V.H.2 Advanced Manufacturing Technologies for Hydrogen Energy Systems*

Chuck Ryan
Vice President, Technology
National Center for Manufacturing Sciences (NCMS)
3025 Boardwalk
Ann Arbor, MI 48108
Phone: (734) 995-4905; Fax: (734) 995-1150
E-mail: chuckr@ncms.org

DOE Technology Development Manager:
JoAnn Milliken
Phone: (202) 586-2480; Fax: (202) 586-9811
E-mail: JoAnn.Milliken@ee.doe.gov

DOE Project Officer: Jesse Adams
Phone: (303) 275-4954; Fax: (303) 275-4753
E-mail: Jesse.Adams@go.doe.gov

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*Congressionally directed project

Objectives

- Working with the Department of Energy (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.

Technical Barriers

This program addresses the following technical barriers from the following sections of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

- Fuel Cells (3.4.4.2)
  (B) Cost
  (A) Durability
- Storage (3.3.4.2)
  (A) System Weight and Volume
  (B) System Cost
  (D) Durability/Operability

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 5,000 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.

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.

Accomplishments

After screening, solicitation and review processes, nine projects have been selected for funding:

1. High Pressure Composite Over-Wrap International Standards Organization (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 Proton Exchange Membrane (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 Membrane Electrode Assembly (MEA) 3 Process

Six of the projects are now underway and producing results. The remaining three are in the midst of contract negotiations which should conclude in the 3Q 2006.

Future Directions

Projects approved for funding are each working on their agreed-upon Statements of Work.

Introduction

NCMS, in partnership with DOE, will focus upon key manufacturing technology issues designed to greatly improve the affordability of hydrogen-powered systems. NCMS has expertise in identifying, developing and demonstrating science-based manufacturing processes, test/diagnostics, and efficient assembly solutions. NCMS also uniquely adds value by rapidly "catalyzing" collaborations, technology transfer and integration programs for manufacturing technologies. NCMS has a twenty-year history of creating robust, market-oriented public and private partnerships in the national interest, addressing current and anticipated manufacturing issues emerging from many new technologies, including the manufacturing of alternative energy technologies.

Approach

For this initiative, NCMS identified and developed critical manufacturing technology assessments vital to the affordable manufacturing of hydrogen-powered systems. NCMS leveraged technologies from other industrial sectors and worked with its extensive industrial membership to initiate feasibility projects on those manufacturing technologies identified as key to reducing the cost of the targeted hydrogen-powered systems. These developed technologies will enable U.S. industry attain faster implementation of high-volume hydrogen fuel cell systems.

Results

Task 1: (Completed in 2005) Developing the Manufacturing Technology Roadmap for Affordable Hydrogen-Powered Systems

- Fifty-three ideas were submitted in response to a call for project ideas.

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.

Working with DOE, the following nine projects were approved for funding.

1. High Pressure Composite Over-Wrap ISO Container (Specialty Gas Transportation, Lincoln Composites, Florida Hydro, and Louisiana State University)

- Objective: Address the carbon fiber thread over-wrap configuration and its subsequently tested strength to 5,000 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 high-density polyethylene (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.
- Results: Specialty Gas Transportation awaited a decision by DOE to increase funding. In mid-April 2006, DOE decided not to award the larger effort at this time, but directed NCMS to continue to fund a scaled-down effort. The team is currently in contract negotiations.

2. Innovative Inkjet Printing for Low-Cost High-Volume Fuel Cell Catalyst Coated Member (CCM) Manufacturing (Cabot Superior MicroPowders [CSMP], MTI MicroFuel Cells)

- Objective: Provide an innovative solution based on inkjetting for low-cost, high-performance, high-volume fuel cell CCM/MEA manufacturing to accelerate fuel cell commercialization.

- Tasks:
  - Demonstrate advanced electrocatalyst inks for ink jetting.
  - Improve the print platform for double-sided printing of CCM.
  - Demonstrate CCM performance improvement >20%.
  - Attain Platinum loading reduction >20%.
  - Build a small pilot plant for CCM manufacturing.
- Results:
  - Cabot invested to install an advanced Eiger Mini Mill system. The Pt/C ink particle size has been reduced uniformly to target sub-micron size scales.
  - Non-contact drop-on-demand jetting of electrode inks onto membrane is providing an advantage over conventional CCM/MEA production approach with unique layer structure and high catalyst utilization.
  - Solvent and dispersant systems have been investigated and optimized with ink stability >3 days.
  - New printheads have been purchased and installed for printing CCM.
  - Low Pt loading has been demonstrated at CSMP, direct methanol fuel cell CCMs using newly developed supported catalysts meet MTI's latest Pt loading target.

3. Non-Destructive Testing and Evaluation Methods (ASME Standards Technology, Digital Wave, Lincoln Composites, and TransCanada Pipelines)

- Objective: Investigate 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.
- Results: Project agreements executed on 24 April, Task work now proceeding.

4. Novel Manufacturing Process for PEM Fuel Cell Stacks (Protonex, Parker Hannifin)

- Objectives:
  - Demonstrate 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.
- Tasks:
  - Lay-out of overall stack architecture.
  - Design and optimize manifolding.
  - Transition to mid/high-volume techniques.
  - Compression mechanism and molding.
  - Optimization/qualification of the volume manufacturing process.
- Results:
  - Work completed on the design and optimization of the manifolding to enable a one-step injection molding process for a fuel cell stack. The focus has been on manufacturability and cost. To this end, the part count and number of manufacturing steps were reduced. The integral runner and bipolar plate design selected eliminate the need for small runner handling during assembly and reduced the overall stack part count by more than 60%.
  - In the area of compression molded bipolar plates, several avenues have been investigated. Plates were quoted with traditional compression molding techniques. Some alternative techniques were investigated including alternative binder systems which allow for molding of a "dry" mix to reduce process complexity, cycle time and material handling costs. Several sets of small plates have been made and tested using these techniques.
  - Several alternative stack potting resins have been identified and samples have been requested. These materials all offer different process and performance advantages, such as higher durability, lower moisture permeability or lower cost.
  - An assembly fixture has been designed and fabricated to aid in the manual assembly process. Later this fixture can be adapted to semi-automated assembly processes. It greatly speeds the assembly process and reduces the possibility of a misaligned plate or layer or MEA.
  - A life test stand is under construction to allow for continuous testing of four stacks

simultaneously with real-time data acquisition. For each stack, the voltage, current, temperature, air flow rate and hydrogen utilization will be monitored to compare the relative life of stacks constructed from different materials and using different construction processes.

5. Affordable High-Rate Manufacturing of Vehicle Scale Carbon Composite High-Pressure Hydrogen Storage Cylinders *(*Profile Composites, Battelle Pacific Northwest National Laboratory, Toyota)

- 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 original equipment manufacturers for inclusion on their vehicle programs.
  - Provide complete test and validation of 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 resin transfer molding of braided overwrapped cylinders.
  - Testing and certification of cylinders.
- Results: The team is currently in contract negotiations.

6. Manufacturable Chemical Hydride Fuel System Storage for Fuel Cell Systems (Millennium Cell, Dow Chemical, Edison Welding Institute [EWI], NextEnergy)

- Objective: 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.
- Tasks:
  - 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 to provide a robust process and product.
  - Select four manufacturing-friendly plastic materials for each major component to meet the product requirements.
  - Define and select the optimum manufacturing process for each bladder assembly component.
- Results:
  - There are two basic chemical hydride fuel system architectures in Task 1. Work has focused thus far on one system architecture, the "P" type, based on heterogeneous catalysis of liquid sodium-boro-hydride 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.
  - Work thus far has focused on the membranes. From the standpoints of cost and manufacturability, it is 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 hydrogen 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 hydrogen 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.
  - EWI is the technical lead for Task 3. 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 an ultraviolet 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 radio frequency 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.

7. Manufacture of Durable Seals for PEM Fuel Cells (UTC Fuel Cells and Freudenberg NOK)

- 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.
- Results:
  - Legal agreements executed in May 2006, with task execution commencing in June 2006.

8. Qualifying Low-Cost High-Volume Manufacturing Technologies for PEM Fuel Cell Power Systems (United Technologies Fuel Cell, Lawrence Berkeley National Laboratory)

- Objective: Qualify a low-cost high-volume process that produces PEM fuel cell power system compatible and durable components and focuses on the cost gap between PEM fuel cell power systems and the DOE $45/kW technical barrier.
- Tasks:
  - Identify potential cost saving component(s).
  - Identify PEM fuel cell compatible material.
  - Identify a manufacturing technology and supplier that can produce the component.
  - Redesign component to fit manufacturing technology.
  - Performance test new component.
- Results: Project initiated in April 2006 and the team is now working Tasks 1-3.

9. Develop Low-Cost MEA3 Process (DuPont, SFC Smart Fuel Cell)

- Objective: Perform a feasibility assessment for a rotary screen catalyst deposition process applied for the low-cost manufacture of direct methanol fuel cell MEAs.
- Tasks: Technology will be developed and documented for the MEA manufacturing process. Work scope includes include precision coating methods, drying processes, and web handling techniques.
- Results: The team is currently in contract negotiations.

Conclusions

Addressing manufacturing issues is the vital step in the economic and widespread production of hydrogen storage systems and fuel cells.