2008
Manufacturing R & D
Summary of Annual Merit Review Manufacturing R & D Subprogram

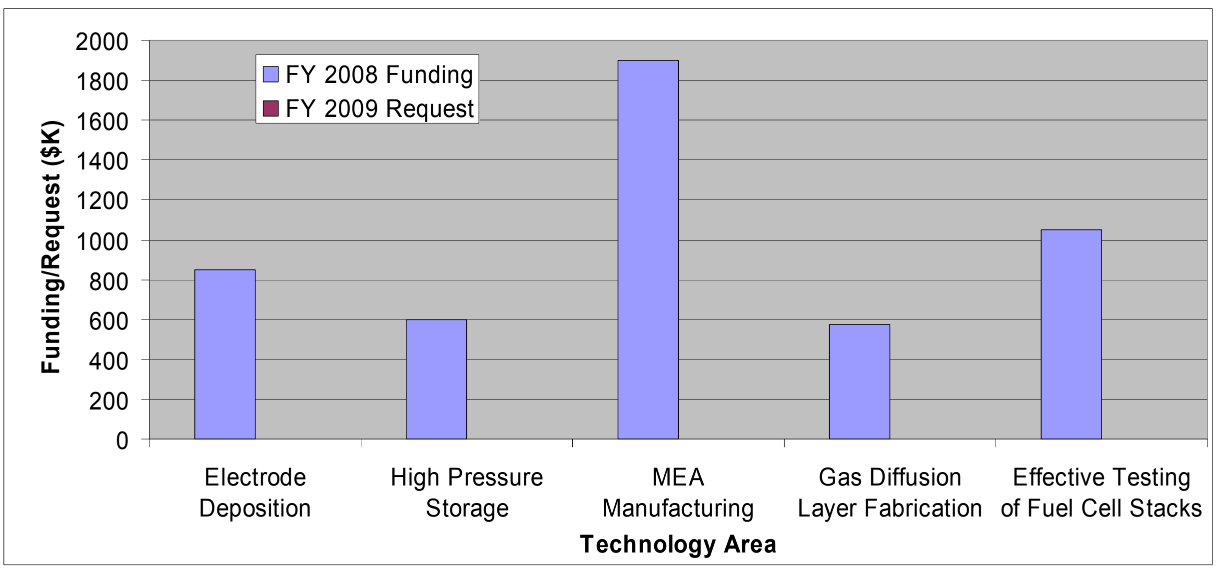
Summary of Reviewer Comments on Manufacturing R & D Subprogram:

Reviewers consider manufacturing research a key element for fuel cell and hydrogen technology commercialization. Overall, the Manufacturing R&D subprogram was judged to be well-managed and focused on addressing program performance targets. Progress was considered good.

As a result of a competitive solicitation, six new R&D projects in the Manufacturing Research Subprogram are being awarded at the end of FY 2008. These new projects will be reviewed in FY 2009.

Technology Focus:

The Manufacturing R & D subprogram continues to concentrate on reducing fabrication costs of the critical path technology, i.e. fuel cells and high pressure storage systems. Cost and quality of stack and storage components continue to be a key focus of the subprogram.



Majority of Reviewer Comments and Recommendations:

In general, the reviewer scores for the manufacturing projects were high to average, with scores ranging from 3.4 to 2.5 for the highest and lowest scores. The majority of the projects were reviewed by four reviewers. The scores reflect the technical progress that has been made over the past year, relevance to the DOE Hydrogen Program, technical approach of the project, extent of technical transfer, and proposed future plans for the project. Key recommendations and weaknesses are summarized below. DOE will respond to reviewer recommendations as appropriate for the scope and coherency of the manufacturing research effort.

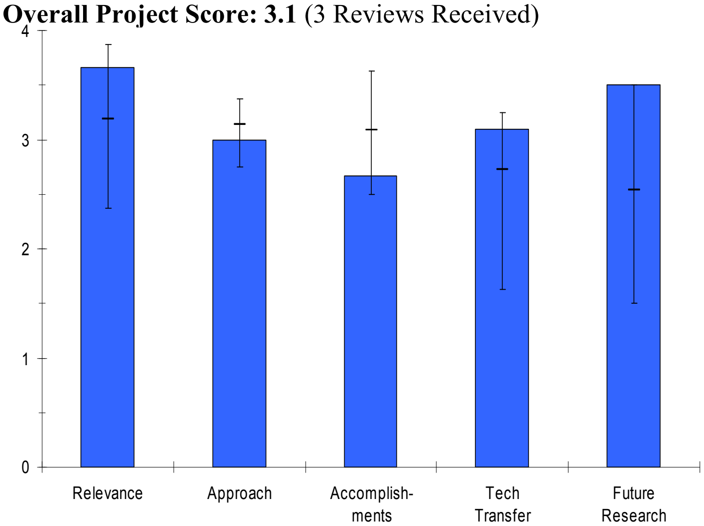
The reviewers were most impressed with the Profile Composites project for rapid manufacturing of carbon composite high pressure storage, giving this project the highest scores for the sub-program in both project relevance and approach. In addition, reviewers were pleased with the progress Protonex has made in reducing cost with its novel fuel cell stack manufacturing process and with the progress by ASME Standards Technology in non-destructive quality assurance testing for carbon fiber hydrogen tanks. While reviewers were generally positive about the relevance of the projects to DOE goals, they demonstrated concern regarding the technology transfer and collaboration of more than half of the projects. Of the nine projects, the reviewers rated the National Renewable Energy Laboratory project highest for its future plans.

Project # MF-02: Fuel Cell MEA Manufacturing R&D
Mike Ulsh; NREL

Brief Summary of Project

The objectives for this project are to 1) evaluate and develop in-line diagnostics for membrane electrode assembly component quality control and validate in-line; 2) investigate the effects of manufacturing defects on membrane electrode assembly performance and durability; and 3) further develop and validate models to predict the effects of local variations in membrane electrode assembly component properties. Fuel cell system cost targets are based on a projection of 500,000 units/year. The supplier base needs high-speed manufacturing methods – and quality control methods to support them – to achieve these volumes.

Overall Project Score: 3.1 (3 Reviews Received)



Question 1: Relevance to overall DOE objectives

This project earned a score of **3.7** for its relevance to DOE objectives.

- In-line manufactured component quality measurement will be important to stack performance and durability.
- Project addresses the need to lower cost of manufacturing of fuel cells and membrane electrode assemblies, which directly supports Department of Energy objectives.
- In-line measurements of membrane electrode assembly components during the manufacturing processes will lead to better process control and lower costs.
- Manufacturing technology assures ability to make fuel cells in quantity and at minimum cost.
- This project stresses metrology of continuous-flow film processes for membrane electrode assembly construction, which is vital for in-process quality control.
- Manufacturing quality control is essential both for minimizing production costs and for ensuring long product life (for consumer satisfaction and acceptance of the technology).

Question 2: Approach to performing the research and development

This project was rated **3.0** on its approach.

- One of the goals is to identify critical defect characteristics to help establish processing parameters and component quality specifications.
- The project is sharply focused on in-line measurements of membrane electrode assemblies and investigation of the influences of manufacturing defects on membrane electrode assembly performance.
- The approach includes both experimental techniques and modeling to understand these complex relationships, which is extremely important for solving manufacturing problems.
- Milestones are realistic.
- Approach in theory (Slide 5) is fine; approach in practice is lacking.
- It is not clear how, and if so in what way, current production lines at companies such as Ballard and Plug Power lack scalability to goal of 500,000 [industry-wide] units/year... It is not clear how this project is informed by current best-practices in existing production lines.
- Project lacks quantitative goals and objectives (e.g., measuring membrane thickness to specified resolution in nanometers with a specified measurement uncertainty).

- Project is spending significant effort in making qualitative (rather than quantitative) evaluations of measurement techniques on swatch samples, rather than in-process (simulated or real), flowing samples (e.g., Slides 7 and 8).
- Quantitative measurements—and advancing the art of quantitative measurements— are what would be essential for meeting quality-control goals.

Question 3: Technical accomplishments and progress toward project and DOE goals

This project was rated **2.7** based on accomplishments.

- Decent progress for less than a year of effort.
- Some techniques evaluated and down-selected.
- Promising new technique described and proof of concept demonstrated.
- A comprehensive assessment was conducted comparing various techniques for measuring membrane electrode assembly characteristics.
- Unfortunately, results were not summarized quantitatively; therefore, it is hard to estimate the degree of effectiveness for any particular applications.
- Optical reflectometer approach seems to have great potential to measure multiple characteristics over large areas. Unfortunately, the technical details were not provided due to invention disclosure restrictions.
- There may still be significant barriers in achieving needed measurement resolutions.
- The results of initial model development are not obvious.
- Project could be much improved by stressing precision and accuracy of different measurement techniques.
- It is not clear what was modeled or what performance was demonstrated by the words, "Initial model development...complete", on slide 13.

Question 4: Technology transfer/collaborations with industry, universities and other laboratories

This project was rated **3.1** for technology transfer and collaboration.

- Several of the major membrane manufacturers are involved.
- The collaborations with other government laboratories and universities are right on target. These collaborations complement the expertise provided by each partner.
- Industry role seems to be limited to just providing guidance. Increased industry collaboration in developing and testing prototype measurement systems at early stages can help the technology transfer at the conclusion of the effort as well as providing some short cuts toward achieving the project goals.
- Partnerships with the Colorado School of Mines and University of Hawaii are positives.
- Project suffers for lack of partnerships with existing manufacturers with production-line experience.

Question 5: Approach to and relevance of proposed future research

This project was rated **3.5** for proposed future work.

- Logical continuation to screen techniques and develop a new technique with interesting potential.
- Segmented fuel cell development is a great idea to achieve the objectives of this project.
- All future activities are well formulated based on the progress so far and overall objectives.
- "In-line validation of diagnostics with partners" is absolutely essential.
- Modeling is informed by good metrology, so should be only second priority.

Strengths and weaknesses

Strengths

- Good level of focus on the in-line measurements.
- Excellent potential for improving the fundamental understanding of the effects of manufacturing defects on membrane electrode assembly performance utilizing the combination of experimental and modeling approaches.
- This project addresses an important need.

Weaknesses

- It seems very difficult to generate well-controlled defects to carry out effective statistical analysis and/or validation of models.
- Early interaction with industry to validate techniques is very important for the success of the project.
- Lack of quantitative results presented (e.g., discussion of precision and accuracies of measurement techniques studied).
- Lack of partnerships with firms that have actual manufacturing experience.

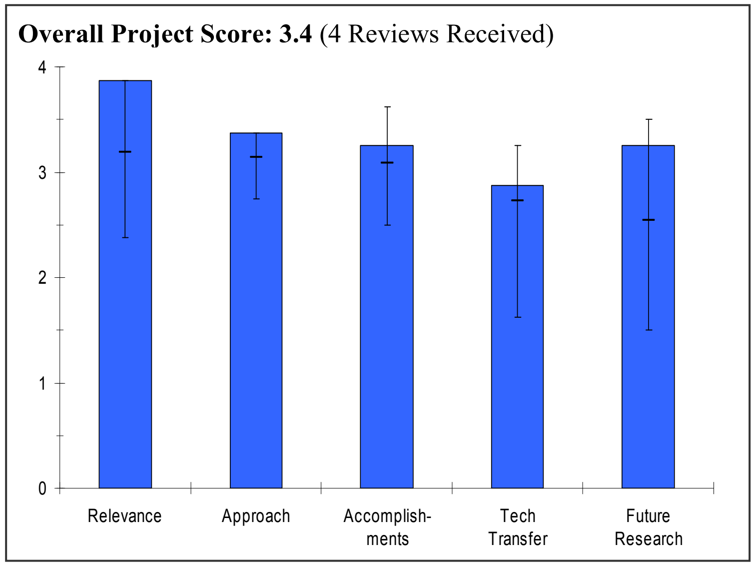
Specific recommendations and additions or deletions to the work scope

- None listed.

Project # MF-04: Rapid Manufacturing of Carbon Composite High Pressure Storage Cylinders (an NCMS project)
Geoff Wood; Profile Composites

Brief Summary of Project

The primary objective for this project is to demonstrate high-rate manufacturing of 35-MPa carbon composite hydrogen storage cylinders. An ability to achieve this objective requires 1) that no process stage take longer than 20 minutes; 2) all individual steps to be "production capable"; 3) all materials to be available in quantity and with potential for automotive volume production; 4) major process risk areas to be demonstrated physically; 5) cylinders to be validated by test program; and 6) showing a complete engineering analysis and process model to achieve under 10-minute production cycle time per cylinder for 70-MPa cylinders.



Question 1: Relevance to overall DOE objectives

This project earned a score of **3.9** for its relevance to DOE objectives.

- Rapid manufacturing focus is important to achieve Department of Energy goals.
- Vehicle cylinders address proton exchange membrane fuel cells for transportation sector.
- 350 Bar is one of the pressures OEMs will want to use.
- High-pressure hydrogen storage is an important aspect of the Hydrogen Fuel Initiative. This project addresses rapid manufacturing of carbon composite storage tanks.
- Although cost information was not provided, significant reduction in production time will eventually result in significant cost reductions.
- The project also claimed a decrease in capital investment for the manufacturing of the tanks.
- On-board storage is one of the major issues to overcome in achieving a competitive hydrogen pathway for fuel cell and other vehicles.
- Cost-effective storage capacity for achieving 300 miles is an overall DOE target—composite high-pressure tanks are an interim solution that would not achieve DOE overall goals, but are a feasible, nearer-term approach to storage.
- As stated in the manufacturing workshop background material, "The manufacturing processes for these (carbon fiber composite) containers are time consuming, very expensive and require multiple inspection steps. Scaling up production quantities while significantly bringing down unit costs will be particularly challenging." The purpose of this project is to address these issues, and particularly to identify and validate high-speed manufacturing operation.
- The primary objective is to demonstrate high-rate manufacturing of 35-MPa (5000 psig) as well as 70-MPa carbon composite hydrogen storage cylinders. Allow for production capacity off a single tooling line to approach that of specialty vehicle manufacturing over 20,000 tanks/line/year based on 3-shift operation (current technology defined by PI as 1000 tanks/line/year).
- This project is highly relevant because it would allow continued demonstration of fuel cell vehicles until other less-costly, greater-volumetric density storage alternatives are developed.
- Development of low-cost hydrogen storage tanks is an important function.

Question 2: Approach to performing the research and development

This project was rated **3.4** on its approach.

- Focus on 20 minute rate of manufacturing is significant improvement.
- Approach also addresses both cost and performance of cylinders.
- Matching vehicle production rates allows for realistic scale-up.
- Good milestone schedule.
- The approach is very systematic and technically robust, covering a wide range of critical issues relevant to manufacturing of carbon composite tanks from design and materials, to manufacturing, testing, and commercialization.
- Very well thought out plan.
- Cost is not directly targeted, but natural outcome of the cycle time reduction and introduction of automation will be the cost reduction, which is correctly identified as an important barrier.
- The approach is to focus on design of updated composite fiber high-pressure tanks (design for new, unique process ability, manufacturability, and materials development); fiber/resin performance under accelerated cure rates and resin system designs; novel manufacturing processes and experimental development; design and development of an automated materials handling system; subscale cylinder burst pressure tests; subscale cylinder laminate tests; full-scale cylinder pressure and cycle tests; commercialization; and to demonstrate each process step in under 20 minutes.
- This is a logical approach formed by a knowledgeable and experienced team in an organized, systematic manner to achieve production capability for all operational steps, demonstration of novel manufacturing, and fabrication of full-scale cylinders for vehicle testing.
- The successful implementation of this approach would achieve the stated objective—considerably faster production of high-pressure tanks (7-9 hours present state-of-art to 20 minutes).
- The reduction to a 30-minute cycle time will benefit the industry.
- Quality control needs to be included in the program activity.
- Need to include reduction in fiber costs.

Question 3: Technical accomplishments and progress toward project and DOE goals

This project was rated **3.3** based on accomplishments.

- Achieved 30-minute process time. On the way toward 20-minute time.
- Moving rapidly toward commercialization opportunities.
- Met similar process speed used by original equipment manufacturers for injection molding process.
- They have achieved excellent progress demonstrating the cycle time reduction from 7-9 hours to about 30 minutes, which is very impressive.
- There is a realistic chance to achieve the ultimate goal of a 10-minute production cycle time per cylinder with automation and fine tuning of the processes, which will meet the production target of 20,000 tanks/line/year.
- Although originally scheduled to end in June 2008, it was indicated that the project is 85 percent complete, which is some concern; however, I am optimistic that they will finish it by the new completion date of August 2008.
- Developed design of Type 3 tank (metal-lined) with separation of fiber placement and resin processing. Currently achieved 30-minute process cycle in FY 2008 with no automation. Designed automation systems to overcome major materials handling issues and implemented development of systems. Tests will be conducted next month.
- Developed a novel methodology to control fiber wrap, which allowed acceleration of fiber placement and improved processing materials.
- Demonstrated process for achieving 20 minutes, currently implementing more robust and repeatable systems. Tooling up for full-scale cylinder, re-designed tooling approach as required for control of overall process. Developed and designed and currently implementing third-generation materials handling system.
- Approach to achieve 10-minute overall cylinder production cycle time. It appears that 18-minute overall production cycle is best achieved at subsystem and suggests that 19 minutes at commercial scale is achievable.

- Progress appears to be reasonable but more needs to be done (additional tests to be conducted within the next six weeks) including demonstration of automation and handling system and process demonstration for complete manufacturing cycle.
- 70-MPa cylinder development would be done in FY 2009.-
- The 30-minute production rate is a benefit and should help this company in cylinder manufacturing for all applications. This is only at a small size.
- The benefits need to be demonstrated at a full size storage vessel.

Question 4: Technology transfer/collaborations with industry, universities and other laboratories

This project was rated **2.9** for technology transfer and collaboration.

- Coordinated well with rest of team.
- Not sure how other companies can benefit from this work as it doesn't appear this will transition beyond Profile, Inc.
- Still needs to be tested for hydrogen leakage. So far only hydraulic testing has been done.
- The project team includes all the key players: fiber producer, resin producer, machine tool builder, and the end-user.
- I was very glad to see a domestic machine tool builder is part of the team.
- There seems to be highly effective collaboration among the team members.
- The purpose of this task is to demonstrate commercial carbon composite tanks with the primary goal of achieving 35-MPa (5000 psig) tanks and also 70-MPa (~10,000 psig) tanks. Geoffrey Wood and his company produce carbon composite tanks. The cost sharing partners include Toyota, A&P Technology, Bayer, and MAG-Cincinnati with significant commercial interest and manufacturing capability.
- This project benefits this company and transfer of technology is not included.
- The project would not identify how they achieved the 30-minute cycle.

Question 5: Approach to and relevance of proposed future research

This project was rated **3.3** for proposed future work.

- Identified appropriate follow-on target of research 700 Bar cylinders.
- Attempting to reduce manufacturing time even further, down to 10 minutes.
- The immediate future plan includes more testing, automation, and cost model refinement, which are on target for accomplishing the ultimate goal.
- Health monitoring is included in the longer term plans. It is correctly identified that health monitoring will be critical for the effective use of these tanks.
- The 70-MPa pressure cylinder development is also planned for FY 2009, which should be the next logical step in the development based on the knowledge and experience gained in the development of the lower pressure cylinder in the first phase of the project.
- In FY 2008 the principal investigators will complete a new tooling approach for full-scale cylinders; demonstrate the automation and handling systems; perform process demonstrations for the complete manufacturing cycle; refine the cost model and include automation factors; and complete the test cycle for cylinders and provide cylinders for partners.
- In FY 2009, the principal investigators will initiate systems for health monitoring of cylinders by beginning development for 70-MPa cylinders; and initiating production for 35-MPa cylinders.
- This future work must go on within a new contract.
- Limited details provided.
- It appears that the bulk of the future work would be done under a time extension or a new contract.
- The "proof of the pudding" will be the integrated production of the cylinders.
- The project addresses full size cylinders in the future. The research does not benefit the fuel cell community as a whole, but sponsors development at a single company.

Strengths and weaknesses

Strengths
- Very capable principal investigator/team with strong manufacturing focuses.
- The project team has used a systematic, technical approach.
- The project team has done a good job of utilizing the expertise of companies in the project team.
- A novel manufacturing approach led to significant reduction in cycle times (although not much information was provided about this novel method due to intellectual property protection issues).
- This is an important study because early to intermediate on-board storage will require high pressure tanks while other advanced storage technologies are developed and demonstrated.
- Cheaper tank storage will allow the validation of early fuel cell vehicles.
- This is a knowledgeable team with significant experience in high-pressure carbon composite tanks.
- The technology builds on high pressure tank experience from natural gas vehicles.
- Profile Composites appears to have good understanding of cylinder manufacturing processes.

Weaknesses
- The principal investigator cannot relate cycle time reduction to overall cost reduction.
- The project experienced a one–and-a-half-month slippage in schedule.
- Project will not benefit other manufacturers unless the principal investigator better shares information.
- Profile Composites did not provide much information was related to cost modeling and estimates.
- Profile Composites was not particularly aware of other research and development activities that are very relevant to this project (e.g. another National Center for Manufacturing Sciences project develops a health monitoring system using inexpensive acoustic emission sensing for defect detection).
- A high-pressure storage tank for hydrogen is just an interim solution.
- An integrated demonstration for complete manufacturing process remains to be done.
- The 70-MPa experimentation remains to be developed.
- Profile Composites needs to determine the final cost improvements.
- Profile Composites does not include quality control in the development activity.

Specific recommendations and additions or deletions to the work scope

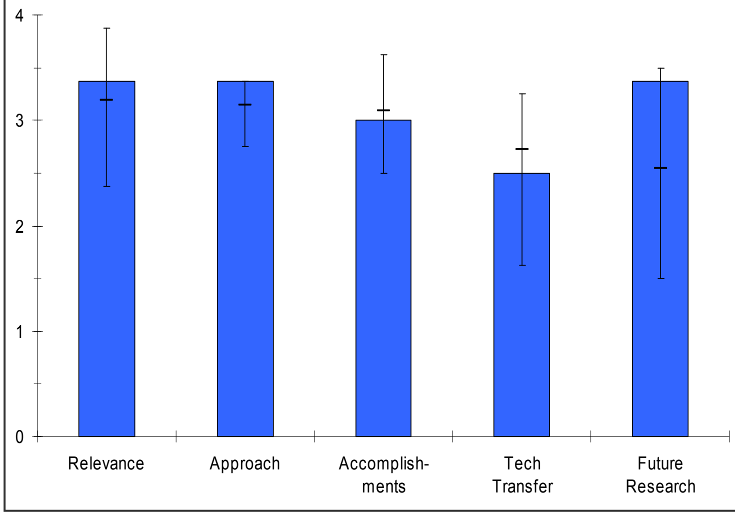
- The principal investigator should upgrade the quality control activities.
- The principal investigator should increase the technology transfer activity.

Project # MF-05: Technologies for Mass-Manufacturable Manifolds and Durable Seals for PEM Fuel Cells in Transportation Applications (an NCMS project)
Patricia Cosentino; UTC Power

Brief Summary of Project

The objectives for this project are to 1) evaluate/select material for manifolds and durable seals for polymer electrolyte membrane fuel cells; 2) develop a manufacturing process using those materials; 3) assemble a short stack using the new seals; and 4) assemble the seal into a full-size unit for in-house or field testing. Polymer electrolyte membrane fuel cells require inter-cell seals (interfacial seals) to separate reactants and coolant streams. Fuel cells utilizing external manifolds require a high-speed system for sealing the manifolds to the exterior of the stack. The current design for both these seals is expensive and has low yields.

Overall Project Score: 3.1 (4 Reviews Received)



Question 1: Relevance to overall DOE objectives

This project earned a score of **3.4** for its relevance to DOE objectives.

- Cost is one of the critical issues for the Hydrogen Fuel Initiative. These two projects approach cost reduction through materials selection and manufacturing technologies.
- Seals are expensive, currently have low yields, have too many components. Manifolds currently require 100 percent inspection. However, seals and manifolds are not critical cost or durability drivers.
- The project fully supports Department of Energy objectives by addressing the cost reduction needs of seals and balance-of-plant components,.
- Rapid assembly of fuel cell components and the effects of seal additions is an important manufacturing issue.

Question 2: Approach to performing the research and development

This project was rated **3.4** on its approach.

- The approach is logical and sound, progressing from materials selection to sub-scale proof and full-scale verification.
- The principal investigator had a go/no-go criteria built into milestone schedule and went through material selection with a 20,000-hour durability target in mind.
- UTC Power tried to find an existing product to qualify in the manifold.
- UTC Power tried to reduce the number of seal components.
- The principal investigator included full-size testing.
- This project is actually two projects – one for seals and the other for manifolds. I don't understand the logic of combining these projects into one project. This approach prevents the team from focusing sharply on the barriers.
- The technical approach seems to depend on mostly experimental comparison of materials; not much evidence was provided about any analytical study about material selection for compatibility.
- Well structured project with objectives identified. The speaker referenced use of Technology Readiness Levels as a means to judge progress.

Question 3: Technical accomplishments and progress toward project and DOE goals

This project was rated **3.0** based on accomplishments.

- Both projects have been successfully completed, resulting in significant changes in weight, cost, and inspection times.
- The project team realized a ten-times reduction in scrap by using a "cold sensor" tool.
- UTC Power reduced seal process time by 15 times.
- UTC Power reduced inspection from 100 percent to less than 5 percent.
- UTC Power improved the process capabilities and reduced seal components from 4 to 2.
- One part of the project was scheduled to finish in December 2007; it is only 80 percent complete. The other part is scheduled to finish in Aug 2008, and it is only 75 percent complete.
- It is not clear what is significantly new in the manufacturing process that resulted in the 10x reduction in material scrap.
- It is not clear how many different types of material were tested to down select to two.
- It is not clear what the results are of *in situ* testing on short stack, which was identified among the early steps in the technical approach chart.
- It is not clear what significantly new fabrication process was used that resulted in 90 percent cost savings.
- The information shared by this presentation did not allow a full evaluation of technical accomplishments. The presenter claimed good results but did not share details.

Question 4: Technology transfer/collaborations with industry, universities and other laboratories

This project was rated **2.5** for technology transfer and collaboration.

- The teams on the two projects are good.
- General Pattern was a good choice for a partner (injection molding).
- The project team includes a major seal producer, which should bring necessary expertise to deal with difficulties in seal production and testing.
- It was not clear what the roles of Lawrence Berkley National Laboratory and General Pattern are on the manifold manufacturing part of the project.
- There is no technical transfer of information. All technology belongs to UTC Power or to Freudenberg-NOK.

Question 5: Approach to and relevance of proposed future research

This project was rated **3.4** for proposed future work.

- The manufacturing technologies project is complete.
- The low-cost/high-volume seals project has only a few months remaining. Future work will prove the concepts and techniques at full scale.
- Future plans include long-term short stack testing.
- The project will not require DOE funding for follow-up because UTC plans to do further testing and employ the technology.
- The experience gained in material selection and manifold manufacturing will help in design and assembly of full-size stack and durability tests.
- Automating the process for actual production is a natural next step in this development.
- Testing will be done on a subscale level. Full-size testing is anticipated.

Strengths and weaknesses

Strengths
- UTC Power will be able to employ the results immediately.
- Teaming with seal manufacturer was a strength of the project.
- UTC Power has identified a seal material that allowed process time reduction by a factor of 15.

- UTC Power has identified the process and equipment for highly automatable application.
- UTC Power is well established fuel cell manufacturer.

Weaknesses

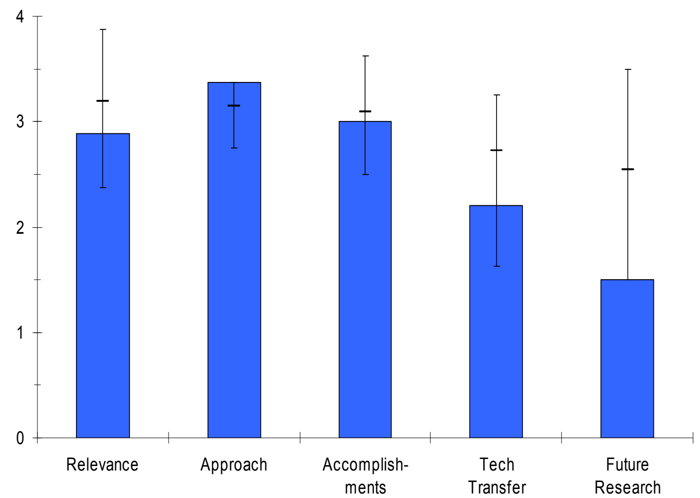
- The team has shown a lack of focus on the main technical barriers.
- The team has shown a lack of a clear technical plan for the manifold manufacturing part of the project.
- The project team developed injection molding, but does not have a market for this high-rate process. This focus appears to be a poor use of funding to develop unneeded manufacturing technology.
- The principal investigator did not provide sufficient information to evaluate the project's progress.

Specific recommendations and additions or deletions to the work scope

- Increase information to evaluate success. Use marketing data to choose manufacturing projects.

Project # MF-06: Develop Low-Cost MEA3 Process (an NCMS project)
Dennis Kountz; DuPont Fuel Cells

Overall Project Score: 2.8 (6 Reviews Received)



Brief Summary of Project

The objectives for this project are to 1) develop a low-cost process for manufacturing DuPont's MEA3 and 2) develop product by process transfer functions. DuPont completed the study of low-cost MEA3 processes to understand the effect of manufacturing parameters on the performance of the MEA3. The feasibility of static screen versus a roll printing processes was studied for manufacturing direct methanol fuel cell MEA3s. A preliminary assessment of transfer function and MEA3 performance was also explored.

Question 1: Relevance to overall DOE objectives

This project earned a score of **2.9** for its relevance to DOE objectives.

- Evaluation of high-throughput screen printing addresses manufacturing cost.
- The project addresses the screen printing processes for low-cost membrane electrode assembly manufacturing, which fully supports the Department of Energy objectives.
- There are early market opportunities for adoption of direct methanol fuel cell technology for portable electronics.
- Adoption of direct methanol fuel cell technology requires lowering costs and providing more consistent product quality.
- Development of low-cost membrane electrode assemblies is an important and relevant activity.
- High-rate production of membrane electrode assemblies is an important aspect for fuel cell systems.
- The project addresses direct methanol fuel cell technology which is not in the mainstream of DOE projects.

Question 2: Approach to performing the research and development

This project was rated **3.4** on its approach.

- DuPont's established rotary coater technology is being applied to direct methanol fuel cell membrane electrode assembly manufacture.
- The project is sharply focused on coating and laminating processes for membrane electrode assembly manufacturing. It considers all the important process variables such as yield, productivity, quality, capacity, and line balance issues associated with manufacturing.
- A systematic development path was identified.
- Project approach was well founded: A systematic variation of parameters (listed on Slide 9) in parameter space to maximize output performance.
- Approach appears good involving an adequate amount of ink formulation plus engineering development.
- The approach might be improved if the source of the voltage decay was identified.
- The rotary coating process provides high-rate production; however, it was not clearly explained how the rotary process for catalyst deposition worked with roll-to-roll processing.
- The approach identified important aspects of membrane electrode assembly fabrication; however, these aspects were not discussed in the handout or in the presentation.

Question 3: Technical accomplishments and progress toward project and DOE goals

This project was rated **3.0** based on accomplishments.

- Data were shown on graphs with no label values. Although improvement is shown, it is not possible to gauge the actual values of performance.
- A new screen printing method was developed with a new ink formulation, screen type, and relevant dimensions.
- Performance comparison tests were conducted demonstrating the improvement using this new process.
- The cost was reduced to a level acceptable by the customer.
- Results are shown on Slides 15 and 16: Variation in parameters resulted in incremental improvement over old technology at low current densities, and substantial improvement at higher current densities.
- DuPont has demonstrated impressive progress.
- DuPont reported success in developing roll-to-roll processing and a rotary printing method.
- DuPont reported improved performance with improvements in processing.

Question 4: Technology transfer/collaborations with industry, universities and other laboratories

This project was rated **2.2** for technology transfer and collaboration.

- A fuel cell company is involved.
- The main project partner is the customer of membrane electrode assemblies, but it is not clear what role this team member played in the development of this process.
- Project reporting suffered by lack of "lessons learned" that might benefit other industry participants.
- The role of Smart Fuel Cell, Inc was not clear.
- Some University collaborations might have given the project better fundamentals for such concepts as ink formulation, mechanical issues, adhesion, etc.
- There appears to be no technology transfer in this project.

Question 5: Approach to and relevance of proposed future research

This project was rated **1.5** for proposed future work.

- The project is completed.

Strengths and weaknesses

Strengths
- DuPont demonstrated a very systematic development path.
- DuPont demonstrated improvement in fuel cell performance.
- The process is applicable to proton exchange membrane fuel cells as well.
- DuPont achieved demonstrable performance improvements in a direct methanol fuel cell system.
- DuPont brings extensive experience in roll-to-roll processing.

Weaknesses
- The methods of cost analysis and cost reduction were not made clear.
- The uncertainty and repeatability of performance measurements were not clear.
- The performance test details were not provided.
- Absent documentation of "lessons learned," the project benefits were unnecessarily limited for industry at large.
- The project did not provide sufficient detail to evaluate process.

Specific recommendations and additions or deletions to the work scope

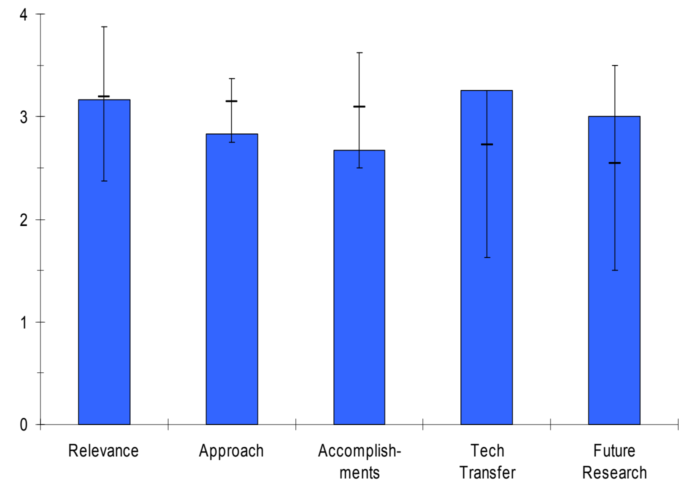
- This would have been more valuable with a fundamentals aspect that would provide information to the whole DOE program that could be used.

Project # MF-07: NIST Fuel Cell Manufacturing Research Project Metrology for Fuel Cell Manufacturing
Eric Stanfield; NIST

Brief Summary of Project

The objectives for this project are to 1) develop a pre-competitive knowledge base of engineering data relating performance variation to manufacturing process parameters and variability; 2) identify and evaluate the capability and uncertainty of commercially available non-contact, high-speed scanning technologies for applicability to bipolar plate manufacturing process control; and 3) evaluate the suitability of Optical Scatterfield Metrology as a viable measurement tool for *in situ* process control of catalyst coatings.

Overall Project Score: 2.9 (3 Reviews Received)



Question 1: Relevance to overall DOE objectives

This project earned a score of **3.2** for its relevance to DOE objectives.

- Objectives are to establish the link between component, i.e., plate and catalyst coated membrane (CCM), characteristics and performance/durability of a cell/stack.
- It is not yet clear whether the high measurement accuracy is necessary.
- This very important activity will enable lower cost manufacturing.
- This project is likely to provide pre-competitive information that the entire industry can use to help achieve Department of Energy's ultimate objectives.

Question 2: Approach to performing the research and development

This project was rated **2.8** on its approach.

- The non-design-specific nature of the work is good.
- Evaluation of candidate non-contact measurement techniques may be applicable to plates, cloth gas diffusion electrodes, and membranes.
- The approach is good and the choice of the three areas is appropriate.
- Why do you think variation in manifold channels will affect performance?
- The approach is solid.
- Optical Scatterfield Metrology will elucidate ink and deposition problems but not Platinum content.

Question 3: Technical accomplishments and progress toward project and DOE goals

This project was rated **2.7** based on accomplishments.

- Optical Scatterfield Metrology is interesting but it has not been conclusively demonstrated.
- The progress has been a bit slow due to slow funding arrival and needs to run faster now.
- The accomplishments are good considering the slow start.

Question 4: Technology transfer/collaborations with industry, universities and other laboratories

This project was rated **3.3** for technology transfer and collaboration.

- The interactions are broad and cover most of the relevant areas.
- There are lots of interactions with manufacturers.

Question 5: Approach to and relevance of proposed future research

This project was rated **3.0** for proposed future work.

- The proposed future work is clearly laid out and includes Go/No-Go decisions.
- National Institute of Standards and Technology is following a logical path to identifying and evaluating non-contact measurement techniques.
- National Institute of Standards and Technology has good plans for the future.

Strengths and weaknesses

Strengths
- This work is appropriate for the Government Agencies to perform.
- There is a great need for online instrumentation.

Weaknesses
- The concept of "design for metrology" versus "design for manufacture" may not be unreasonable from a cost and performance standpoint.
- It is unclear whether the legal problems will hold up progress.
- The validity of targeted metrics should be questioned. Are these important and at what scale?

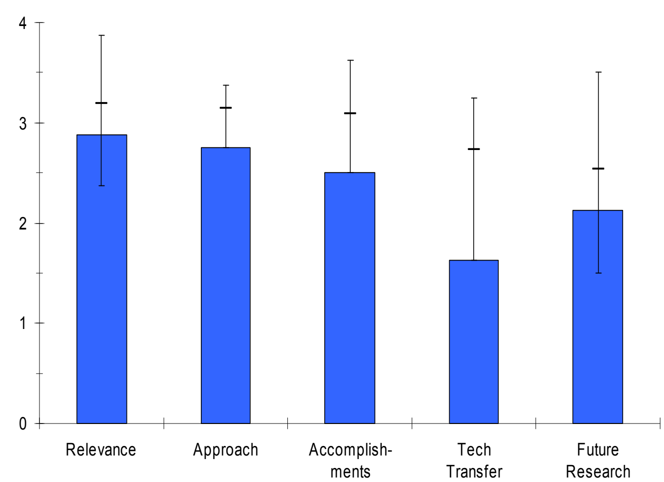
Specific recommendations and additions or deletions to the work scope

- None listed.

Project # MFP-01: Innovative Inkjetting and Spray Deposition for Low-Cost, High-Performance Fuel Cell Catalyst Coated Membrane Manufacturing
Hanwei Lei; Cabot Corp.

Brief Summary of Project

Overall Project Score: 2.5 (4 Reviews Received)



The overall goal of this project is to provide innovative solutions for low-cost, high-performance, durable next generation membrane electrode assembly manufacturing to accelerate direct methanol fuel cell commercialization. The objectives for this project are to 1) improve printing/deposition technology to manufacture membrane electrode assemblies with >95 percent production yield with improved performance; 2) demonstrate a manufacturing throughput of greater than 1,000 membrane electrode assemblies per month per shift; 3) identify two hydrocarbon membranes with lower methanol and water crossover and higher dimensional stability than Nafion; 4) demonstrate a hydrocarbon membrane electrode assembly with greater than 20 percent performance and cost advantages over Nafion; and 5) demonstrate hydrocarbon membrane electrode assembly durability greater than 1,000 hours.

Question 1: Relevance to overall DOE objectives

This project earned a score of **2.9** for its relevance to DOE objectives.

- The project addresses the needs for portable power applications.
- Although there are common threads for transportation applications, the gaps are not clearly identified. For example, the major focus is on direct methanol fuel cell commercialization. How can the technology developed in this project be extended to other fuel cell applications more common for transportation?
- The project addresses the need for development of low-cost catalyst coated membrane (CCM) for direct methanol fuel cells for portable applications.
- An earlier market entry of direct methanol fuel cell could assist in the development of a fuel cell manufacturing base; however, ink jetting of catalyst on CCM is not a likely technology to be used in the Hydrogen Fuel Initiative.
- This project develops technology for low-cost patterning of catalyst particles on membranes.
- The project goals are very relevant. Inkjet preparation is a feasible route for manufacture of membrane electrode assemblies.

Question 2: Approach to performing the research and development

This project was rated **2.8** on its approach.

- The project is sharply focused on utilizing hydrocarbon membranes with significantly smaller catalyst particles than are commonly used and depositing them with inkjet printing and spray deposition technologies.
- Reducing the size of catalyst particles and spreading them more uniformly and in a better controlled manner will help reduce the cost of membrane electrode assemblies.
- Cabot has conducted a selection process for hydrocarbon membranes and applied the coating once the selection was completed.
- Cabot has addressed all the objectives they started out with.

- The presented info on project design is vague and without identification of specific barriers.
- The approach presented lacks enough detail to complete assessment.
- The approach ties to Department of Energy objectives and barriers not shown.
- This project supports manufacturing methods and the reduction of catalyst loading by depositing catalyst only where it might be useful.
- The idea of transferring an established technology—ink jet printing—to the new application of catalyst deposition is interesting.
- The approach appears good. However, the amount of detail provided in this presentation makes it hard to judge whether the presenter is accounting for likely problems.

Question 3: Technical accomplishments and progress toward project and DOE goals

This project was rated **2.5** based on accomplishments.

- The principal investigator was able to reduce the size of catalyst particles to about 1 micrometer and develop necessary modifications to the inkjet printers to be able to deposit catalyst layer on the hydrocarbon membrane.
- Cabot carried out tests to compare the performance of hydrocarbon membranes with Nafion and demonstrated improvements.
- Cabot also claimed to have completed more than 1000 hours of operations in durability tests, but did not show any data from those tests.
- The timing of this project is not clear. According to the timeline, it was supposed to be completed in June 2006. In the Key Milestones, Phase II was mentioned, but it was not clear whether the accomplishments listed were part of Phase I or II. The presenter's response was also not clear.
- The principal investigator presented Limited quantitative metrics for parameters by which assessment of accomplishments can be made.
- The power density shown does not meet general objectives.
- The single set of comparative data shown is vague.
- For demonstration of attainment of manufacturing objective, statistical data as to yield, performance, cost, latitude, etc is needed.
- Technical results for Objectives 1, 2, 3 and 5 were not presented. Partial results for Objective 4 were shown qualitatively.
- The presentation stressed the slightly better performance of membranes produced using this method (and of different materials) than a Nafion reference.
- While cost reduction was the project objective, no data was presented on cost.
- While patterning was a project objective, no data was presented on patterning.
- While durability was a project objective, no data was presented on durability.
- The accomplishments seem good but the amount of detail provided is really inadequate.

Question 4: Technology transfer/collaborations with industry, universities and other laboratories

This project was rated **1.6** for technology transfer and collaboration.

- They mentioned one partner, but apparently that company is only their customer.
- The presenter claimed that their collaborations are proprietary and, therefore, did not reveal any useful information.
- No outreach shown to National Laboratories or Universities.
- Cabot is working with an US company (Mechanical Technology, Inc.), but no results were shown.
- The major effort is with a European Company (Smart Fuel Cells).
- Grantee worked with Mechanical Technology, Inc. to demonstrate membrane operation on a direct-methanol fuel cell platform.
- This project had no partners with a proton exchange membrane fuel cell platform.
- This project only utilized grantee's powered catalyst; transference to other catalyst formulations was not demonstrated.

Question 5: Approach to and relevance of proposed future research

This project was rated **2.1** for proposed future work.

- The project seems to have achieved the major objectives. Even the durability demonstration listed as the future work has apparently completed. Improving manufacturing efficiency via better database management is not necessarily addressing any technical barrier.
- It is not clear what is planned for optimizing the depositing process.
- Only a generic description of future work presented. Not enough detail was provided to make an assessment of future work.
- The 1000-hour durability target is to be addressed in future, but no metric was given for "durability."
- Future plans include "further improve manufacturing efficiency," but it is not clear what the current manufacturing efficiency is (or what the future goal might be).
- Future goal of demonstrating durability was a goal of the project past.
- Not enough detail was provided even with discussions with the presenter.

Strengths and weaknesses

Strengths
- The proposed technology provides much better control over the membrane electrode assembly geometry, enabling any shape of catalyst coated membrane, eliminating costly waste of catalyst layer.
- The process provides flexibility for the vendor to adapt to different end-user performance requirements.
- The use of a hydrocarbon membrane improves the catalyst adhesion, improving durability.
- The project is under budget.
- Some testing was performed and data shown.
- The principal investigator indicates the development is successful.
- The principal investigator presented a successful demonstration of a marginally better catalyst coated membrane than Nafion reference.
- The company has a strong position in carbon.

Weaknesses
- Not much hard data/information was made available due to the proprietary nature of the project.
- The comparison with Nafion was done solely by experimental means. There was no analytical study to assess a cost, performance, or durability comparison.
- The project timeline and budget information are inconsistent.
- The limited data presented makes assessment difficult.
- The stated objectives were not demonstrated.
- The current performance of the process is unclear.
- The applicability of the process to proton exchange membrane platforms and catalysts, in general, is unclear.
- It is not clear where the expertise in ink formulation is from. Not enough detail was provided to judge the project fairly.

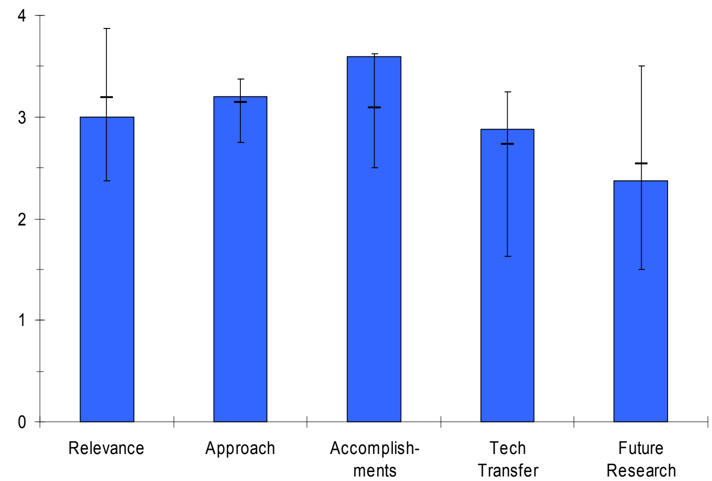
Specific recommendations and additions or deletions to the work scope

- Limited technical benefit was shown for support of the expected DOE manufacturing base.
- Specific objectives relevant to DOE Program barriers should be added. The accomplishments relative to those objectives need to be demonstrated and disseminated.

Project # MFP-02: Novel Manufacturing Process for PEM Fuel Cell Stacks
Michael McCarthy; Protonex Corp.

Brief Summary of Project

Overall Project Score: 3.2 (4 Reviews Received)



The Phase 1 objectives for this project are to 1) design and develop mass-producible stack architecture and components and optimize the stack assembly; 2) develop and optimize one-step integral casing/sealing of the stack assembly; and 3) establish technical and cost benefits of a one-step injection molding process. The Phase 2 objectives of this project are to 1) develop a concept modular assembly and balance-of-plant component integration; 2) design/develop and assemble sub-modules of the balance-of-plant components with appropriate interfacing of sub-modules with the fuel cell stack; 3) integrate a fuel cell system prototype using modularized balance-of-plant components; and 4) evaluate and demonstrate the system benefits of the modular balance-of-plant.

Question 1: Relevance to overall DOE objectives

This project earned a score of **3.0** for its relevance to DOE objectives.

- This manufacturing program's relevance to the Department of Energy's technical and cost targets is unclear.
- The project addresses manufacturing of proton exchange membrane fuel cell stacks for portable power applications (about 1-kW range). Scale-up issues for the automotive/transportation applications are not addressed (although it is listed as future work).
- The project addresses the manufacturability issues by reducing part counts and introducing novel sealing technology by injection molding. It also addresses the modular manufacturing and integration of balance-of-plant components into fuel cells to reduce the overall manufacturing costs of fuel cells, which is one of the main DOE objectives.
- The project focused on low-cost proton exchange membrane stack sealing and assembly/manufacture, as well as modular balance-of-plant design/build. The project addresses portable applications where earlier market entry would assist in the development of a fuel cell manufacturing base.
- Stack sealing and assembly/manufacture could be applicable to automotive stacks but the automotive industry would consider other approaches as well. The automotive supply chain would subcontract out bipolar plate and seals integrated as a component.
- The project fits well with the DOE's goals and objectives in its effort to design and develop fuel cell stack architecture, components, and an optimized stack assembly suitable for mass production.
- If successful, the project's outcome should enhance the manufacturing capabilities for fuel cells by providing techniques for handling high fuel cell production volumes and achieving better consistency and quality control.
- The project is aligned with DOE objectives with regards to its focus on the development of modular assembly and balance-of-plant integration. This aspect will provide simplicity and help achieve the cost reductions needed to move fuel cells from niche to mass markets.

Question 2: Approach to performing the research and development

This project was rated **3.2** on its approach.

- For small stacks (<1 kW), this sealed-stack concept nay make sense. For much larger systems (>>1 kW), this concept will add size, weight, and cost.
- The project is focused on stack design to enable elimination of gaskets between individual membranes and bipolar plates.
- This project addresses the elimination of gaskets, which generate significant difficulties for stack assembly.
- The approach of using injection molding to achieve these objectives is impressive and proven feasible by this project.
- The technical approach addresses the development of a complete system integrated with balance-of-plant, which is a good indication of the developers' understanding of problems associated with early commercialization opportunities.
- The project continues development of Protonex's one-step sealing approach based on adhesive molded stack design.
- Additional detail on the project design and metrics for barriers is needed, i.e. how success is defined.
- The relationship to DOE barriers and specific targets is needed.
- The project is nearly 95 percent complete and the technical approach has enabled Protonex to reach this level within the stipulated period of performance (Sep-05 to Jun-08).
- All FY 2006, FY 2007, and most of FY 2008 milestones have been accomplished.

Question 3: Technical accomplishments and progress toward project and DOE goals

This project was rated **3.6** based on accomplishments.

- The technical targets have been met.
- Although they have not provided direct cost figures, the four times reduction in build times is a good indication of manufacturing cost savings.
- They have designed, assembled, and sealed over 30 systems with integrated balance-of-plant demonstrating the feasibility of the technical approach.
- The project participants must have gained significant knowledge and insight with the impressive amount of tests (over 50,000 hours) they conducted; however, there is no publicly available paper describing the accomplishments for widespread understanding and criticism of those accomplishments.
- Significant progress exceeded the self-established target for stack power density.
- Stack manufacturing time reduced to 25 percent, but it is not clear whether this improvement meets the cost target, since the improvement is not identified quantitatively.
- The system endurance test results are promising, but no metric was identified for success of the test.
- All claimed accomplishments appear to have fulfilled all progress metrics and milestones.
- Unclear whether interim milestones were met within the stipulated cost and schedules, but overall the project's accomplishments are up to date.
- A finished modular fuel cell assembly was available for display at the poster session.

Question 4: Technology transfer/collaborations with industry, universities and other laboratories

This project was rated **2.9** for technology transfer and collaboration.

- An end-user (e.g., electronics or auxiliary power unit original equipment manufacturer) should be involved.
- There seems to be good collaboration between Protonex and Parker Hannifin. The presenter was from Protonex, but was knowledgeable about all aspects of the project.
- There may be a benefit to adding a membrane electrode assembly supplier to this project.
- Non-proprietary technology was not disseminated to benefit overall fuel cell community.
- The only other partner listed is Parker Hannifin, a manufacturer of motion and control technologies and systems. The company is well established and possesses the capabilities needed to cover product development, manufacturing, and sales/marketing needed to promote fuel cell products based on their past history.
- Given Parker Hannifin's competency in fuel cell balance-of-plant components and integrated subsystems, both companies will have the synergistic resources to focus on the commercialization of economic fuel cell systems for the portable power market.

Question 5: Approach to and relevance of proposed future research

This project was rated **2.4** for proposed future work.

- The project has been completed.
- Future company plans are to scale up to higher power levels.
- Some key issues are identified such as expanding operational development and reducing balance-of-plant parasitic losses, but it is not clear if they are the main barriers left.
- Not much information was provided related to the approaches to be taken to address the outstanding issues.
- The goal to scale up to higher power levels is worthy to achieve DOE goals in transportation applications.
- Approach not sufficiently detailed to assess future efforts.
- Only generic, non-specific targets were identified.
- This manufacturing process may be relevant to other components.
- It was unclear whether the proposed future work is part of the an existing Statement of Work for the project or a future project with new funding. Given that the project is 95 percent complete and most goals and milestones have been accomplished, it is unlikely that the listed future work can be accomplished within the project's duration that ends June 2008.

Strengths and weaknesses

Strengths
- An impressive one-step injection molding process was developed to eliminate gaskets.
- Protonex has integrated balance-of-plant into the design and manufacturing of complete fuel cells.
- The project provides significant advances in design and assembly of fuel cell stacks and balance-of-plant.
- The project has developed, designed, and manufactured multiple stacks and systems demonstrating small volume manufacturing potential.
- The focus and targets for stack and balance-of-plant are appropriate for Protonex.
- Protonex demonstrated a single-step injection molding process for 250-W fuel cell stacks at a scaled-up manufacturing facility.
- Protonex demonstrated that their modular balance-of-plant components could be produced at reduced costs and improved reliability.
- Protonex created the opportunity to develop multiple systems for the Department of Defense and commercial markets.

Weaknesses
- The main focus is low-power applications.
- The focus in balance-of-plant integration is good in addressing near term opportunities for commercialization, but it is not highly relevant to DOE's goals and strategies for the transportation applications.
- Statistical data validating manufacturing accomplishments not were presented regarding the following: efficacy of manufacturing process (i.e. yield), component and system variability, unit cost and production rate, failure rates, performance, cycle times, etc.
- Non-proprietary results were not disseminated.
- There is limited applicability to automotive program.
- None - the project appears to have been completed on schedule while meeting all project goals.

Specific recommendations and additions or deletions to the work scope

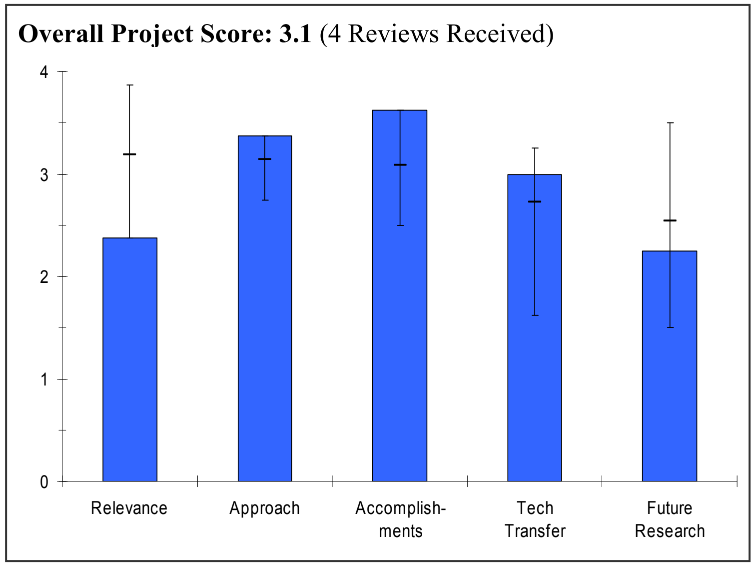
- Complete the current program.
- None—the project is 95 percent complete.

Project # MFP-03: Manufacturable Chemical Hydride Fuel System Storage for Fuel Cell Systems

Richard Mohring; Millenium Cell

Brief Summary of Project

The objectives for this project are to 1) develop manufacturing concepts to reduce the process and product costs of chemical hydride hydrogen generation and storage technology; 2) develop a modified design to demonstrate high volume manufacturability of fuel cartridges based on Millennium Cell's patented Hydrogen on Demand® technology; 3) utilize strengths of the National Center for Manufacturing Sciences partners to achieve highly reliable fuel cartridge/tank performance (Dow – material selection, EWI – sealing techniques, NextEnergy – system testing); and 4) assess recyclability for all fuel system components consistent with performance and manufacturability.



Question 1: Relevance to overall DOE objectives

This project earned a score of **2.4** for its relevance to DOE objectives.

- The project addresses fuel storage systems for low power applications, which are not highly relevant to the Department of Energy's objectives related to transportation applications.
- There is no path to scale up to higher power applications.
- The project addresses the development of a manufacturable design for a low-cost chemical hydride generation and storage cartridge for portable applications where earlier market entry would assist in the development of a fuel cell manufacturing base.
- A direct application of this technology to the manufacturing base for transportation fuel cells is limited.
- This project supports early adoption of fuel cells in portable electronic devices.
- This project addresses the problem of fuel logistics by the development of a user-friendly fuel cartridge system.
- This project addresses manufacturing issues associated with hydrogen storage technology, which needs to overcome both technical and cost barriers.

Question 2: Approach to performing the research and development

This project was rated **3.4** on its approach.

- The approach presents a very comprehensive experimental evaluation of various materials, processes, and end products. However, analytical evaluation is not given any priority in selection of materials and understanding the processes.
- Barriers are identified and divided into subtasks which are addressed sequentially according to plan.
- Alternative paths identified and pursued where necessary.
- This project focuses on the development of suitable materials to make fuel cartridges affordable while maintaining their functionality.
- Significant technical and manufacturability issues were defined and addressed in this project in a well-designed work plan.

Question 3: Technical accomplishments and progress toward project and DOE goals

This project was rated **3.6** based on accomplishments.

- A comprehensive experimental study was conducted resulting in significant cost reductions in manufacturing of a revolutionary fuel-on-demand system.
- Significant progress was made toward low-cost materials and manufacturing techniques overcoming indicted barriers.
- Final configuration indicated as a solution has not been fabricated and tested as of yet.
- The company achieved many, if not most, of its technical objectives.
- In this project the investigators made excellent progress toward meeting the objectives. The project is now complete.

Question 4: Technology transfer/collaborations with industry, universities and other laboratories

This project was rated **3.0** for technology transfer and collaboration.

- There is a good evidence of effective collaboration among the partners of the project. The nature of the experimental work requires such collaboration.
- Collaboration with other companies was beneficial to the project.
- Information was disseminated to the project partners. However, dissemination of information to the fuel cell industry is limited.
- The company has terminated the employment of all employees and has ceased operations; the intellectual property has not been transferred to a new owner.
- Little or nothing was published in the open literature, limiting technology transfer opportunities.
- Development was specific to grantee's fuel fluid; generalization to other means of chemical storage has not been demonstrated.
- The principal investigator worked with partners and collaborators effectively to understand the technical issues and to develop and test the component hardware.

Question 5: Approach to and relevance of proposed future research

This project was rated **2.3** for proposed future work.

- Although some issues were identified as the future work, it appears that the Millenium Cell Company no longer exists and the presenter was not very optimistic that the research would continue unless another company would obtain the license. Therefore, I believe the future of this project is not very optimistic.
- Remaining barriers were identified and specific approaches to solutions were identified.
- The plans lack sufficient detail.
- The future of the company is highly doubtful and is dependent on fresh venture funding.
- Future plans would be dependent on the terms of financing arrangements or intellectual property licensing, if any.
- The future plan calls for scale up and optimization which is the next logical step in the process development. However, the current project has been completed successfully.

Strengths and weaknesses

Strengths
- The fuel-on-demand concept is revolutionary and this project demonstrated that it may be feasible for high-volume applications.
- The project is well organized and was managed according to plan.
- Critical barriers to project success were identified and addressed.
- The project team demonstrated systems engineering for portable, premium power.

Weaknesses

- This approach is not an alternative to hydrogen tanks for transportation applications.
- There is no clear path to scale up this approach for higher power applications.
- Applicability of project results to manufacture similar components for transportation application is limited.
- Statistical data validating manufacturing accomplishments was not presented regarding efficacy of manufacturing process, ie yield, production rate, component and system variability, unit cost and production rate, performance, etc.
- The future is uncertain, because the company ceased operations before the completion of development.

Specific recommendations and additions or deletions to the work scope

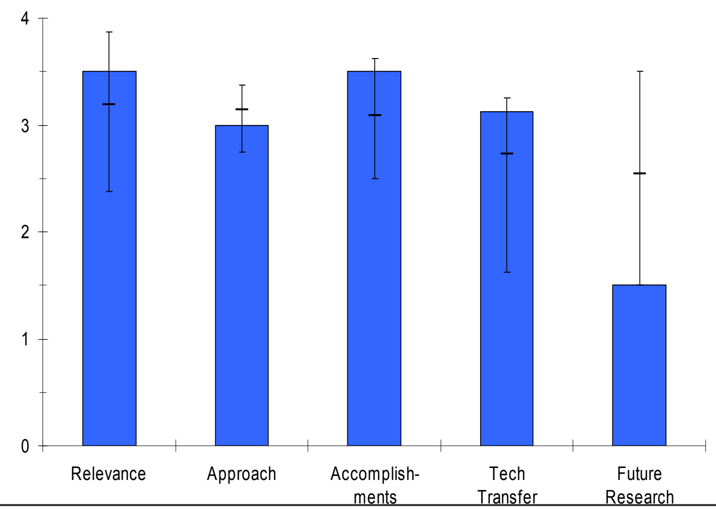
- The project is nearly complete at this time; continue to end of plan and end.

Project # MFP-04: Non-Destructive Testing and Evaluation Methods
Jim Ramirez; ASME Standards Technology

Brief Summary of Project

The objectives for this project are to 1) investigate the feasibility of using nondestructive evaluation (NDE) methods in the evaluation of composite pressure vessels; 2) determine if nondestructive evaluation methods can be a suitable substitute to existing destructive testing currently used to determine pressure vessel integrity; and 3) investigate the use of stacked piezoelectric transducers in Modal Acoustic Emission (MAE) phased arrays for composite tank monitoring.

Overall Project Score: 3.2 (4 Reviews Received)



Question 1: Relevance to overall DOE objectives

This project earned a score of **3.5** for its relevance to DOE objectives.

- The project addresses the non-destructive testing of carbon fiber hydrogen tanks. Thus, it fully supports the Department of Energy objectives related to hydrogen storage and manufacturing for hydrogen storage.
- As high pressure tanks are planned for the future transportation applications, it is critical to be able to test these tanks inexpensively and non-destructively for safety and security of commercialization.
- Project focused on investigation of feasibility of using Non Destructive Test Methods for composite pressure vessels, but concentrated on Modal Acoustic Emission technique.
- Other approaches addressed briefly in poster, but principal investigator not present at Annual Merit Review.
- This project supports both manufacturing (quality assurance) and safety.
- This project develops best methods to guard against the bursting of pressure vessels containing hydrogen.
- Non-destructive testing for quality assurance of pressure vessels is very relevant to DOE goals. However, this does seem to be something that industry should do on its own.

Question 2: Approach to performing the research and development

This project was rated **3.0** on its approach.

- The project is about developing a generic method and applying it to fuel cell storage and distribution applications. As such, it is not addressing all the technical barriers, such as cost reductions, to manufacturing of carbon fiber tanks.
- The project focuses on the application of non-destructive evaluation methods (phased array acoustic emission sensing) using inexpensive sensors with high signal/noise ratios.
- Barriers identified as fault sensitivity and nondestructive evaluation cost, but these were not quantified. Further information required, ie detectability vs. fault size, critical fault size, etc.
- Feasibility of techniques other than Modal Acoustic Emission were not evaluated technically.
- This project explored several methods of testing pressure vessels to ensure their integrity.
- The approach is sound.

Question 3: Technical accomplishments and progress toward project and DOE goals

This project was rated **3.5** based on accomplishments.

- The project demonstrated excellent results using this technology and inexpensive Polyvinylidene film sensors.
- They were able to detect defects as small as 0.005 inches using phased array technology.
- By demonstrating feasibility of using Modal Acoustic Emission methods as an alternative to current destructive testing methods, they achieved the objective of reducing cost of hydrogen storage systems.
- Good progress was shown on Modal Acoustic Emission in reducing cost and increasing sensitivity with phased array, analog/digital result agreement, and use of Polyvinylidene film instead of piezoelectric sensors.
- Demonstrated that faults and location could be identified.
- Lower cost Modal Acoustic Emission materials could be permanently inserted in tank structure at manufacture to forewarn of failure.
- Modal Acoustic Emission representative (from Digital Wave) provided significant amplification of results.
- Since acoustic noise results from energy generated in initiation of failure process, the relationship between initial fault size and ultimate safe stress must be determined for each material.
- Although this was a multifaceted project, the speaker could only best represent the Modal Acoustic Emission method.
- Modal Acoustic Emission is strictly not a "non-destructive" evaluation method because it detects the formation of cracks under pressure.
- Modal Acoustic Emission is a useful tool for (a) engineering validation, (b) manufacturing inspection, and (c) real-time detection of imminent vessel failure.
- Good progress was made.

Question 4: Technology transfer/collaborations with industry, universities and other laboratories

This project was rated **3.1** for technology transfer and collaboration.

- Although the main technical contributions are provided by Digital Wave, other participants seem to have good interactions providing realistic, commercial cases to develop meaningful solutions.
- No technology transfer or presentations indicated except among the team.
- Partnership with the American Society of Mechanical Engineers to document best practices promotes wide acceptance through the voluntary consensus standards process.

Question 5: Approach to and relevance of proposed future research

This project was rated **1.5** for proposed future work.

- There are no future plans related to overcoming any barriers.
- The main plan is to package the system for end-user friendly applications.
- No future research plan shown.
- Project is finished and future work was not addressed.
- Voluntary consensus standards are subject to continual updates and periodic revalidation.
- Not applicable. Project completed.

Strengths and weaknesses

Strengths
- Very powerful approach for improving location sensitivity and signal to noise ratio.
- Modal Acoustic Emission definitely shows a potential for nondestructive evaluation of flaws in pressure vessels and should be explored further, but inadequate information was made available to make a definite decision regarding feasibility and efficacy.
- Utilization of the voluntary consensus standard process.
- Use of Modal Acoustic Emission as early warning signal of pressure vessel failure.

Weaknesses
- The method is ideal for detecting brittle fracture, which is observed in carbon fiber tanks. However, if different materials are used in the future, the method may not be as effective.

- No quantitative comparison was shown with other techniques re: sensitivity, cost, reliability, confidence level, etc. To be considered seriously much further work is required.
- No information was provided showing the use of Modal Acoustic Emission in other industries.
- I would have liked a fuller brief on the other technologies tested.

Specific recommendations and additions or deletions to the work scope

- If further Modal Acoustic Emission testing indicates feasibility of nondestructive evaluation process, statistical data showing fault detection efficacy should be developed.