

2006 DOE Hydrogen Program Review *Advanced Manufacturing Technologies for Renewable Energy Applications – an DoE/NCMS Partnership*

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This presentation does not contain any proprietary or confidential information



Project ID # CCP 1

Overview

- **Timeline**
 - Project start date
October 2004
 - Project end date
March 2007
 - 50% Percent complete
- **Budget**
 - Total - \$6,179,040
 - DOE - \$4,943,232
 - In-Kind -
\$1,235,808
 - Funding received in
FY04 - \$2,943,232
FY05 - \$2,000,000
- **Barriers**
 - Covered on next slide
- **Partners**
 - National Renewable
Energy Laboratory
 - Listed on project
descriptions

Technical Barriers and Targets from the HFCIT Program Multi-year Program Plan

- **Technical Barriers**

 - Fuel Cell Components

 - O. Stack Material and Manufacturing Cost

 - P. Durability

 - Fuel- Flexible Fuel Processors

 - N. Cost

 - Hydrogen Storage Systems

 - A. Cost

 - B. Weight and Volume

 - D. Durability

- **Technical Targets**

 - Costs:** Range from \$10/kWe for fuel- flexible systems to \$45/kWe for integrated systems operating on direct hydrogen; Storage system costs of \$2/kWh net.

 - Durability:** Targets are all 5000 hours or greater. Portable storage systems equivalent to 300,000 miles.

 - Weight and Volume:** Target is 3 kWh/Kg net useful energy/maximum system mass

Objectives

- ✿ Working with DOE and the private sector, identify and develop critical manufacturing technology assessments vital to the *affordable manufacturing* of hydrogen- powered systems.
- ✿ Leverage technologies from other industrial sectors and work with the extensive industrial membership base of NCMS to do feasibility projects on those manufacturing technologies identified as key to reducing the cost of the targeted hydrogen- powered systems.

Approach

- ✿ Identify Manufacturing Hurdles to Hydrogen-Powered and Storage Systems
- ✿ Rank as to impact for producing affordable structures
- ✿ Institute collaborative development projects that address the manufacturing technology issues deemed of highest impact.
- ✿ Provide a clearinghouse of information to promote technology utilization

Progress/Results –

Task 1: Identifying manufacturing technology issues vital for affordable hydrogen-powered systems

Based upon workshop results and other information to date, key manufacturing issues were identified in the following areas:

- Hydrogen storage structures
 - Manufacturing processes
 - Assembly processes
 - Joining technologies
 - Manufacturing of fittings, valves, tubing, (plumbing)
 - Parts reduction/simplification
- Efficient/lean manufacturing of Fuel Cells
 - Coating processes
 - Automated manufacturing
 - Assembly technologies

Key Manufacturing Issues

- Sealing Technologies
 - Fuel cell stacks
 - Components
- Balance of Plant
 - Discrete parts manufacturing and assembly
 - Parts reduction/simplification
 - Water/heat management
- Inspection and Safety
 - Non- destructive testing and evaluation methods
 - Leak- testing
 - Sensor technologies

Task 2: Manufacturing Technology Development and Implementation

Subtask 1: Develop and implement collaborative development projects amongst technology providers, commercializing companies, and end-users that address the manufacturing technology issues deemed of highest impact to meeting targets.

Progress: Nine projects identified and formed in conjunction with the Department of Energy

NCMS/DoE Projects

1. High Pressure Composite Over- Wrap ISO Container
2. Non- Destructive Testing and Evaluation Methods
3. Affordable High- Rate Manufacturing of Vehicle Scale Carbon Composite High- Pressure Hydrogen Storage Cylinders
4. Manufacturable Chemical Hydride Fuel System Storage for Fuel Cell Systems
5. Novel Manufacturing Process for PEM Fuel Cell Stacks
6. Innovative Inkjet Printing for Low- Cost, High- Volume Fuel Cell Catalyst Coated Membrane (CCM) Manufacturing
7. Manufacture of Durable Seals for PEM Fuel Cells
8. Qualifying low- cost high- volume manufacturing technologies for PEM fuel cell power systems.
9. Develop Low Cost MEA3 Process

High Pressure Composite Over-Wrap ISO Container

Objective:

- ✿ The specific manufacturing issue being addressed is the carbon fiber thread over-wrap configuration and its subsequently tested strength to 5000 psi, as well as the completely constructed composite tubes' measured permeability factor for hydrogen.

Tasks:

- Sourcing the carbon fiber thread material so that the cost of the fiber falls within acceptable limits.
- Engineering the configuration of the carbon fiber thread over-wrap to achieve the following product capabilities:
 - Containment of hydrogen with minimum permeation factor; Safety factor of at least 2.25; Durability of at least 300,000 miles; Passing the burst test.
- Engineering the HDPE Formula to achieve the following product capabilities:
 - Containment of hydrogen with minimum permeation factor; Safety factor of at least 2.25; Passing the burst test.
- Positioning of carbon fiber thread over-wrapping machines on the manufacturing floor, and positioning the HDPE tube between the weaving machines in such a way as to achieve the desired engineering design parameters.

High Pressure Composite Over-Wrap ISO Container

Team Members:

Specialty Gas Transportation, Lincoln Composites, Florida Hydro, and Louisiana State University

Status:

Specialty Gas Transportation was awaiting a decision by the Department of Energy to fund a program that would have coordinated with this project. In mid- April, DoE decided not to award the larger effort at this time, and thus this project awaits a NCMS- DOE decision on whether to drop the effort or re- scope.

Non-Destructive Testing and Evaluation Methods

Objective:

- ✿ The investigation of non-destructive testing and evaluation methods to enable manufacturers to test and determine the integrity of their products at much reduced times and costs.

Tasks:

- Investigate test methods for composites to determine composite strength or the working stress.
- Investigate the best practices for ultrasonic testing inspection devices that measure the structural modulus of composites.
- Investigate the best practices of utilizing full waveform analysis of acoustic emissions to determine an energy value.
- Investigate the best practices related to thermography examination techniques.
- Investigate hydrostatic test requirements.

Non-Destructive Testing and Evaluation Methods

Team Members:

ASME Standards Technology, Digital Wave, Lincoln Composites, and TransCanada Pipelines

Status:

Project agreements executed on 24 April, task work now proceeding.

Affordable High-Rate Manufacturing of Vehicle Scale Carbon Composite High-Pressure Hydrogen Storage Cylinders

Objectives:

- ✿ Demonstrate a process for making a 350 bar hydrogen/hythane storage cylinder in less than a 10 minute true-cycle time
- ✿ Provide 10 cylinders to OEM's for inclusion on their vehicle programs
- ✿ Provide complete test and validation on the cylinders
- ✿ Provide complete suite of test and property tests for use in the development of a future 700 bar tank
- ✿ Show a development path for achieving a 6- minute cycle time per cylinder

Tasks:

- Design development and coordination of requirements
- Screening and evaluation/down-selecting of candidate materials
- Development of superplastically formed liner
- Manufacturing and process development for RTM of braided overwrapped cylinders
- Testing and certification of cylinders

Affordable High-Rate Manufacturing of Vehicle Scale Carbon Composite High-Pressure Hydrogen Storage Cylinders

Team Members:

Profile Composites and Battelle PNNL, Precarn, unidentified OEM

Status:

In contracting phase with collaborative team members. Profile Composites is working with Precarn in Canada to secure additional funding that will broaden the scope of this project.

Manufacturable Chemical Hydride Fuel System Storage for Fuel Cell Systems

Objective:

- ✿ To develop a manufacturing process to produce cost effective flexible bladder and cartridge systems to manage the fuel and discharged fuel of a chemical hydride based hydrogen storage system.

Team Members:

Millennium Cell (Technical Lead), Dow Chemical, Edison Welding Institute, and NextEnergy

Manufacturable Chemical Hydride Fuel (CHF) System Storage for Fuel Cell Systems

Project Task 1.1 Millennium Cell – Technical Lead

- ✿ The objectives of this task are to clearly define the present product and process so all participants are working from the same knowledge base, and to establish metrics for the manufacturing technologies that will provide a robust process and product.

The tasks in this section are:

- Defining the fuel/borate bladder functions (1.1.1), defining the current manufacturing process (1.1.2), and defining the materials and system requirements (1.1.3).
- There are two basic CHF system architectures under each of the subtasks. Work has focused thus far on one system architecture, the “P” type, based on heterogeneous catalysis of liquid sodium borohydride fuel solutions. All the fuel/bladder functions and current manufacturing processes and associated component designs are documented and supplied to the team. In addition, the materials and system requirements are documented for attributes such as physical, chemical, thermal, processing, product design, cost, and quality.

Manufacturable Chemical Hydride Fuel (CHF) System Storage for Fuel Cell Systems

Project Task 1.2 Dow Chemical – Technical Lead

- ✿ The objective of this task is to select four manufacturing- friendly plastic materials for each major component that will meet the product requirements. The tasks in this section are: select possible candidates (1.2.1), conduct materials testing (1.2.2), and finalize candidates (1.2.3).
- Work thus far has focused on the membranes. From the standpoints of cost and manufacturability, it would be preferable to replace the existing vented bladders that incorporate bonded hydrogen- permeable membranes with a single bladder material. Published information on hydrogen permeability of polymeric films indicates that it is unlikely that a bladder will be constructed of a non- porous material that meets these criteria. Silicone rubbers have among the highest H₂ permeabilities of such materials, but even so, the required thickness would be too small to allow the bladder to withstand the operating pressure of the device. Fluoropolymer membranes owe their considerable H₂ permeability not to the native properties of the polymer but to the existence of micropores in the film. The incumbent material for bonded membranes in this application has a nominal pore size of 0.2 microns, thus it is reasonable to assume that other microporous films with similar pore sizes would be candidates for this application. From a cost and commercial availability standpoint, microporous polypropylene appears to be the leading candidate due to its inherent hydrophobicity and physical properties.

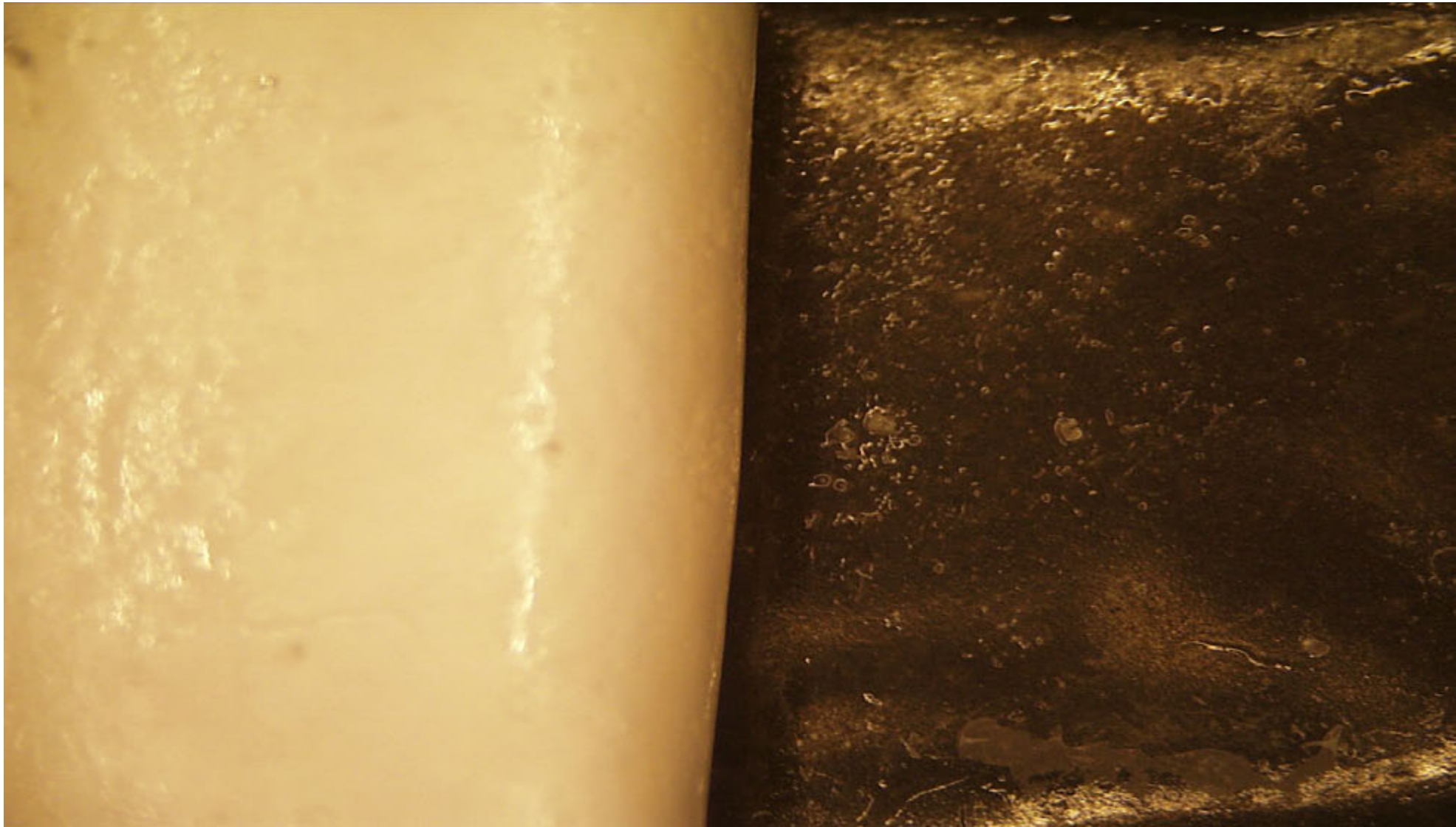
Manufacturable Chemical Hydride Fuel (CHF) System Storage for Fuel Cell Systems

Task 3: Project Task 1.3

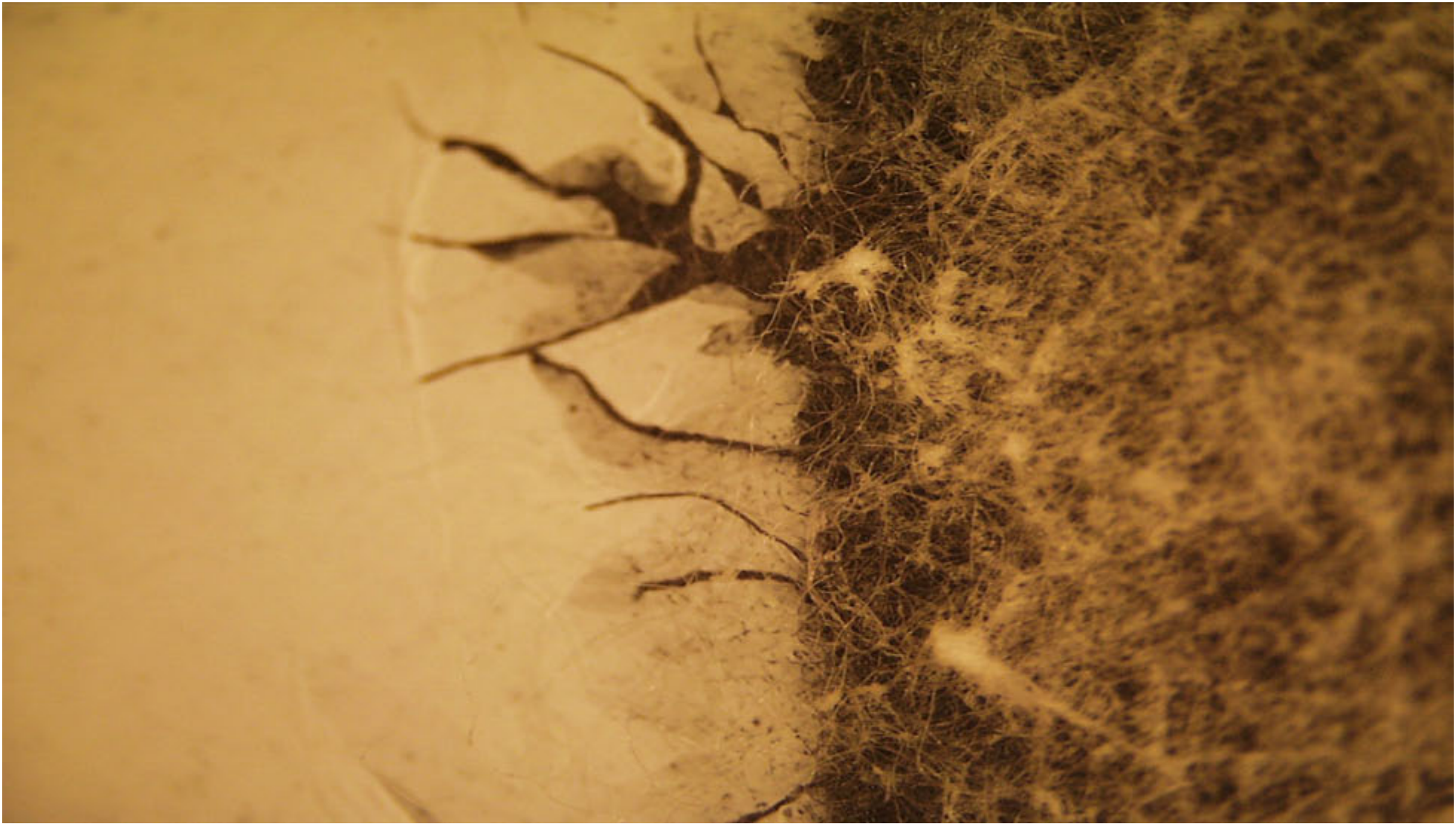
- ✿ The objective of this task is to define and select the optimum manufacturing process for each bladder assembly component. The tasks in this section are: bladder sealing process study (1.3.1), membrane sealing process study (1.3.2), and fitment sealing process study (1.3.3).
- EWI is the technical lead on this project task and work has focused on two preliminary aspects of the bonding problem. Most of the effort has been devoted to finding adhesives that could be used to bond the membrane vents to the existing bladder material. The expectation is that the porosity of the membrane vents will allow for a mechanical interlocking bond. A low viscosity adhesive formulation will therefore be preferred. For the existing bladder material, it appears that a simple surface pretreatment may be required for bonding.
- Several adhesive types have been screened. The best combination uncovered to date combines a UV curable adhesive with a surface treatment on the bladder material. This combination provides good open time for assembly, rapid cure and good bond strengths.
- Work has also focused on outlining the evaluation program for the welding processes. For the existing bladder material, a process evaluation program for heat-sealing, laser welding and RF welding has been formulated. Evaluation of the hot tool welding process parameters has also begun. The materials of construction will determine which welding process will be preferred for each step of the assembly process.

A membrane from a failed system





Interfacial peel failure surface for UV-curable adhesive. The adhesive is failing in a cohesive mode. Teflon surface (left) and urethane surface (right).



As previous but with polyethylene membrane side bonded to the urethane. The adhesive is pulling the laminate (right - bonded to urethane) off the PTFE (left). Failure is substrate failure of the membrane at the laminate interface.

Manufacturable Chemical Hydride Fuel (CHF) System Storage for Fuel Cell Systems

Plans for Next Quarter and Key Issues:

Project Task 1.1

This task will be completed by end of Q2. There are no key issues under this task.

Project Task 1.2

Work should be completed for the P type system architectures and the majority of the work completed for PA type (acid catalyzed hydrolysis) system architectures. A key issue will be finding a compatible low-cost vent membrane material.

Project Task 1.3

Work should be completed for P type system architectures and the majority of the work completed for PA type system architectures. A key issue will be defining a robust process for bonding the bladder and vent membranes.

Project Task 1.4

Work to begin next quarter. The objective of this task is to define and select the optimum manufacturing process for the cartridge housing. The tasks in this section are: identify cartridge manufacturing technologies (1.4.1), conduct manufacturing trials (1.4.2), obtain cartridge tooling (1.4.3), and define and finalize process (1.4.4).

Novel Manufacturing Process for PEM Fuel Cell Stacks

Project

- Stack Manufacturability in 250- 300 Watt Range
- Low Cost Volume Compatible Process
- Compatible with Roll to Roll MEA (Scalable)
- Single Step Molding Eliminates Compressive Seals

Partners



- Protonex – Advanced Fuel Cell Technology
- Parker Hannifin – Volume Manufacturing Expertise



Novel Manufacturing Process for PEM Fuel Cell Stacks

Process and Approach

- Practical Operating Conditions
 - Reasonable Temperatures
 - Low Pressure
- Liquid Cooled to Handle Environmental Extremes
- Volume Compatible Scalable Process
 - Low Part Complexity and Count



Technology

- Roll- to- Roll MEA
 - Low Cost
- Simple Low Tolerance Assembly
- Single Step Injection Molding and Sealing
 - No Compressive Seals
 - Low Cost Scalable Process
 - No Tight Tolerance Parts



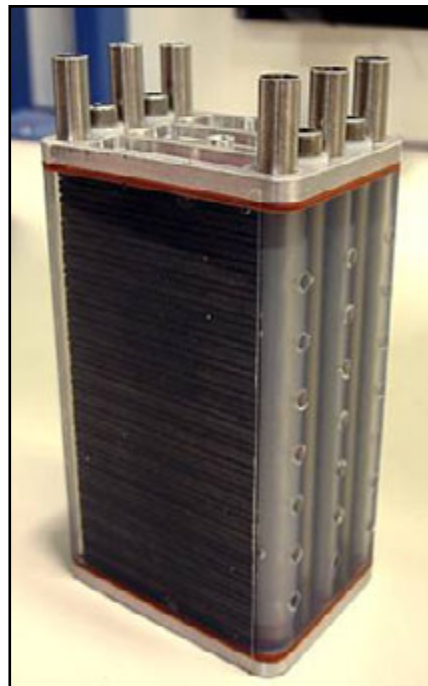
Novel Manufacturing Process for PEM Fuel Cell Stacks

Performance Data

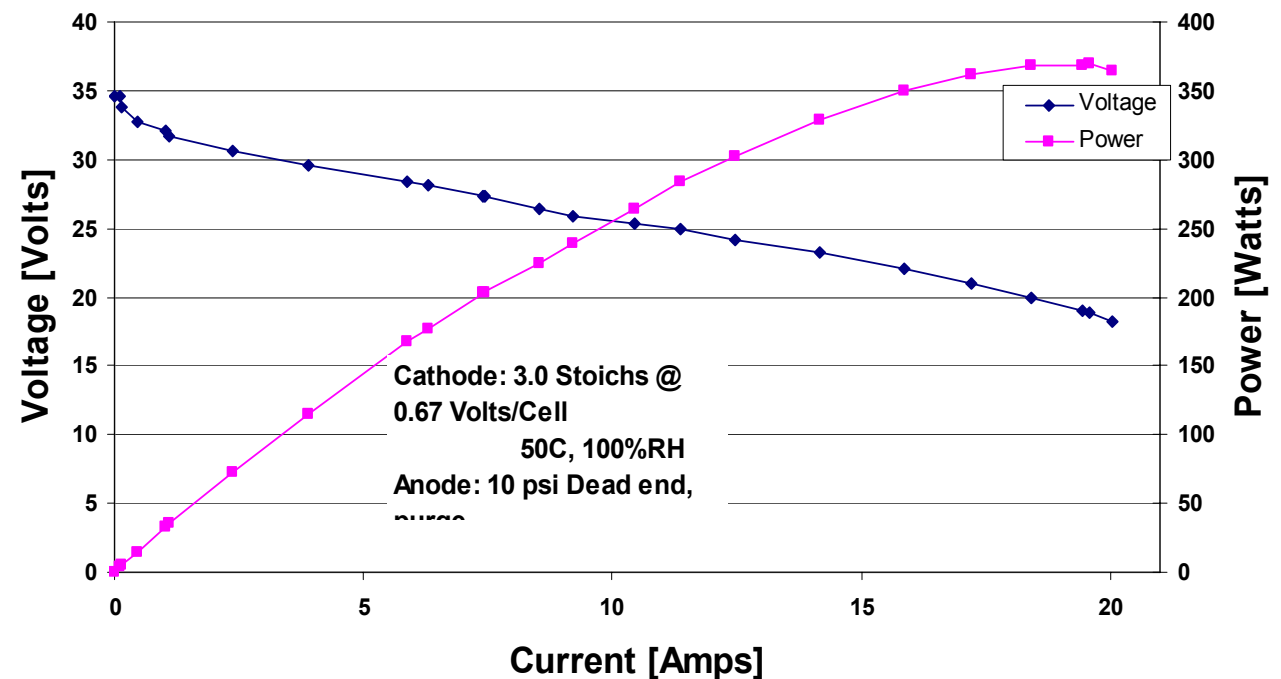
- Power 310 W
- Specific Power 458 W/kg
- Volumetric Power 576 W/L
- Active Area Ratio 49%

Operational Data

- Cathode Inlet Pressure 0.9 psi
- Anode Pressure 10 psi
- Coolant Temperature 51 C



Polarization Curve
36 Cell 18 cm² per Layer Stack



Novel Manufacturing Process for PEM Fuel Cell Stacks

Further Project Activities

- Compression Molded Bipolar Plates
- Continuous Duty Life Testing
- Assembly Process Optimization
- Alternative Stack Molding Materials for Improved Performance and Process Throughput
- Process Yield Analysis
- Volume- Compatible MEA Cutting Methods

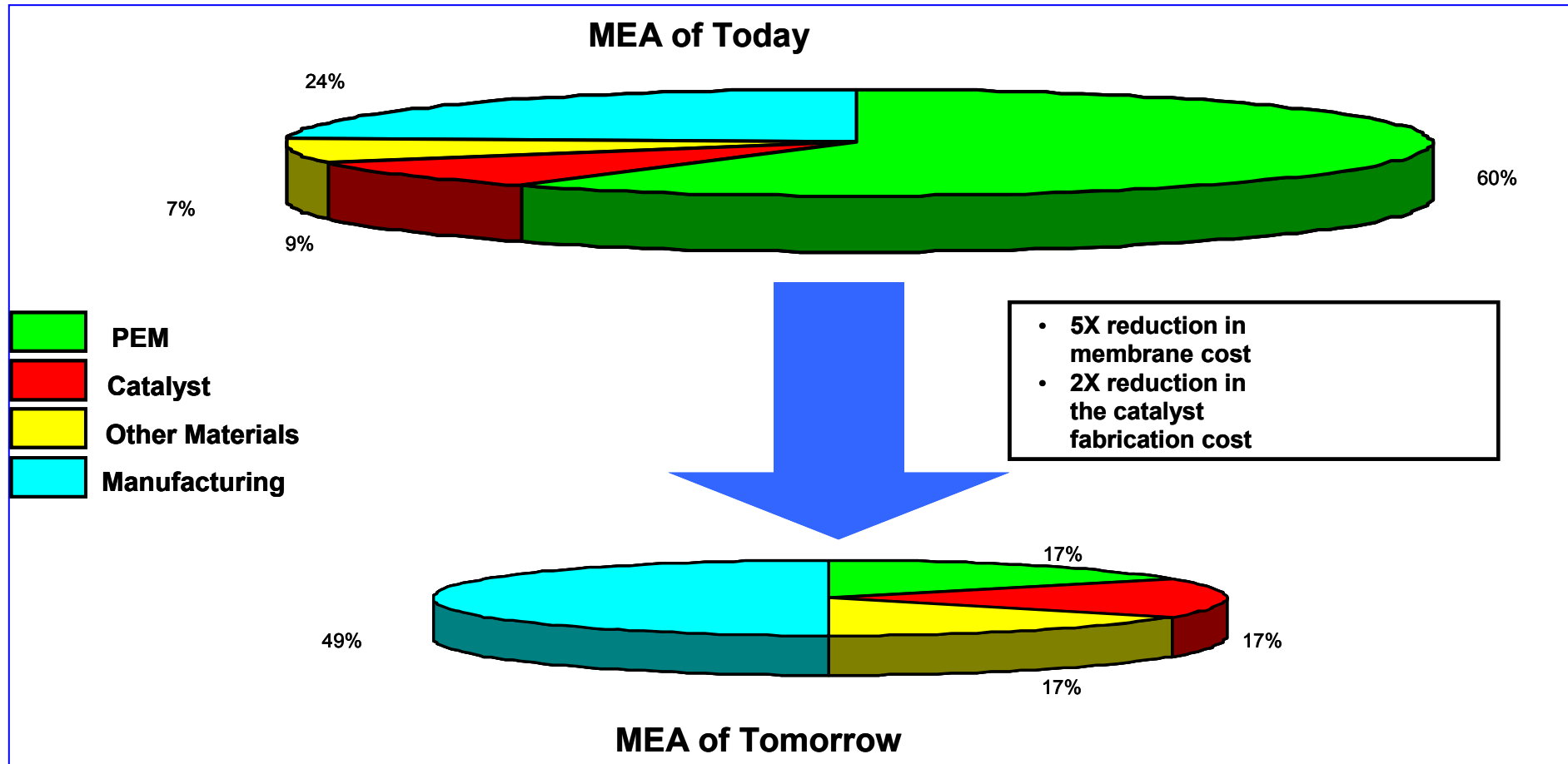


Innovative Ink-jet Printing for Low-Cost, High-Volume Fuel Cell Catalyst Coated Membrane Manufacturing

Team Members:

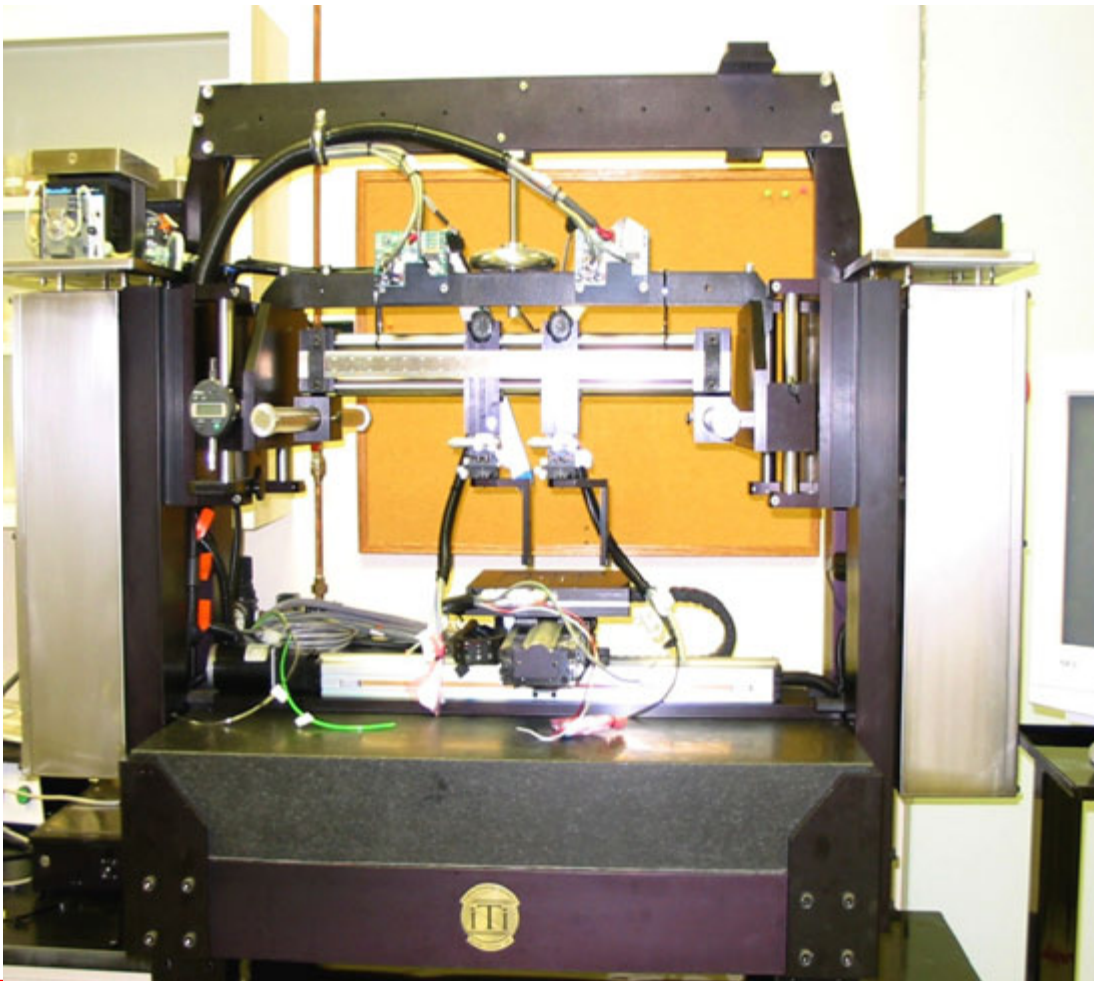
- Cabot Superior MicroPowders
- MTI MicroFuel Cells

The Cost of MEA Manufacturing Becomes More Significant “Tomorrow”



The goal of this NCMS-DOE program is to provide an innovative solution based on inkjetting for low-cost, high-performance, high-volume fuel cell CCM /MEA manufacturing to accelerate fuel cell commercialization.

CSMP Inkjet Platform for CCM/MEA



Non-contact drop-on-demand jetting of electrode inks onto membrane provides advantage over conventional CCM/MEA production approach with unique layer structure and high catalyst utilization.

NCMS-DOE Program (*Cabot SMP & MTI MicroFC*)



**The value of new CCM will be demonstrated
in MTI MicroFuel Cells' Units.**

Manufacture of Durable Seals for PEM Fuel Cells

Objective:

- ✿ Investigate the feasibility of molding an advanced elastomeric material onto the carrier material in a high-volume production process.

Tasks:

- Material Processing Determination for Processing
- Tooling Design and Fabrication
- Molding and Process Optimization
- Stack Verification of Seals

Team Members:

UTC Fuel Cells and Freudenberg NOK

Status:

Legal agreements expected to be executed in May 2006, followed by kickoff and task execution.

Qualifying low-cost high -volume manufacturing technologies for Proton Exchange Membrane Fuel Cell (PEMFC) Power Systems



UTC Power

A United Technologies Company





Overview

Timeline

- March 2006 Contract signed
- April 2006 Project Kick-off
- Finish March 2007

Barriers

- Barriers to be addressed
 - Adapting low-cost high volume manufacturing technologies to PEM systems
 - Identifying compatible material for PEM systems
 - Performance of the selected manufactured product 18

Budget

- Total project funding
 - **Cost Share** - \$302K
 - **UTC Power** - \$271K
- Funding for FY06/07 - \$271 K

Partners

- Material Testing - Lawrence Berkeley National Laboratory (LBNL)
- Manufacturer/Supplier - Will be based on technology chosen



Objectives

Overall	<ul style="list-style-type: none">▪ Qualify a low- cost high- volume process that produces PEMFC power system compatible and durable components and focuses on the cost gap between PEMFC power systems and the DOE \$45/kW technical barrier.
2006	<ul style="list-style-type: none">▪ Develop a component design that utilizes a low- cost high- volume manufacturing technology to reduce cost▪ Establish a PEMFC material compatibility test
2007	<ul style="list-style-type: none">▪ Performance testing on new component to qualify low- cost high- volume manufacturing technologies for PEMFC



Approach

Task 1: Identify potential cost saving component(s)

- High Cost
- Labor Intensive

Task 2: Identify PEMFC compatible material

- LBNL and UTC Power will develop material compatibility test plan
- LBNL will test manufacturing material sample for PEMFC compatibility
- LBNL and UTC Power will develop a monthly and final report plan

Task 3: Identify a manufacturing technology and supplier that can produce the component

- Establish selection criteria for manufacturing technology and supplier

Task 4: Redesign component to fit manufacturing technology

- UTC Power/Supplier to do component design
- Supplier to do Tool design
- Supplier/UTC Power design review(s)

Task 5: Performance test new component

- UTC Power to evaluate new component performance/durability



Future Work

2nd Quarter 2006

- Identify high cost power system component(s)
- Update project timeline
- Establish material compatibility test plan with LBNL

3rd Quarter 2006

- Select low- cost high- volume manufacturing process and supplier
- Material selection and begin testing samples for the applied process
- Component design for the applied process

4th Quarter 2006

- Material compatibility testing completed
- Manufactured components completed
- Begin component performance testing

1st Quarter 2007

- Component performance testing completed
- Project completion



Summary

Relevance: Reduce overall PEMFC power systems cost by targeting high cost components for redesign with low- cost high- volume manufacturing technologies

Approach: Use a low- cost high volume manufacturing processes that focus on the DOE cost targets and are compatible with PEMFC power systems

Accomplishments and Progress: Project kick- off April 2006

Technology Transfer/Collaborations: Establish partnership with LBNL

Proposed Future Research: Apply other manufacturing processes to PEMFC power systems. i.e. Cell Stack Assemblies (CSA's)

Develop Low Cost MEA3 Process

Objective:

- ✿ Perform a feasibility assessment for a rotary screen catalyst deposition process applied for the low cost manufacture of direct methanol fuel cell MEAs.

Deliverable:

- ✿ Technology will be developed and documented for the MEA manufacturing process. Work scope includes include precision coating methods, drying processes, and web handling techniques.

Team Members:

DuPont and SFC Smart Fuel Cell

Develop Low Cost MEA3 Process

Status:

DuPont and SFC Smart Fuel Cell could not agree on a working relationship, with intellectual property issues at the center of the disagreement. An alternate working partner is now being sought. Once successful, this project will quickly initiate.