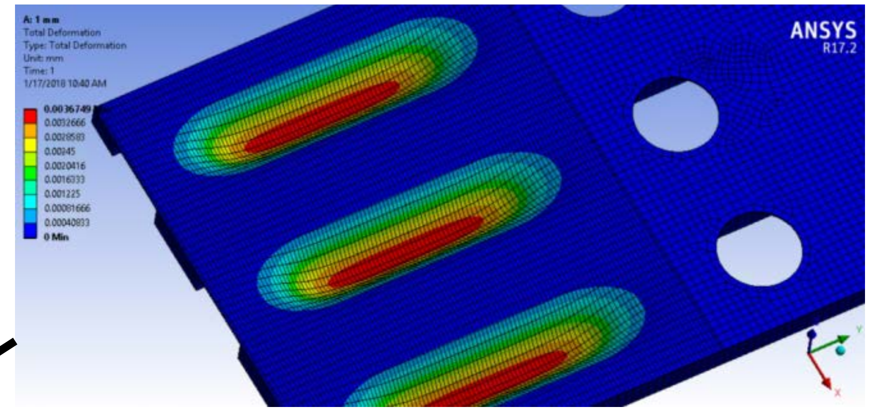
Accomplishments: Leak Rate and Pressure Drop

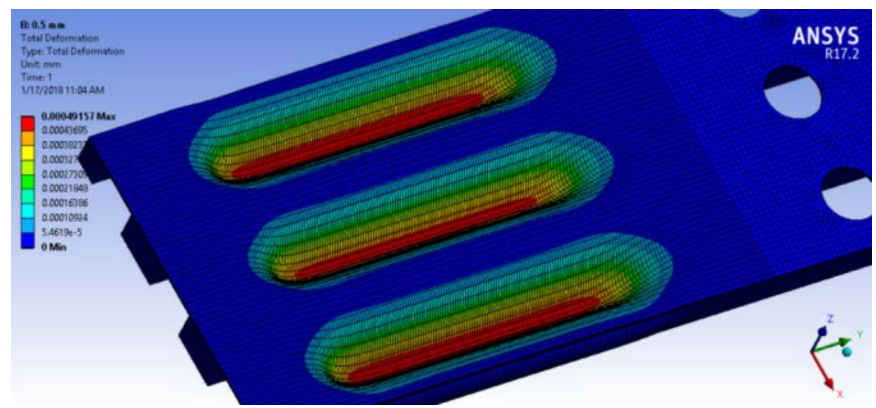
Reliable sealing of architecture established, 1 mil SS foil can support load over fluid inlet and exit passages

Leak Rate for Single Cell 50 cm²

	200 kPag	400 kPag	10,000 Cycles @400 kPag
Overboard	0 sccm	0 sccm	0 sccm
Anode-Cathode	0 sccm	0 sccm	0 sccm
Anode-Coolant	0 sccm	2 sccm	8 sccm
Cathode-Coolant	0 sccm	4 sccm	11 sccm



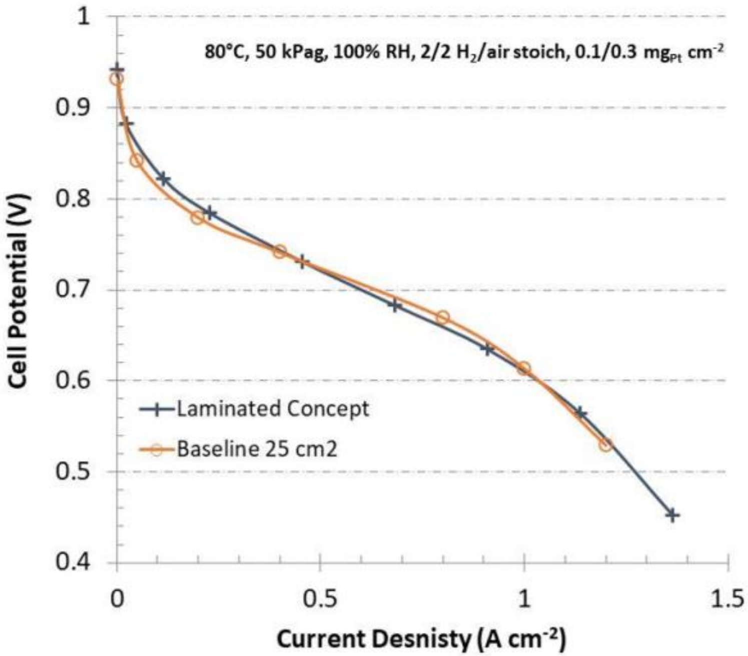




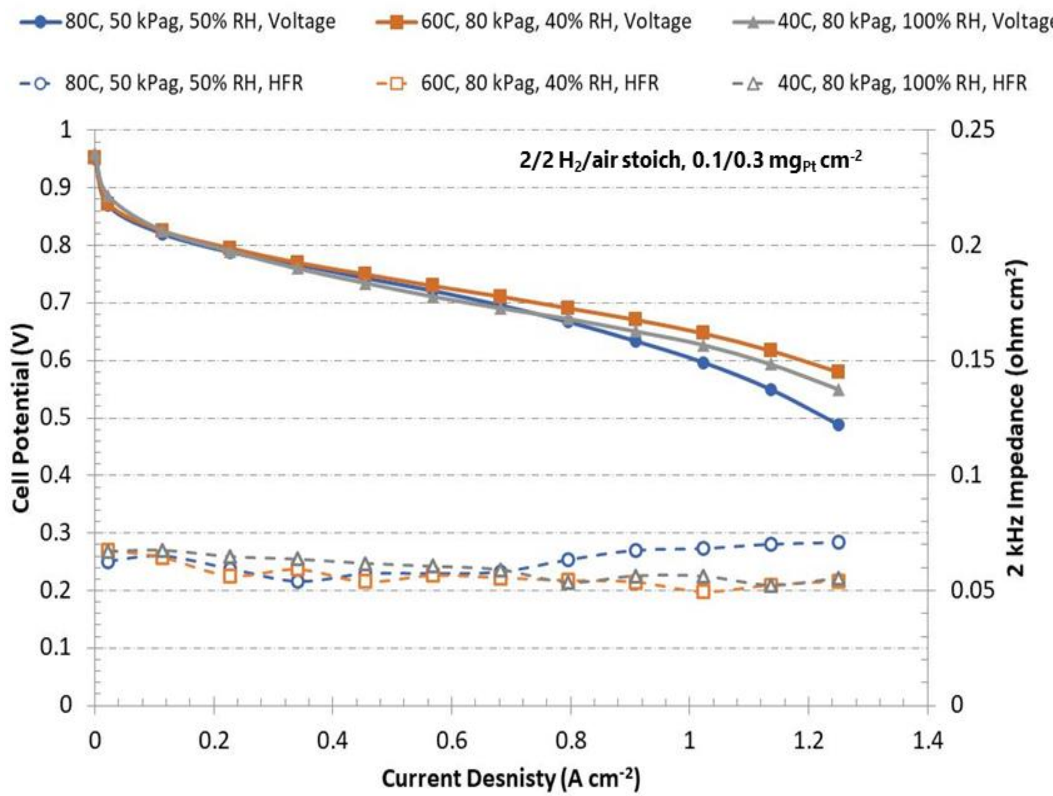
The thin foil deforms under seal load. Finer pitch tunnels reduce pressure drop. Additional architectures being considered.

Accomplishments: Performance Testing

Consistent polarization at varied operating conditions, overall performance limited by MEA (not the BPP)



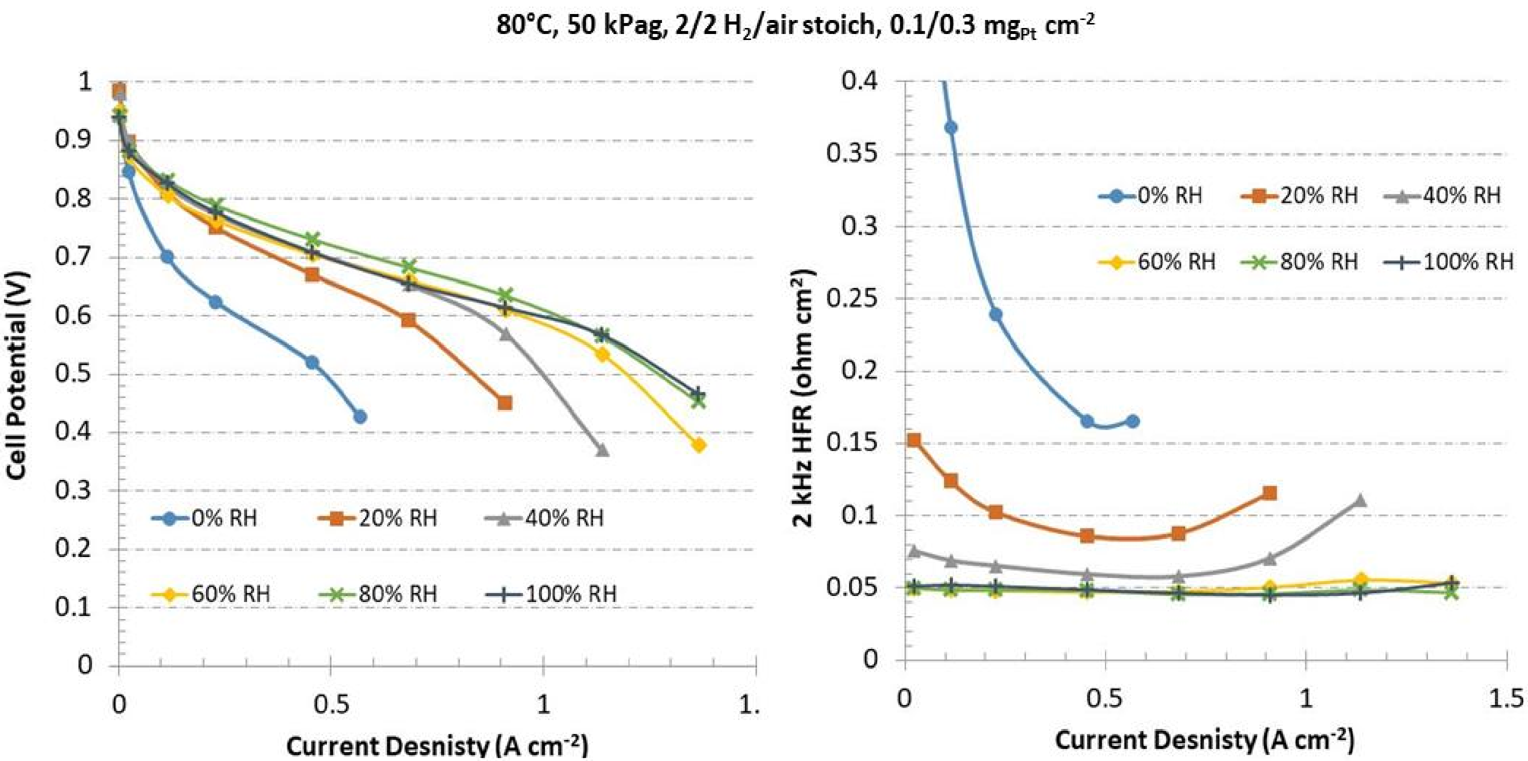
MEA performance was compared with standard 25 cm^2 test hardware (Scribner Assoc.) and the laminated BPP hardware. Similar polarization indicates improved MEA performance will translate directly to the laminated BPP concept.



Initial testing indicates robust performance across several operating conditions. Performance improvements are anticipated as MEA and GDL are optimized in future work.

Accomplishments: RH Sensitivity

Open gas distribution enables robust performance at wet conditions, membrane dry-out occurs at dry conditions

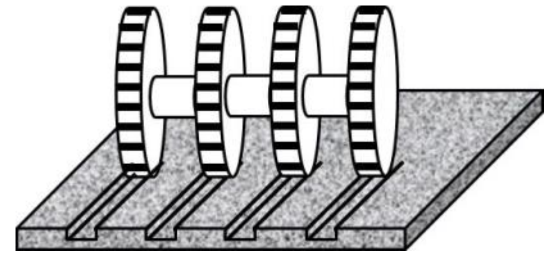


With saturated outlets, performance is relatively consistent and ohmic resistance is comparable. At 40% RH inlets and dryer (sub saturated outlets), losses at high current density are directly related to membrane drying. It should be noted that numerous parameters can be adjusted in the porous ribs to improve dry performance if desired. This can include hydrophilic treatments, decreased porosity, or increased rib width.

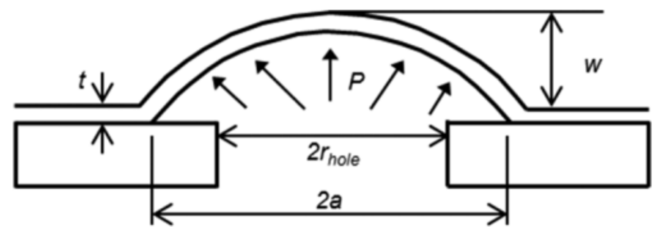
Collaboration

- **SUNY Alfred State Energy Storage and Conversion Lab**
  - **Relationship:** Facility Use Agreement
  - **Extent:** assembly, characterization
- **Fuel Cell OEMs and Suppliers**
  - **Relationship:** customers and development partners
  - **Extent:** specifications for next-gen PEMFCs (no cost)

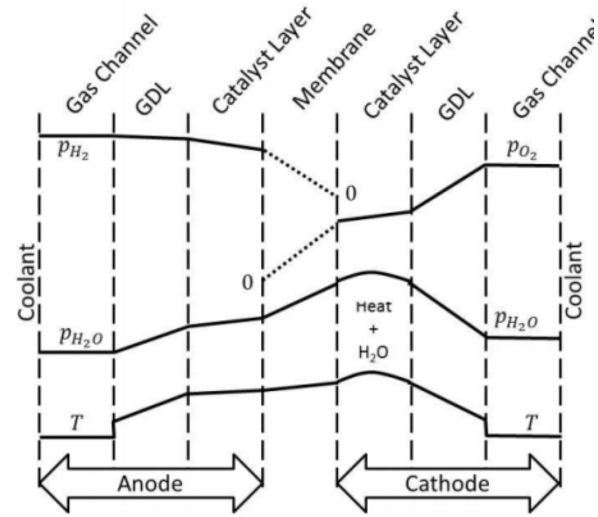
Remaining Challenges and Barriers



- **GDL with Channels Manufacturing**
  - **Currently developing a parallel blade demonstration fixture and engaging carbon fiber manufacturers (wet-laid forms, fiber tow lands)**



- **Material Compatibility and Durability**
  - **Thermal/pressure cycling and contamination studies required**



- **Performance Optimization**
  - **Thermal resistance of GDL critical, asymmetric configurations, hydrophilic lands**

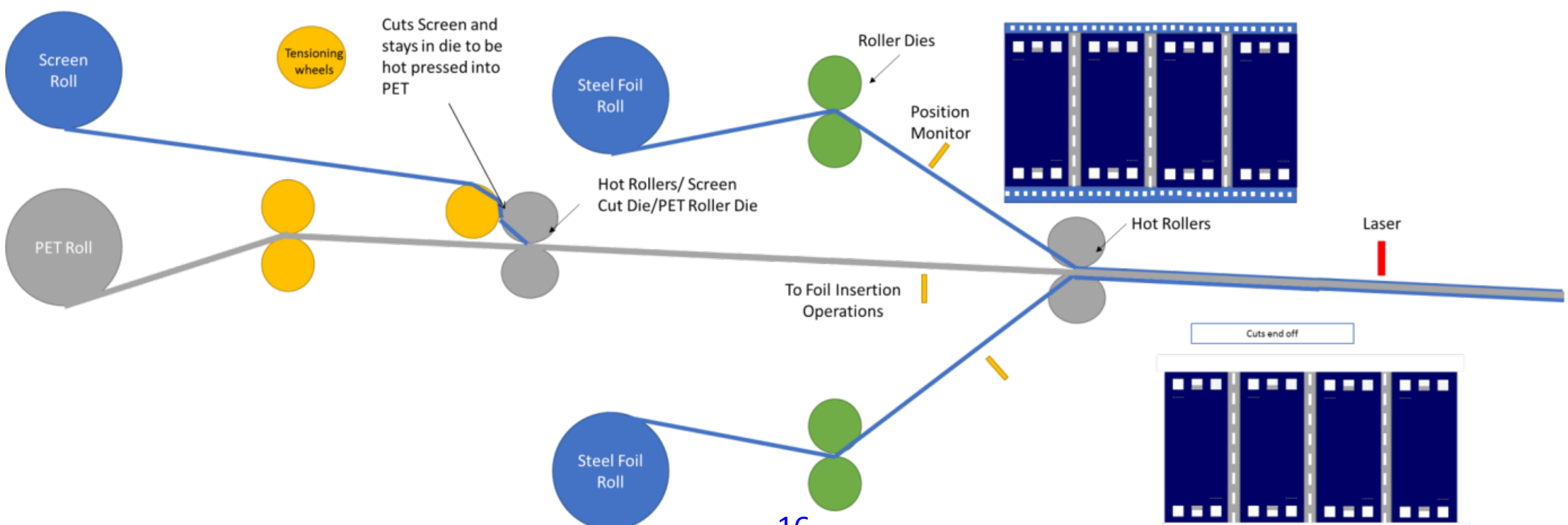
Future Work

In Process

- Evaluation of corrugated architecture
  - Thermal cycling and performance experiments
- Laminated design iterations
  - Tunnel structures, plastic frame material, coolant layer
  - Additional performance testing
- Reporting
  - Peer-reviewed publications

Next Phase of Development

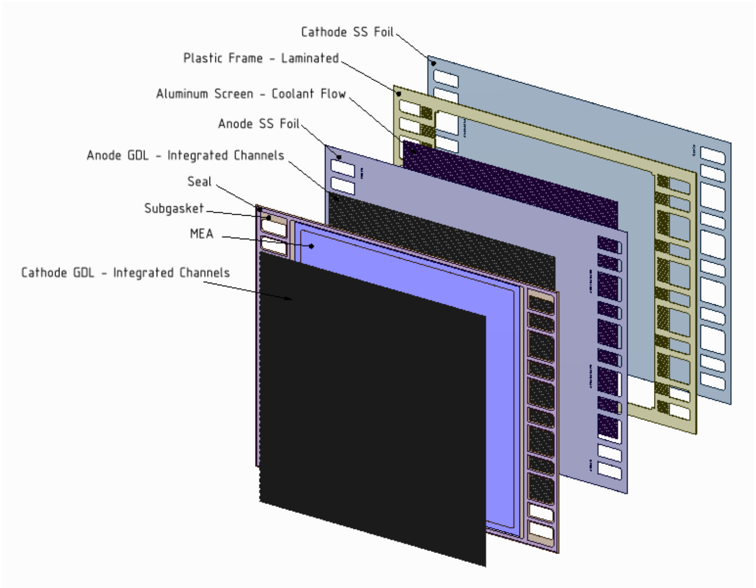
- Prototype of large active area
  - Single cell testing
- Manufacturing equipment
  - Demonstration level R2R plate manufacturing
    - Gold coated SS, die cutting, coolant layer, GDL with channels, UEA with gasket
- Short Stack testing
  - Third party validation

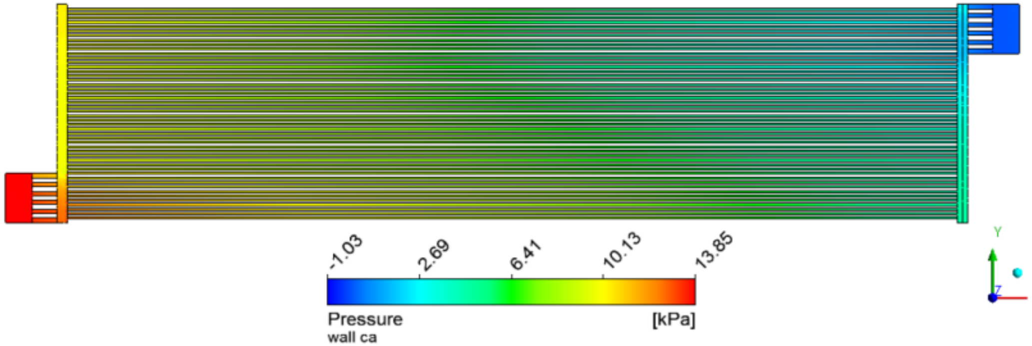


Any proposed future work is subject to change based on funding levels

Technology Transfer Activities

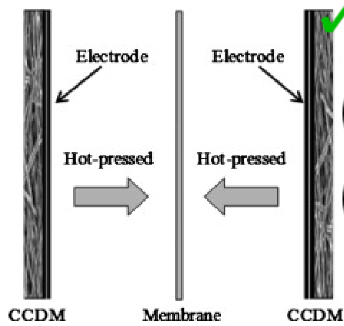
- **Patents**
  - **Disclosed through iEdision**
  - **Provisionals filed**
  - **Non-provisional applications complete**
- **Future Development Path**
  - **Exploring tech transfer with multiple potential end-users**
- **Future Funding**
  - **No additional funding requested at this time**

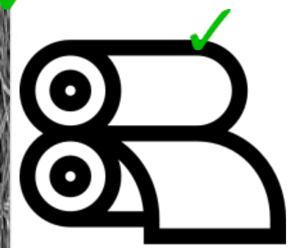


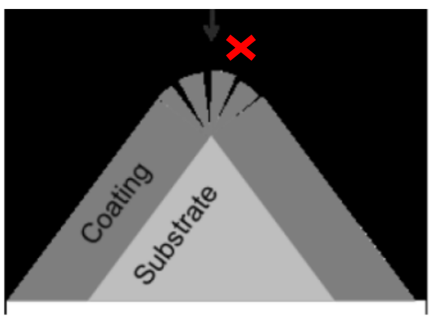


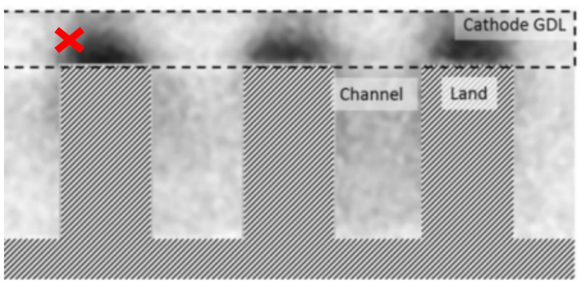
Summary

- Two BPP concepts considered to enable R2R UEA manufacturing
  - Reduced cost and mass relative to stamped SS BPPs
  - Minimized channel span (< 0.4 mm) reduces GDL stiffness requirements
  - Enables lower cost carbon fiber substrates (acrylic precursor, lower carbonization temperature)
  - Prototypes capture all critical elements of BPP (elastomer seals, coolant layer, headers, tunnels, etc.)
- Laminated BPP with channels in the GDL selected as primary path
  - Exceeds DOE 2020 mass target by 2x (0.16 kg/kW_{net}) and approaches cost target ($4.80 $\$/kW_{net}$, 40 % reduction relative to 3 mil stamped BPPs)
  - 1 mil SS foil utilized, no forming reduces requirements for physical and tribological properties of plate coatings
  - Prototyping of GDL channels demonstrated and manufacturing processes being investigated
  - Sealing architecture validated at small-scale, revised tunnel structure improved pressure drop
  - Porous lands provide stable performance under wet and dry operating conditions
  - LAA design with multiple headers can provide even flow distribution in channels







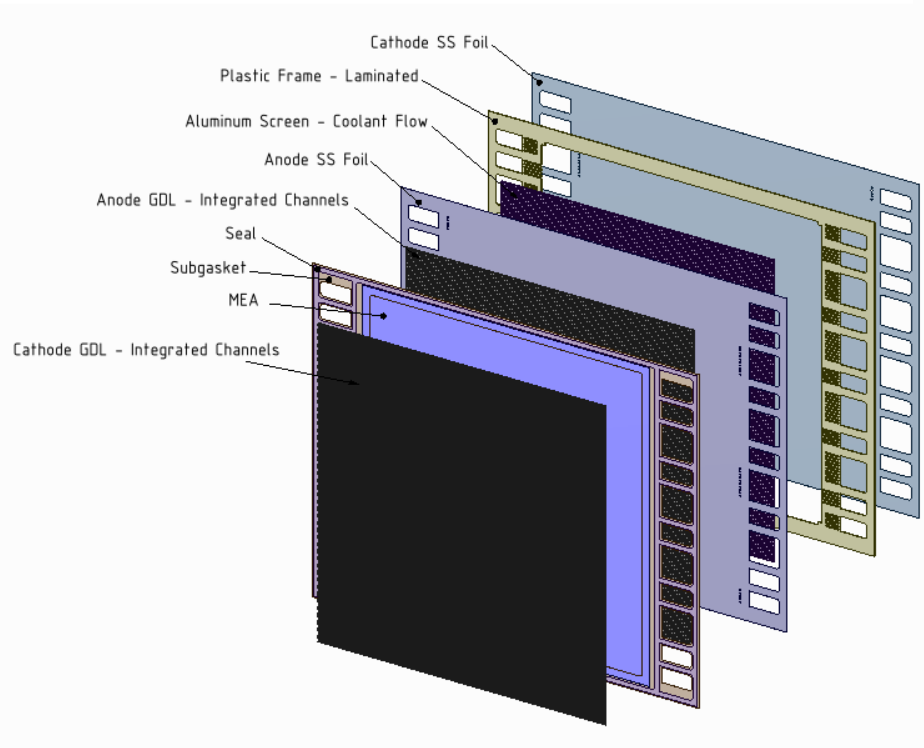


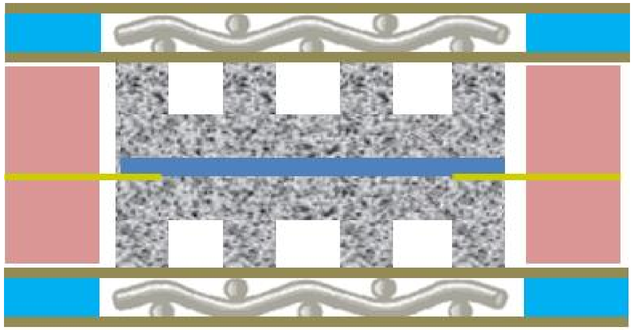
Technical Back-Up Slides

Technical Back-Up: Full Scale BBP Architectures

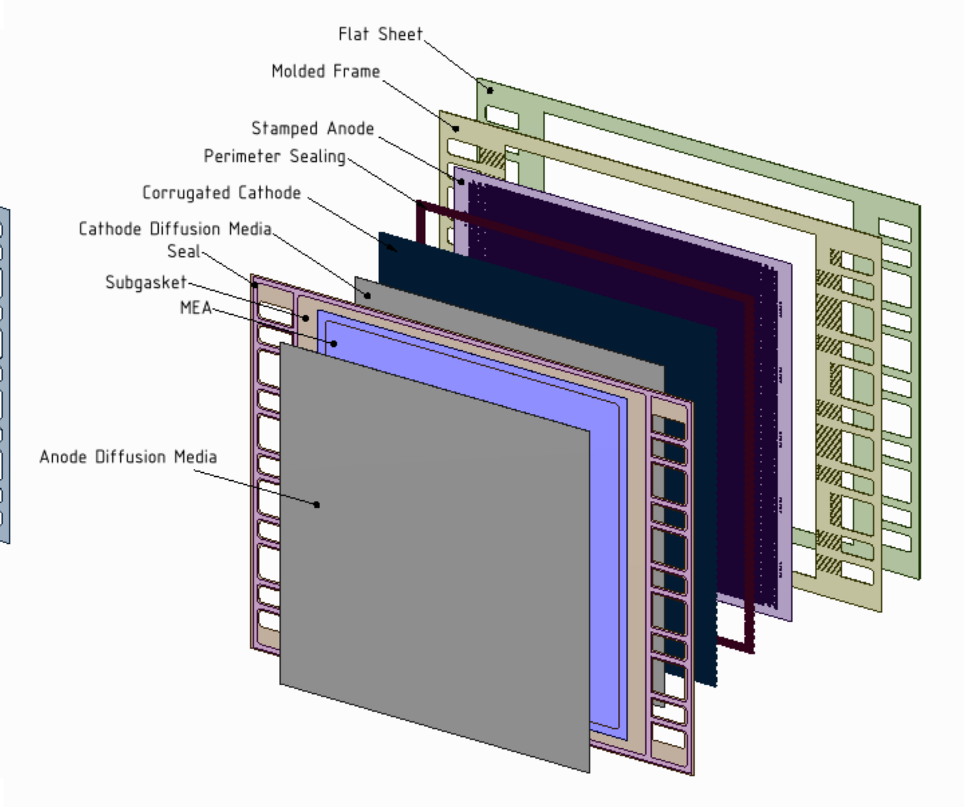
Full-scale plates designed for cost and mass modeling, include geometry for flow distribution and continuous manufacturing

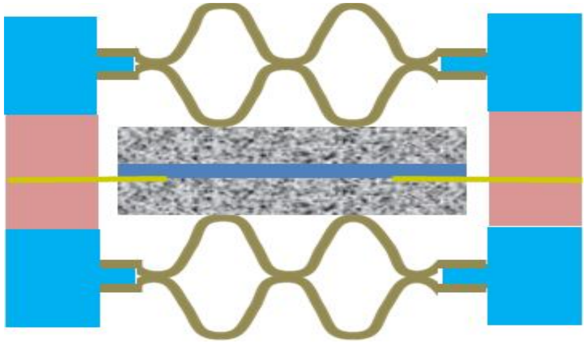
Laminate Structure with Integrated GDL Channels





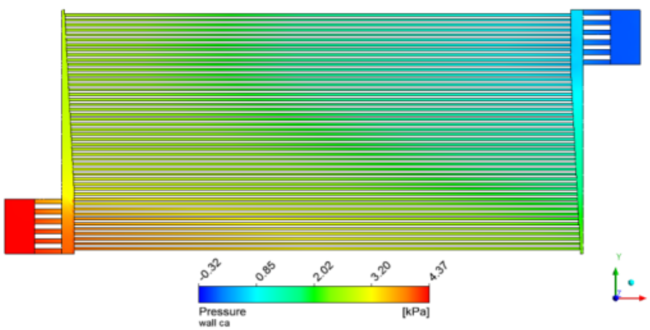
Corrugated Flow Field with Plastic Fran

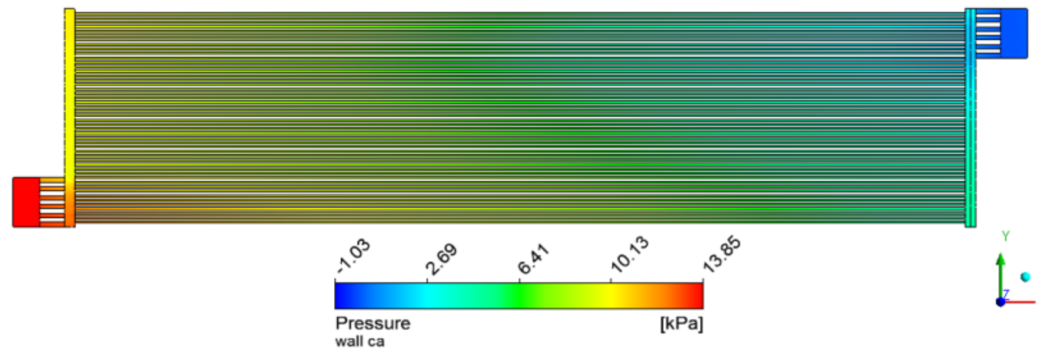


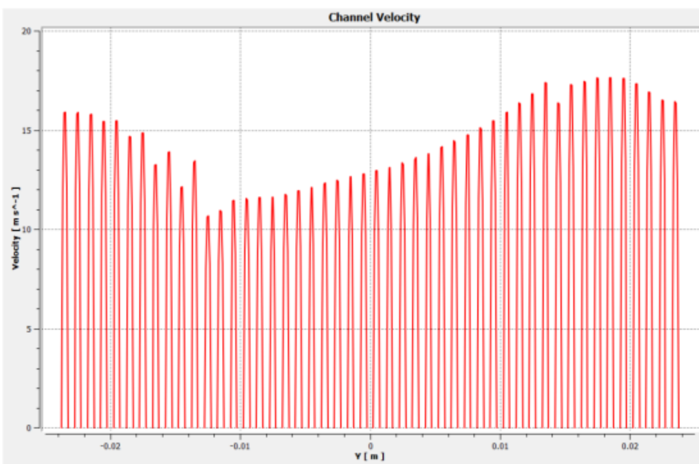


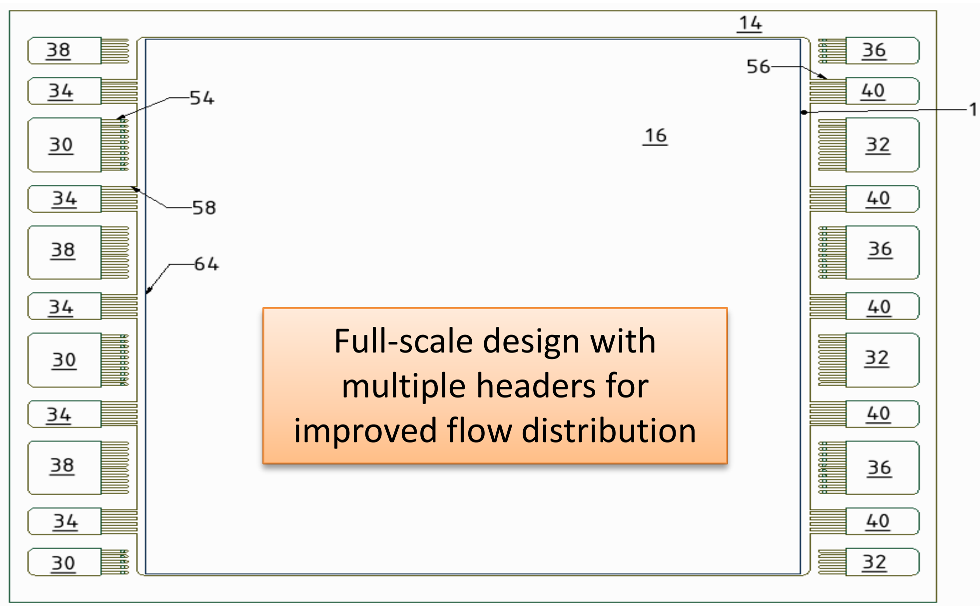
Technical Back-Up: Flow and Pressure Drop for Large Active Area

Full-scale designs utilize multiple headers to improve flow distribution







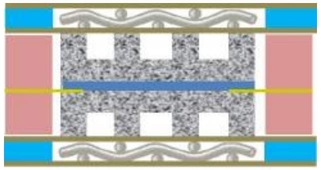


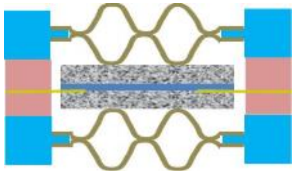
Key Results

1. The pressure drop was about 4 kPa for the test size cell and about 14 kPa for the full size cell which should be acceptable for stability and system operation.
2. The channel velocity distribution was about +/-23% for all of the configurations which is larger than desirable.
   a. The full scale design will need to use multiple headers to feed the full plate width due to the limited size of the feed channel.

Technical Back-Up: Design Concerns and Key Challenges

Summary of design risks used to select laminated concept for development





Issue	Laminated with GDL Channels	Corrugated with Plastic Frame
Thermal Expansion	Low – laminated frame constrained with gasket load, room for expansion tolerance	High – plastic/metal interface adhesive critical, unproven
Material compatibility (adhesives, plastics)	Low – minimal reactant contact with plastic, low cost PET currently utilized, bonding is not critical	Moderate – chemically compatible plastics have higher cost and require high mold pressure
Maturity of Manufacturing Processes	Moderate – laminating processes well established, GDL channel forming needs development, wet-laid forming unproven	Low – all processes established, molding thickness tolerance will add cost, sealant application slow, corrugation tool wear
Cell Repeat Distance	Moderate – 1.4 mm minimum	Low – 1.2 mm minimum but requires corrugation tool development
Tunnel and Feed Pressure Drop	Low – thin foil deformation under gasket load, flow distribution in feed region	Low – tunnel dimensions in plastic frame are constrained (small), flow distribution in feed region
Final Cost	Low – assumptions must be validated	High – additional manufacturing steps

Technical Back-Up: Parameters Used for Cost and Mass Modeling

Cost model developed using technical cost modeling concepts, replicated DOE baseline BPP costs[1, 2]

	Cost Model Parameters	Mass Model Parameters
System Size	80 kW_{net}	80 kW_{net}
Cell Count	379	379
Active Area	312 cm^2	312 cm^2
Total Area	500 cm^2	500 cm^2
Stainless Steel	316SS, $11.10/kg	8 g/cm^3
Gold Coating (10 nm)	$0.27 / plate	n/a
Forming Machine and Tool Cap Cost	$2.1M (progressive stamp) $662K (die)	n/a
Laminate Cutting Press and Die Cap Cost	$89K (cutting press) $100K (cutting die)	n/a
Laminate	15 mil, adhesive coated PET at $1.67/$m^2$	1.4 g/cm^3
Coolant Layer Cutting Press and Die Cap Cost	$89K (cutting press) $50K (cutting die)	n/a
Coolant Layer	Al Screen, $2.00/$m^2$	2.7 g/cm^3, 60% open
150 μm GDL	$5.56/$m^2$	2.3 g/cm^3, 80% open
GDL Channel Cutter Cap Cost	$200K	n/a
500 μm GDL	$7.59/$m^2$	2.3 g/cm^3, 80% open
R2R Laminate Assembly	$300K	n/a
Plate Mold Cap Cost	$300K	n/a
PEI Plate Frames	$1.50 / plate	1.3 g/cm^3
Adhesive Dispensing Equip. Cap Cost	$250K	n/a
Plastic Frame Assembly	$300K	n/a

[1]Brian D. James et. al, "Mass Production Cost Estimation of Direct H2 PEM Fuel Cell Systems for Transportation Applications: 2016 Update" (link), September 2016
[2]Brian D. James et. al, "Bipolar Plate Cost and Issues at High Production Rate" (link), February 2017

Technical Back-Up: Manufacturing Sequence Considered in Cost Model

Only proven and high throughput methods were considered