2012 DOE Hydrogen and Fuel Cells

Program Review

High Speed, Low Cost Fabrication of Gas Diffusion Electrodes for Membrane Electrode Assemblies

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MN007

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Overview

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Timeline

- Start: 1 July 2009
- End*: 30 June 2013
- 75% complete

(* no cost extension)

Barriers

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

Budget

- Total project funding: $3.06M
  - DOE share: $1.99M
  - Contractor share: $1.07M
- Fed. funding received in FY11: $302K
- Est. Fed. funding for FY12: $250K

Partners

- Case Western Reserve University
- X-Ray Optical Systems

Membrane Electrode Assembly (MEA)

5 Layer Assembly

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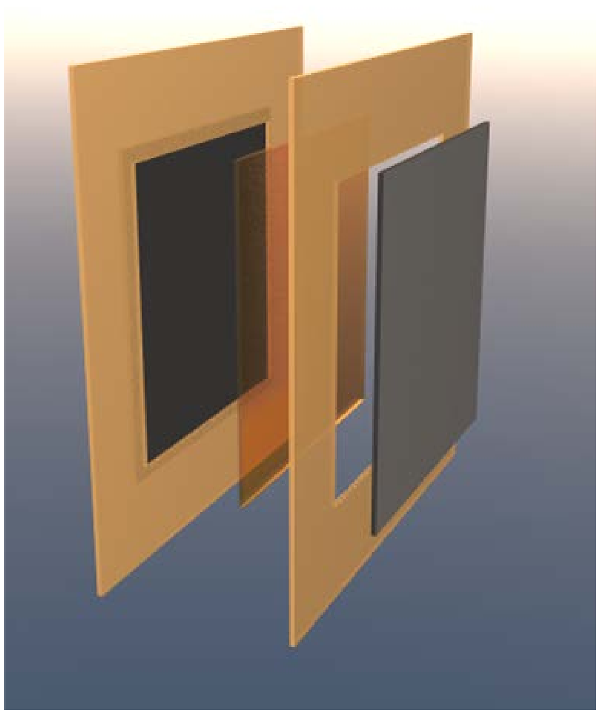

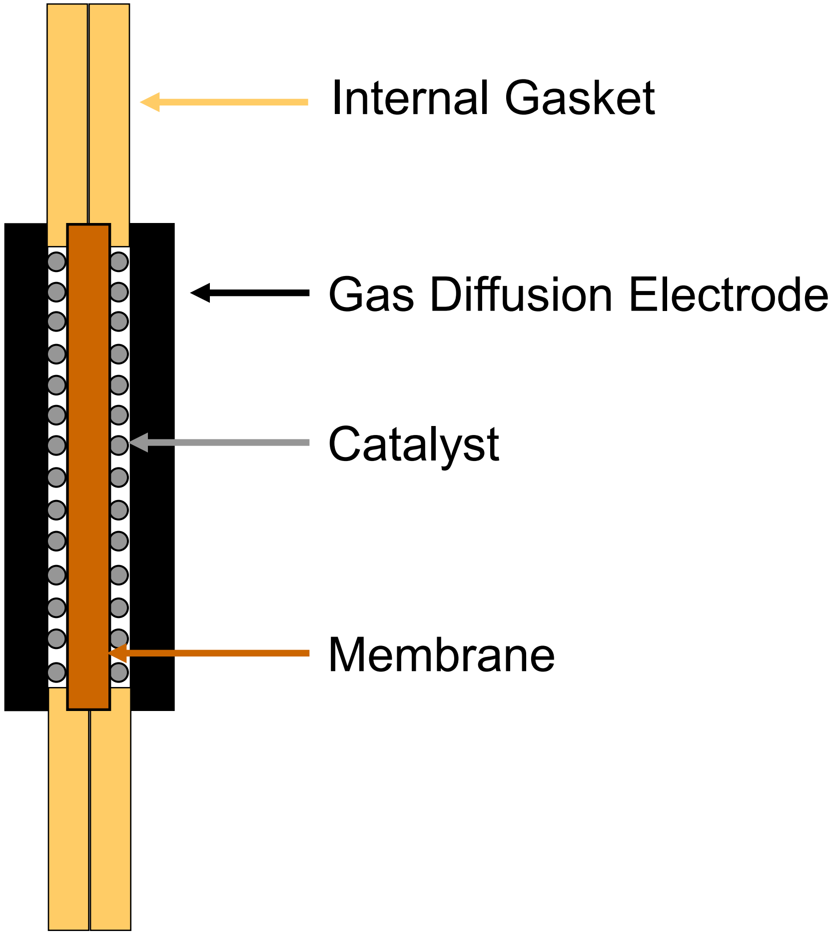

Relevance

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Overall Objective

- Reduce cost in fabricating gas diffusion electrodes (GDEs)
    - Focus on GDEs used for combined heat and power generation (CHP).
- Relate manufacturing variations to actual fuel cell performance in order to establish a cost effective product specification within six-sigma guidelines.
- Develop advanced quality control methods to guide realization of these two objectives.

Objective(s) this reporting period

- 3X throughput increase on full width/length cloth
- Scope focus: expand efforts on non-woven paper

Directly Addresses Barriers

- (A) Lack of High Volume Membrane Electrode Assembly (MEA) Processes
    - High speed or throughput coating
- (F) Low Levels of Quality Control and Inflexible Processes.
    - On-line Pt measurement.

Addresses key DOE targets

Targets: 1–10 kW_e Residential CHP FC Operating on Natural Gas

	2008 Status	2012	2015	2020
Electrical efficiency at rated power	34%	40%	42.5%	45%
CHP energy efficiency	80%	85%	87.5%	90%
Factory cost* per kW	$750	$650	$550	$450

*Cost includes materials and labor costs to produce 50k/yr stacks

Approach: Milestones and Go/No Go

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Tools → Build → Tools → Test

	Tools	Build	Test
Task	**Task 1**: On-line QC to guide the process by Y1 **Task 2**: Model impact of defects by Y1	**Task 3**: full length coating by Y2 **Task 4**: Increase line speed by Y2 (go/no go June 2011) **Task 5**: Full cloth width roll by Y2/Y3; paper>best cloth total cost	Performance Defects/Uniformity Relate defects to performance
Milestone	**T1**: On-line Pt measurement, on-roll porosity measurement **T2**: Verify Model, calculate defect limits	**T3**: >240 lin m **T4**: 2X throughput increase (go/no go): 3X final goal **T5**: full width (>100 cm) & length at 3X throughput: paper 30% lower total cost over cloth	**Main Concept** Use advanced dispersion and ink formulations to make aqueous solid - binder suspensions compatible
Status	**T1**: complete, modified for full width cloth. On-roll porosity canceled due to vendor failure **T2**: Base model established	**T3**: complete **T4**: go/no go met. >2X throughput **T5**: full width/length cloth >3X throughput. Paper at pilot scale	

Technical Accomplishments and Progress

Tasks 3-4-5: **Inks** for Full Length & Width Roll Coating, 2X speed

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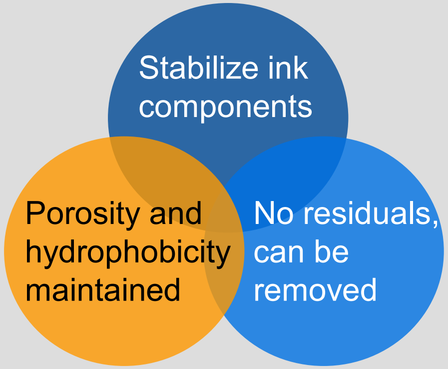
- **Accomplishments:** Extended ink formulations to stabilizing anode catalyst suspensions that have been subject to very high energy dispersion. Scaled microporous layer (MPL) ink 15-fold. Scaled all catalyst inks 10-fold.
- **Key Challenge:** MPL ink scale up caused severe bubble formation, which lead to variable viscosities. Solved through additive and process modification.



Ink additive selection rules combined with high energy dispersion led to success

	Cost decrease vs. benchmark	Capacity increase vs. benchmark
MPL	37%	3.0X
Anode	31%	2.1X
Cathode	40%	2.4X

Break-through in ink-making increased capacity, decreased labor content

Technical Accomplishments and Progress

Tasks 3-4-5: **Coating** Full Length & Width Roll, 3X speed

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- **Accomplishments:** Quality gains preserved for length>300l.m, width 1.17m
- **Key Challenge:** Final product thinner than benchmark. Re-engineered MPL architecture to compensate for different packing densities

Metric	Benchmark-start	This Program
Agglomerates (avg. over roll)	$18/m^2$	$1.6/m^2$
Pt variation (via on-line XRF, roll average)	+/- 2 gm Pt/m^2	+/-0.4 gm Pt/m^2
Performance		
$0.2 A/cm^2$ H_2/air, $45 cm^2$ test cell, 160 °C	0.657V	0.683V
$0.5 A/cm^2$ H_2/air, $45 cm^2$ test cell, 160 °C	0.573V	0.598V
$0.2 A/cm^2$, 1.4/5 Reformate (71% H_2, 27% CO_2, 2% CO)/Air, $45 cm^2$ test cell, 180°C	0.668V	0.689V
$0.5 A/cm^2$, 1.4/5 Reformate (71% H_2, 27% CO_2, 2% CO)/Air, $45 cm^2$ test cell, 180°C	0.571V	0.589V
Note: reformate running at 5X air stoichiometry, 180°C		

Significant improvement in quality

Technical Accomplishments and Progress

Task 4: Key Metrics for coating throughput

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- **Accomplishments:** Exceeded both go/no go of 2X and program goal of 3X throughput. Effective throughput boost by reducing number of application passes.
- **Key Challenge:** Applicator settings with new inks different than benchmark. Significant optimization needed.

Throughput metric *Normalized to Benchmark*	**Benchmark (at program start)**	**This Program (to date)**
Average line speed, lin.m/min Sum $(S_1, S_2, \ldots S_n)$/number of applications (n), where S=coating rate of each step	1	1.16
Highest single line speed, one pass (lin. m/min)	1	1.67
Coating throughput, m^2 GDE/hr	**1**	**3.94**
Cost Savings (in labor hrs)		75%

Coating throughput, m^2 GDE/hr is most relevant metric

Technical Accomplishments and Progress
Task 5: Non-woven/paper substrates

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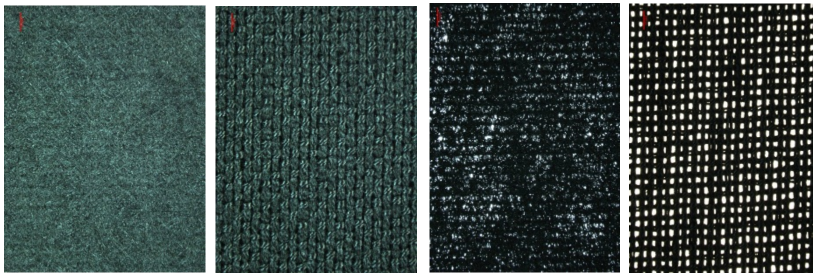
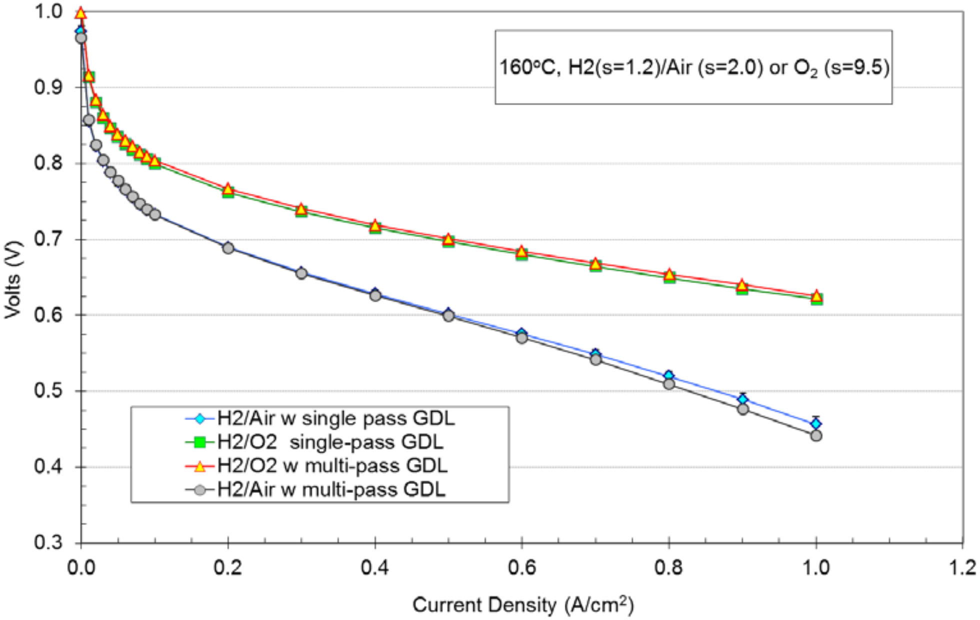
- **Status:** 2011 AMR demonstrated production machine scale MPL fabrication. 2011/12 focus was on substantial reduction of application steps for MPL and catalyst layer
- **Approach**: Increase viscosity of ink without loss of stability. Investigate new application process to handle higher viscosity inks
- **Results**: Demonstrated potential for single-pass MPL.



Non-woven | Woven | Non-woven Light-box | Woven Light-box



Comparison of single-pass to multi-pass MPL

Target for non-woven is to reduce cost 30% over best woven configuration

Collaborations

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Task 2 Defects

- **NREL – Michael Ulsh**
  - Providing GDEs with defects for advanced defect detection

Tasks 3-4-5 (higher throughput GDEs)

- **ClearEdge Power Systems** – Julia Song, Ph.D.
  - Validated materials for use in µCHP applications at stack scale
  - Valuable feedback on material thickness specification
  - Confirmed performance gain found at subscale testing with full stacks

These collaborations were initiated outside the original team tasks in this DOE program

Proposed Future Work

Over last year of project

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- **Task 5: Demonstrate non-woven platform reducing total cost by additional 30% (materials + labor) over best woven scenario**
  - Scale MPL to production level
  - Develop anode/cathode catalyst inks and application process that approach two or less coating passes

Summary Slide

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- Reduced total GDE labor costs by ~75% due to new high energy dispersion with advanced formulations.
- Achieved June 2011 go/no go (2X throughput increase).
- Exceeded program goal (3X throughput increase at full width) to 4X improvement (by June 2012)
- Demonstrated proof of principle for one step MPL coating on non-woven

Platform	Improved Ink	Coating Pilot	Coating Production 1/2 width	Sintering	Coating Production full width+throughput
Cloth					
MPL	37%	>55%	>55%		
Cathode	40%	>40%	>40%	This period (>50%)	
Anode	31%	>40%	This period (>50%)		
Paper					
MPL					
Cathode					
Anode					
	← Phase I →				Phase II

% indicates reduction in labor-hours.
No benchmark for paper but have achieved similar or greater results compared to cloth

Technical Back-Up Slides

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Background on high temperature MEAs

Benefits of HT PEM technology: Reduction of system complexity

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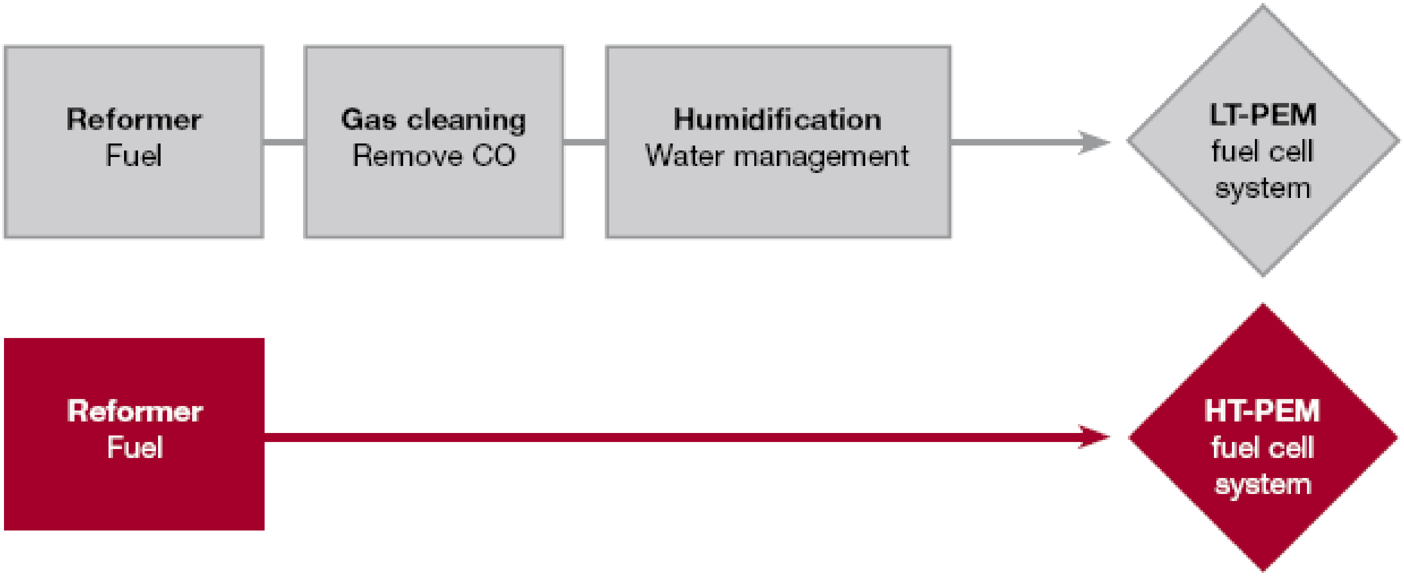

High temperature PEM technology allows to simplify the fuel cell system, especially in the case of reformate feed.

MEA-components

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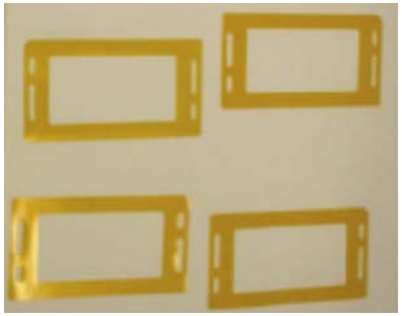
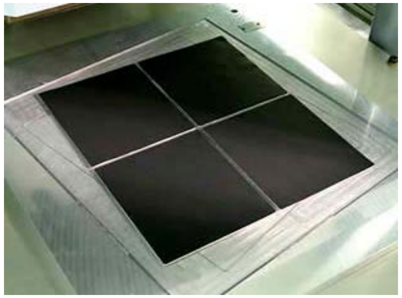


2 x Subgasket

- Polyimide



1 x Anode / 1 x Cathode

- Gas diffusion electrode (GDE) with catalyst coating
- Catalyst is coated on top of microporous layer

1 x Membrane

- PBI based and charged with phosphoric acid
- Catalyst is not coated on the membrane

Celtec-P MEA Advantages

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Technology

- Broad operating temperature window: 120 – 180 °C
- No humidification necessary
- High tolerance to CO and H_2S
- No water management system necessary for exhaust

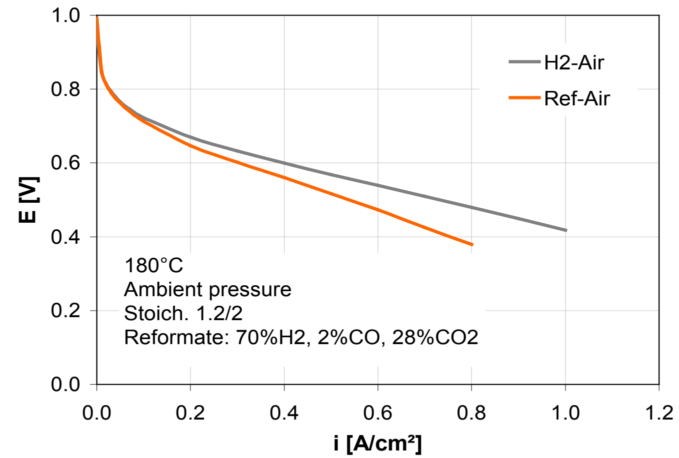
Materials

- Membrane with Polybenzimidazole (PBI) and Phosphoric Acid (low cost)
- Gas diffusion electrodes (roll to roll processing)

Applications- end use

- Simplified overall FC system

Performance under reformate gas conditions



Unique CO-tolerance