Digital Fabrication of Catalyst Coated Membranes

Peter C. Rieke
Silas A. Towne
Pacific Northwest National Laboratory

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Project ID
MF_07_Rieke

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Overview

Timeline

- Project start date: 2007
- Project end date: 2009
- Percent complete:100%

Barriers

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

Budget

- **Total: $ 315K**
- **FY07: $ 40K**
- **FY08: $ 200K**
- **FY09: $ 75K**

Partners

- Lead Organization:
  - Pacific Northwest National Laboratory
- Collaborators
  - Hewlett-Packard
  - General Motors
  - ImTech

Relevance-Objectives

- Demonstrate Basic Process Steps in Digital Fabrication of CCMs & MEAs
  - Ink formulation and delivery with industry standard print heads
  - Catalyst layer quality and mechanical durability
  - Electrochemical utility
- Define Advantages & Disadvantages of Digital Fabrication
  - Reduce large run MEA fabrication cost
  - Versatile and agile process line
  - Integration of new technology
- Identify Unique Advantages of Digitally Fabricated CCM
  - Z gradation in composition – pore, catalyst, ionomer distribution
  - Variable catalyst loading in XY plane.

Relevance-Barriers

- **A.** Lack of High-Volume Membrane Electrode Assembly (MEA) Processes
  - Transition from hand lay-up to short-run automated fabrication to dedicated production line.
  - Design of agile and versatile production methods
    - Accommodate small and large volume runs
    - Accommodate substrate, size and catalyst composition needs.
    - Rapidly integrate R&D advances in MEA fabrication
  - Optimization of dedicated single product production lines
- **B.** Manual Stack Assembly
  - Integration of CCM fabrication into automated assembly line
- **F.** Low Levels of Quality Control and Inflexible Processes
  - Adaptation of print industry quality control process to MEA fabrication

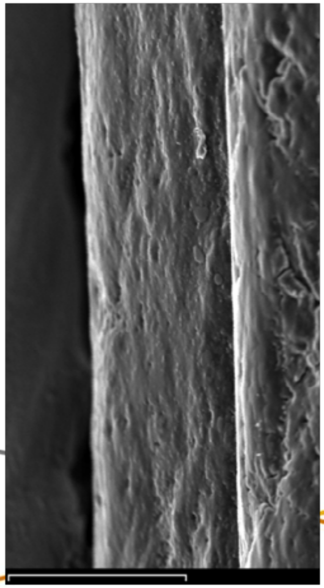
Approach

- Demonstrate feasibility of digital fabrication
  - Ink development
  - Printing demonstration
  - Validate Electrochemical Performance
  - **Milestone: CCMs successfully fabricated and tested in single cells**
- Characterize CCM printing process
  - Evaluate substrate handling methods
  - Print layer thickness, adhesion, uniformity
  - Control catalyst layer composition in Z and XY directions
  - Demonstrate large area CCM fabrication
  - On-line, real-time quality control
  - **Milestone: 4 of 5 print processes characterized**
- Evaluate implications of DF on process line design & economics
  - Changes in process line steps
  - Process line throughput needs.
  - Integration with stack and system assembly steps
  - Identify potential process cost saving and research needs
  - **Milestone: Process line design qualitatively outlined**

Technical Progress

Demonstrate feasibility of digital fabrication

- Ink compositions developed with Pt supported on carbon and PFSA ionomer.
- Dispersion methods developed resulting in ~5 day stability
- HP's TIPS system used to test Ink – Print head compatibility.
  - No large particles
  - No aggregation of particles.
  - Humectants need to prevent nozzle clogging

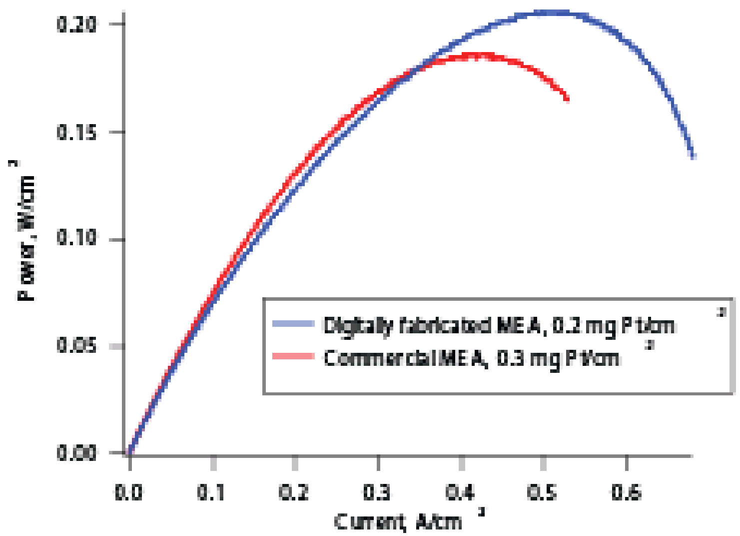


- 10 cm2 CCM fabricated with HP printing equipment
- Very good adhesion of catalyst layer on Nafion®.
- Good uniformity in Z direction
- Uniformity in XY plane dependent on print conditions
- Membrane and Ionomer in H+ form.
- No hot press required.
- Significant processing advantage

Technical Progress

Demonstrate feasibility of digital fabrication (Cont.)

- Electrochemical Viability
  - Digitally fabricated CCM slightly better than commercial CCMs
  - Improvement needed in cell design and operation
  - DF does not adversely impact electrochemical properties



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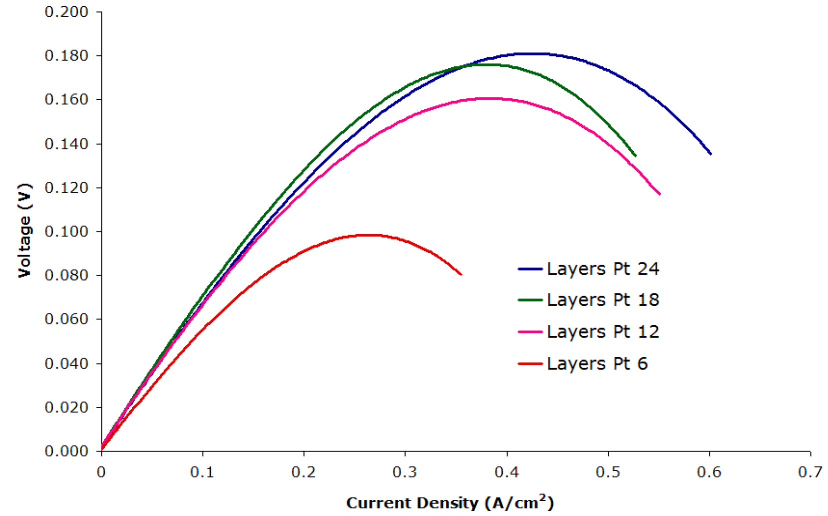
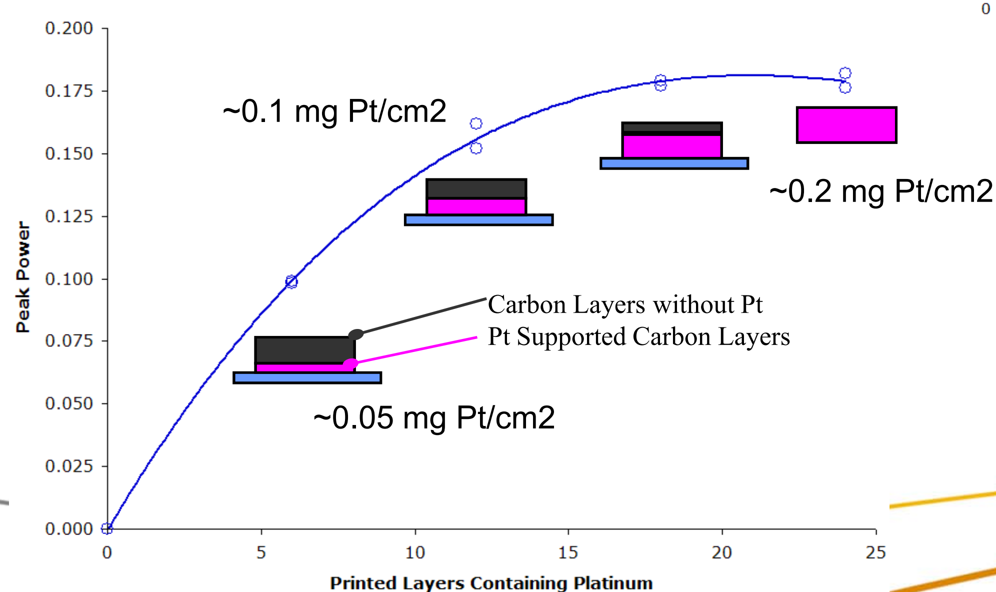
Technical Progress

Characterize CCM printing process

.1 mg Pt loading ~ 90% peak power as 0.2 mg Pt loading





DoD fabrication allows precise optimization of Pt distribution leading to low Pt loading and reduced MEA costs.

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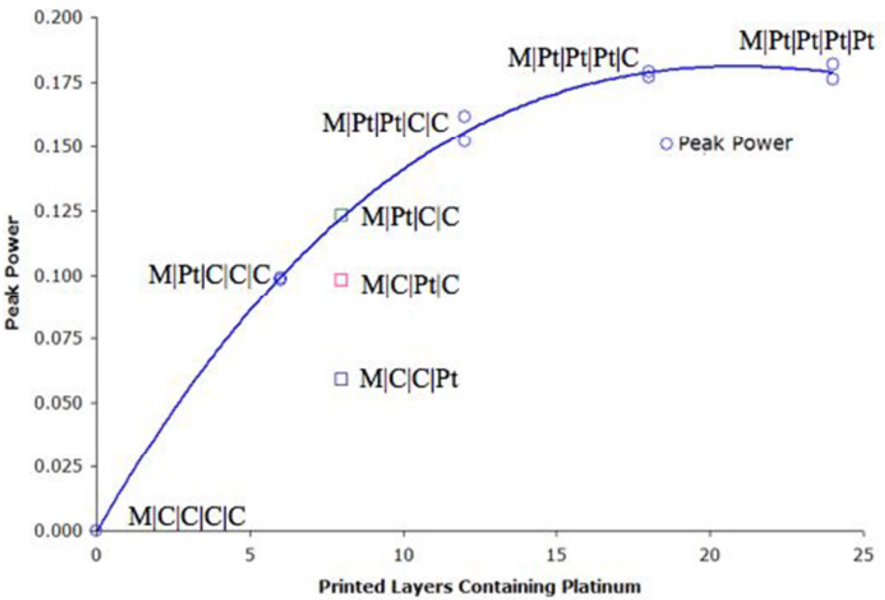
Technical Progress

Characterize CCM printing process (Cont.)

- Electrode structure and composition varied using different inks
- Pt supported on XC-72 and XC-72 printed in various layer.
- Pt near the membrane interface is most active.



Digital Fabrication is a unique tool for building new electrode architectures

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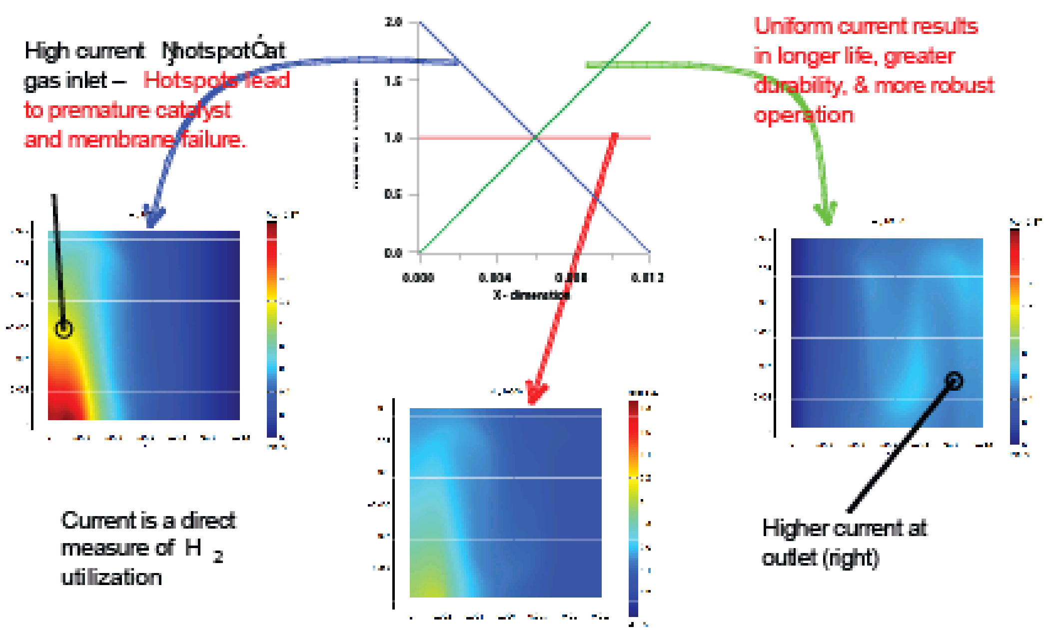
Technical Progress
Characterize CCM printing process (Cont.)

- Finite Element Modeling
- Gradation of catalyst loading impacts current distribution
- Total current not significantly different

Color Scale : Blue 0.00 A/cm² Red 1.87 A/cm²



Catalyst stability, water distribution, thermal gradients may be controlled through optimization of catalyst distribution.

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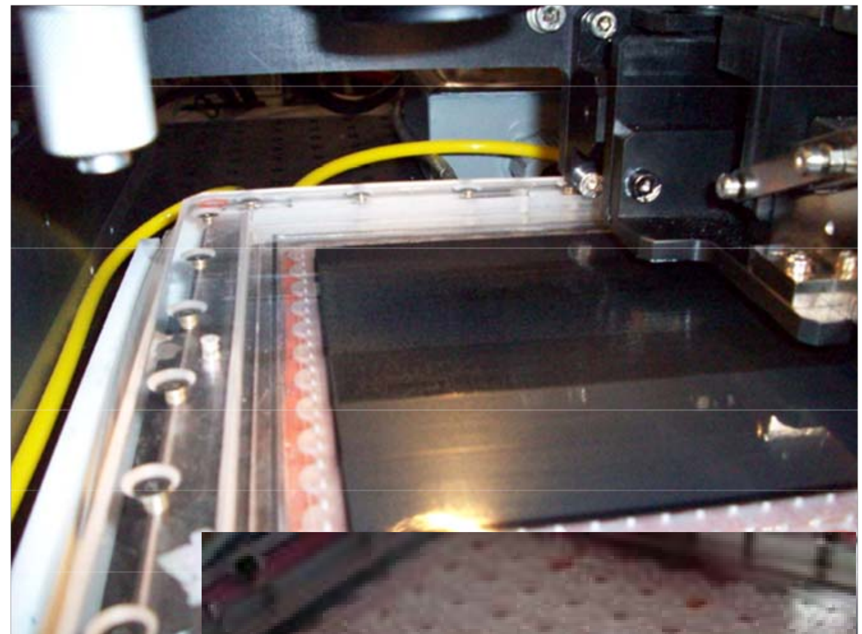
Technical Progress

Characterize CCM printing process (Cont.)

- Demonstrated Printing on Large Area 7 mil membrane
  - 320 cm^2 membrane
  - 180 cm^2 print area
- Print head and fixture collision prevent full area printing
- Water in ink did not significantly swell membrane
- Printing of almost any size & shape should be feasible
- 2 mil membrane cannot withstand tensile forces developed during fixturing



Approximately 20-30 printers required to print CCMs for 500,000 vehicles/year with 70 kW power plants

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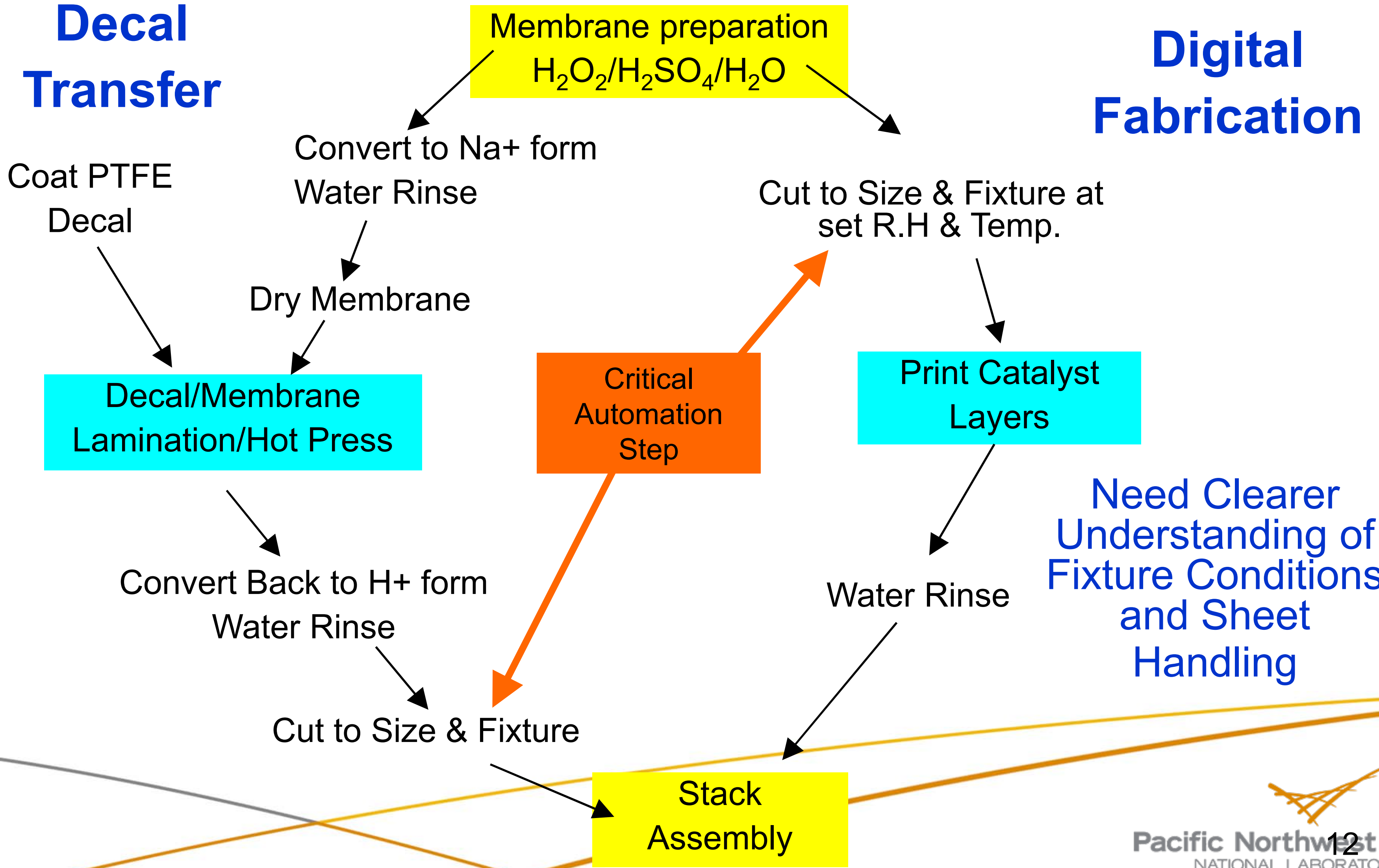
Technical Progress

DF process line design



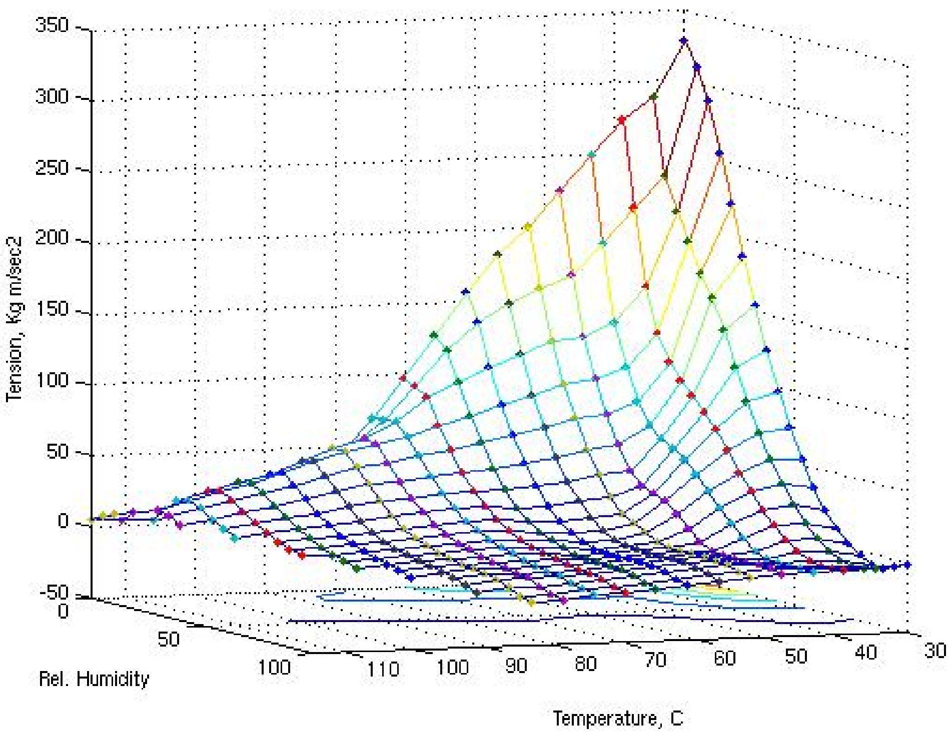
Technical Progress

DF Process Line design (Cont.)

$$E = \frac{(F / A)}{(dl_E / l^0)}$$

$$l = l^0 + dl_E = l^* + dl_S + dl_E$$

- Dimensional changes due to swelling and elasticity
- Proper choice of temperature and humidity when fixing membrane can reduce stresses during printing and cell assembly.



F. Bauer, S. Denneler, M. Willert-Porada, *Influence of Temperature and Humidity on the Mechanical Properties of Nafion® 117 Polymer Electrolyte Membrane,* J. Polymer Science, B, 43 (2005) 786.

Collaborations

- External Collaborations
  - Hewlett-Packard.
    - PNNL is a beta test site for the TIPS printing system. TIPS is used to develop inks.
    - HP also opened their laboratory and allowed us to use their state-of-the-art printing systems.
    - Manufacturing Proposal Partner
  - General Motors
    - Detailed discussions of advantages and limitation of digital fabrication of Catalyst Coated Membranes
    - Manufacturing Proposal Partner
  - ImTech
    - Preliminary design of a print facility for CCM fabrication

Proposed Future Work

- **Process Analysis**
  - Comparison of thermal, piezo and continuous print head technologies
  - Procedures and conditions for handling of PFSA membrane substrate during the printing
- **Process Design Feasibility And Scalability**
  - Design and test of a highly versatile laboratory-scale print-facility
  - Development of inks compatible with the fuel-cell fabrication process that will meet the cell and stack performance criteria
  - Detailed examination of the behavior of ink formulas in print heads and optimization of the print head operating parameters
  - Pre-/post-processing and scalability analysis and integration of the DF process into existing cell, stack and power plant assembly lines.
- **Product Demonstration And Qualification**
  - Screening of electrochemical properties in small (~10 cm2) cell
  - Single cell testing & electrochemical characterization of medium (40-50 cm2) and large scale (>300 cm2
- **Novel CCM Architectures**
  - Optimization of the platinum content and XY & Z placement for enhanced durability and electrochemical performance.
- **Pilot Plant Design And Cost Analysis**
  - Produce design criteria and specifications for a pilot plant facility
  - Quantitatively compare fabrication costs of DF with existing current technology.

Note: Proposed work will be conducted under a new program with contracts under negotiation with DOE

Mandatory Summary Slide

- Digital Fabrication Simplifies Fabrication Process
  - No hot press or lamination steps
  - Fewer chemical transformations
  - On-Demand fabrication
    - No storage of CCM
    - Match of assembly and CCM fabrication through put
- Electrochemical Performance Comparable to Commercial MEAs
  - Better single cell test stand and procedures have been developed
- DF unique in ability to optimize catalyst layer architecture
  - Reduce platinum loading
  - Enhanced durability
  - Better inherent water management