VI.G.3 Advanced Manufacturing Technologies for Hydrogen Energy Systems*

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** Congressionally directed project*

Objectives

- Work with the U.S. Department of Energy (DOE) and the private sector to 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 the National Center for Manufacturing Sciences (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 project addresses the following technical barriers from the appropriate sections of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

Fuel Cells

- A. Durability
- B. 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 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 lengthy issues identification, solicitation and review processes, four projects have been selected for funding:

- High Pressure Composite Over-Wrap International Standards Organization (ISO) Container (Specialty Gas Transportation)
- Innovative Inkjet Printing for Low-Cost High-Volume Fuel Cell Catalyst Coated Membrane Manufacturing (Cabot)
- Non-Destructive Testing and Evaluation Methods American Society of Mechanical Engineers (ASME)
- Novel Manufacturing Process for proton exchange membrane (PEM) Fuel Cell Stacks (Protonex)

Future Directions

- Projects were approved for funding in early July 2005. Following the necessary signing of agreements, each team will start working on their agreed-upon statements of work.
- Supplemental appropriations funding has been added to this project which will result in several more projects organized and funded under this effort.

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, tests/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 seventeen 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. As a premier provider of collaborative research, information, knowledge and expertise to the North American manufacturing and defense community, NCMS has spearheaded numerous technology developments. These include advanced materials, machine tools, automation, electronics, high-performance machining, process control, rapid prototyping/ manufacturing, enterprise integration, information security and environmental technologies - all focused on enhancing the Nation's manufacturing competitiveness in the global economy. NCMS has been working with many of its more than 150 member and nonmember companies, as well as State and Federal agencies, involved in alternative energy development.

Approach

For this initiative, NCMS will identify and develop critical manufacturing technology assessments vital to the affordable manufacturing of hydrogen-powered systems. NCMS will leverage technologies from other industrial sectors and work with our extensive industrial membership to do feasibility projects on those manufacturing technologies identified as key to reducing the cost of the targeted hydrogen-powered systems. In addition, these developed technologies will be made available to U.S. industry for faster implementation of high-volume systems.

Results

Task 1: Developing the Manufacturing Technology Roadmap for Affordable Hydrogen-Powered Systems

Subtask 1

Working with DOE, Industry, Federal laboratories, and Universities, identify key manufacturing capabilities required to produce high-volume, affordable hydrogen-powered systems, including storage.

Subtask 2

Rank and prioritize manufacturing areas for impact on affordable systems. Focus on those manufacturing technology issues that reduce overall production and storage costs tenfold.

In a series of workshops and interactions with government, academia, and industry, the following list of manufacturing issues vital to the storage of hydrogen and to the production of fuel cell components were identified:

- Hydrogen storage structures
  - Manufacturing processes
  - Assembly processes
  - Joining technologies
  - Manufacturing of fittings, valves, tubing, etc. (plumbing)
  - Parts reduction/simplification
- Efficient/lean manufacturing of fuel cells
  - Coating processes
  - Automated manufacturing
  - Assembly technologies
- 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 among technology providers, commercializing companies, and end-users that address the manufacturing technology issues deemed of highest impact to meeting targets.

In a response to a call for project ideas addressing the topics from Task 1, 53 ideas were submitted as indicated in the table below:

	Project Idea	Lead Organization
1*	Pilot Development of a High-Speed, Low-Cost Method to Manufacture PEM Plates and High-Surface Area Membranes	10x Technology
2*	Innovative Ink-Jet Printing for Low-Cost High-Volume Fuel Cell Catalyst Coated Membrane Manufacturing	Cabot
3*	Low-Cost Printing of Planar Solid Oxide Fuel Cells	ENrG
4*	Design for Manufacturing of PEM Fuel Cell Components	Faraday
5*	Gasketed Membrane Electrode Assembly (MEA)	Plug Power
6*	Novel Manufacturing Process for PEM Fuel Cell Stacks	Protonex
7*	Lightweight Metallics for High-Pressure Hydrogen Tanks, Ducts, Lines and Valves	Boeing Rocketdyne
8*	Non-Destructive Testing and Evaluation Methods	ASME

	Project Idea	Lead Organization
9*	Conformable High-Pressure Cellular Hydrogen Storage System with Improved Safety	MER Corp
10*	Manufacturable Chemical Hydride Fuel System Storage for Hydrogen Fuel Cell Systems	Millennium Cell
11*	High-Rate Manufacturing of Vehicle Scale Carbon Composite High-Pressure Hydrogen Storage Cylinders	Profile
12*	High-Pressure Composite Over-Wrap ISO Container	Specialty Gas Transportation
13	Low-Cost Manufacturing Technology for PEM Fuel Cell System Components	OMAX
14	Cost Effective, High-Throughput, Robust Production Technologies for Manufacturing of Functionally Structured Micro-Nano Scale Surfaces	Advanced Heat Transfer
15	Portable Solid Oxide Fuel Cell Assembly and Quality Testing	AMI/U of M
16	High-Speed Discrete Manufacturing System for Fuel Cell Stacks	AvMat
17	Development of a Novel Micro-Gravure Casting and Curing Process to Produce Micron Caliper, High-Temperature Efficient PEM/MEA Fuel Cell Components in Roll Form	Chemsultants
18	Ceramic Fuel Cell Industrial Base Mobilization - Anode Support Development	CoorsTek
19	Vertical Multicavity Molding of Composite Bi-Polar Plates	Dana
20	Low-Cost Manufacturing of High-Performance Interconnect for Fuel Cell Stacks	Delphi
21	Low-Cost Manufacture of Key Membrane Electrode Assembly (MEA) Sub-Components	De Nora/E-Tek
22	Develop Low-Cost MEA3 Process	Dupont
23	Manufacturing of Clad Metals for Solid Oxide Fuel Cell Interconnects	EMS
24	High-Purity Setter Plates for Fuel Cell Applications	ENrG
25	High-Speed Laser Welding of Bi-Polar Plates and Heat Exchangers	EWI
26	Low-Cost Fabrication of PEM Fuel Cell Metal Bi-Polar Plates using Waterjet Technology	Flow International
27	Economical Fuel Cell Hose	Goodyear
28	High-Volume Manufacturing Process for Automotive Flow Field Plates	GrafTech
29	Low-Cost and High-Speed Manufacturing of Graphite Flow-Field Plates	MER Corp
30	Manufacturing Ultra-Thin Nafion Membrane for PEM Fuel Cells	MER Corp
31	Manufacturing of Exhaust Recovery (Energy and Water) Units for Fuel Cell Plants	Midwest Optoelectronics (MWOE)
32	Balance of Plant (BOP) Simplification and Its Impact on Fuel Cell System Reliability	Nuvera
33	Cost-Effective "Over-Ride System" for a Failed PEM Cell in a Stack	PIA Group
34	Hybrid Flow Field Bi-Polar Plate Stack Assemblies	Plug Power
35	Non-Destructive Test and Inspection of Membrane Electrode Assemblies (MEAs)	Plug Power
36	Bonded Cooler Bi-Polar Plate Assembly	Plug Power
37	Fuel Cell Materials Database	PMI

	Project Idea	Lead Organization
38	Product and Laser-Based Process Design for Cost-Effective High-Volume Fuel Cell Production	PRIMA
39	Advanced Plasma Spray Manufacturing for Fuel Cell Coatings	Siemens
40	Non-Destructive On-Line Evaluation of Solid Oxide Fuel Cell Plasma-Sprayed Interconnections by X-Ray Diffraction	Siemens
41	Automated Application of Foam Strips to Bundle Screens	Siemens
42	Manufacturing Research for PEM Fuel Cell Assembly	University of Michigan
43	Collaborative Development of Low-Cost Manufacturing Processes for Proton Exchange Membrane (PEM) Fuel Cell Power Plants	UTC Fuel Cells
44	Reliability and Safety of Fuel Cell Systems	Wayne State
45	Micro/Nano Fuel Cell Development	Western Michigan University
46	Hydrogen Storage Using Metal-Containing Activated Carbon Fibers	Clemson
47	Manufacturing of Efficient Hydrogen Seepage Prevention Jackets for Existing High-Pressure Storage Cylinders	Midwest Optoelectronics (MWOE)
48	Machining, Joining and Metrology of Porous Structures	Ovonic/U of M
49	Fabrication of Open Cell Porous Structure for Holding Metal Hydride Powder and Storing Hydrogen	University of Michigan
50	Solar Hydrogen Production	10x Technology
51	Compact Multi-Fuel Hydrogen Reformer for PEM Fuel Cells Applications	Sygertech
52	Manufacture of Durable Seals for PEM Fuel Cells	UTC Fuel Cells
53	Technology for the Integration of Advanced Sensors into Composite Hydrogen Storage Vessels	NASA

From these project ideas, 12 collaborative teams were asked by NCMS to submit full proposals for consideration for funding. These teams are indicated by an asterisk (*) in the table.

Working with DOE, the following 4 projects have been approved for funding: (DOE comments are indicated in quotes)

- *High Pressure Composite Over-Wrap ISO Container* (Specialty Gas Transportation) – "This project could provide a breakthrough for hydrogen delivery and forecourt bulk storage."
- *Innovative Inkjet Printing for Low-Cost High-Volume Fuel Cell Catalyst Coated Membrane Manufacturing* (Cabot) – "This project, lead by Cabot Superior Micropowders, partnering with MTI Micro Fuel Cells, should reduce the cost of the Catalyst Coated Membrane and Membrane Electrode Assembly. Advanced Electrocatalysts (developed under DOE and National Institute of Standards and Technology programs will be used in the inkjet printing process to demonstrate the combined benefits of high-performance catalysts and innovative manufacturing technology. This project addresses cost and durability targets for transportation as well as targets for consumer electronics."
- *Non-Destructive Testing and Evaluation Methods* (ASME, Digital Wave, Lincoln Composites, Quantum, & Trans Canada Pipelines) – "This was a relatively low budget proposal …..with a strong team: ASME, TransCanada Pipelines, Quantum, Digital Wave and Lincoln Composites. The work scope needs to be improved but there is clearly a need to develop best practices for non-destructive evaluation methods for rapid, reliable testing of tanks. The strength of the team and potential

impact of proposed methods to reduce manufacturing times and costs, while addressing safety, are the positive attributes of the proposal. In final negotiations, vague terms such as "investigate best practices, etc." need to be refined with more concrete deliverables (e.g,. develop, test, and verify non-destructive evaluation methods, and determine level of accuracy, etc.). Applicability to tanks for containing other forms of hydrogen storage materials as well as low temperatures and moderate pressures need to be assessed."

- *Novel Manufacturing Process for PEM Fuel Cell Stacks* (Protonex) – "This project, submitted by Protonex, is to develop and demonstrate a single-step methodology for manufacturing using injection molding. Protonex will partner with Parker Hannifin Corporation. They seem to be concentrating on micro-fuel cells."

Additional projects will be funded based upon supplemental appropriations becoming available in the third quarter of 2005.

Conclusions

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