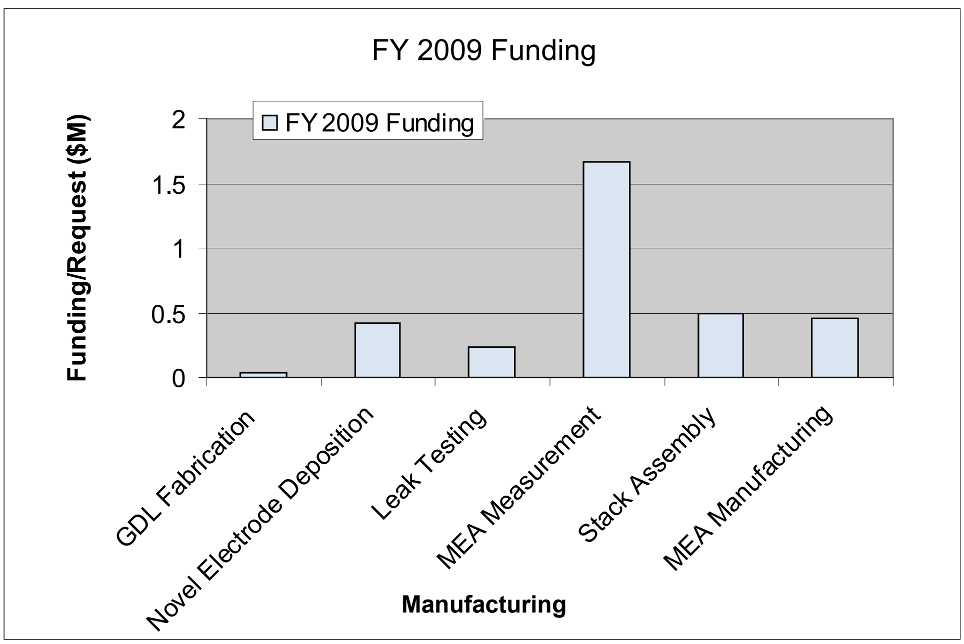
Manufacturing R&D
Summary of Annual Merit Review Manufacturing Subprogram

Summary of Reviewer Comments on Manufacturing R&D Subprogram:

The Manufacturing R&D subprogram develops and demonstrates technologies and processes that will reduce the cost of components and systems for fuel cells, hydrogen storage, and hydrogen production to enable the growth of a strong domestic supplier base. The activities focus on near-term cost goals for early market applications. In FY 2009 six new manufacturing projects, started in late FY 2008, were reviewed along with two continuing projects. The continuing projects addressed fuel cell membrane electrode assembly (MEA) manufacturing and fabrication of catalyst-coated membranes. In addition to new manufacturing R&D on low-cost, durable MEAs, the subprogram added work on gas diffusion layer production and fuel cell stack in-line testing. Two of the new projects addressed lower cost manufacture of high-pressure containment vessels for hydrogen storage.

Manufacturing R&D Funding:

Funding for the Manufacturing R&D subprogram was level for FY 2008 and FY 2009 at approximately $5M per year. All current projects are scheduled to continue through FY 2009 with future efforts subject to appropriations.



Reviewer Comments and Recommendations:

The manufacturing projects were rated high to average with six individual projects rated at 3.2 or higher. Overall ratings ranged from 3.5 to 2.4. All projects were judged to be relevant to the DOE hydrogen and fuel cell activities with good or adequate technical approaches employed in the R&D. In most cases, project progress and accomplishments were judged as satisfactory; however in several projects it was difficult to judge progress since the work had been underway for only six months or less. Project teams were judged to be strong for most projects with partners having demonstrated experience and expertise in the required technical disciplines. In general, reviewers felt that, particularly early in the project, more effort should be devoted to quantifying and validating potential cost reductions. Lower manufacturing costs were judged to be an important rationale for continuation of the projects in the future.

The highest ranked (3.5) projects were:

- "Reduction of Fabrication Cost of Gas Diffusion Layers," Ballard Material Products. Reviewers considered this new project to be highly relevant, with an excellent approach, progress, and strong technology transfer and collaborations.

- "Digital Fabrication of Catalyst Coated Membranes," Pacific Northwest National Laboratory. Reviewers also considered this continuing project to be highly relevant with a strong approach to complete the proposed research and project objectives on schedule in FY 2009.

The lowest ranked (2.4) project was "Inexpensive Pressure Vessel Production through Fast Dry Winding Manufacture," Lawrence Livermore National Laboratory. This project was judged to be relevant but lacked sufficient discussion of technical and cost details due to disclosure restrictions of propriety information.

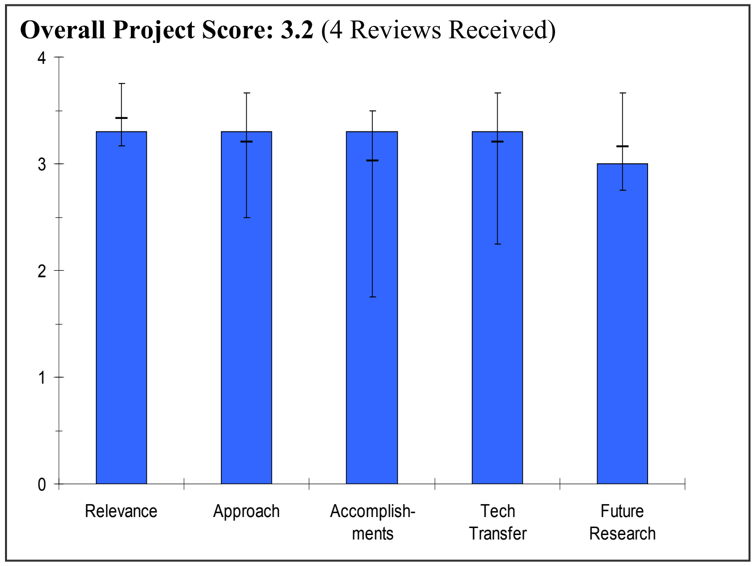
In summary, manufacturing was considered to be an important key element for fuel cell and hydrogen technology commercialization. The Manufacturing R&D subprogram was judged to be well-managed, organized, and focused on addressing programmatic performance targets.

Project # MF-01: Fuel Cell MEA Manufacturing R&D

Michael Ulsh and Huyen Dinh; National Renewable Energy Laboratory
Adam Weber; Lawrence Berkeley National Laboratory

Brief Summary of Project

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



Question 1: Relevance to overall DOE objectives

This project earned a score of **3.3** for its relevance to DOE objectives.

- The objective of this project is to evaluate membrane diagnostics for various types of defects.
- If these in-line, 2-D, image-based diagnostic methods can be reliably used for most or all in-line evaluation of proton exchange membrane (PEM) roll stock production quality assurance, it would have a significant impact on fuel cell costs and reliability.
- An understanding of defect thresholds is important in the identification and development of diagnostic methods.
- MEAs represent a significant opportunity for PEM fuel cell cost reduction, and the project is attempting to address program cost reduction goals.
- The relationship between MEA dimensional defect detection and part/stack/system cost needs to be developed to better understand the cost reduction potential of this effort.

Question 2: Approach to performing the research and development

This project was rated **3.3** on its approach.

- This is a good approach.
- This appears to be a logical approach in establishing relationships between various defects and effects in cell/stack assemblies, then applying specifications to measurement methods.
- The approach towards identifying the means to identify certain defects and the defects' impact on performance and durability is sound.
- It is not yet clear what cost savings can be realized by reducing defect frequency or severity. Additionally, while identifying defective components before delivery is an important aspect of quality control, potentially greater cost savings could be achieved by working towards defect reduction (maybe this is a step left to the component manufacturers).
- Milestones beyond September 2009 could be more clearly identified.

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

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

- This project established a development platform in addition to standard industry practices for membrane samples.
- This is a good use of test methods across single cells and multiple/segmented cells.
- Progression of NREL diagnostic from concept to in-practice since 2008 is good.
- In the segmented cell experiments, the ability to potentially locate a defect in an assembly doesn't translate into in-line membrane and MEA production, but it would be valuable for sub-assemblies and assemblies *if* it works with single and multiple defects.
- Defect identification effort has made appreciable progress but the overall value of the project relies on the successful establishment of defect threshold values through modeling/experimental work and collaboration with industry partners.

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

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

- This is a good mix of universities, small business, national labs, but no industry partner. Collaborations are mostly universities, but the team should consider an industry partner for guidance.
- An impressive set of collaborators, including Nafion®-like and would-be polybenzimidazole membrane suppliers.
- Appropriate collaborators have been identified, but it is not clear to what degree some are contributing. This may be somewhat an artifact of the progression of the overall effort.

Question 5: Approach to and relevance of proposed future research

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

- The team should add industry partners to validate future work. Is there any way to get additional industry partners (in addition to the two) to participate? The program appears to be limited to just these; it would be good to get additional feedback/testing methods from others.
- Proposed work looks good. Maintaining a close relationship among test/diagnostic/model developers and manufacturers will be critical as the project proceeds.
- Future technical efforts are clearly described, but neither decision points nor possible risk mitigation approaches are delineated.
- Future work needs to characterize the cost implications of reductions in deliveries of defective components.

Strengths and weaknesses

Strengths
- Strong base of industry and academic contributors.
- There is good collaboration among the team. Developing procedures and hardware that can have a positive impact on a broad segment of fuel cell industry.
- Good overall technical approach and progress.

Weaknesses
- Should have additional industry partners.
- Critical information, particularly defect thresholds, has not yet been ascertained. This effort should have preceded the identification effort as knowing what you need to find is important in identifying how to find it.
- Cost implications of defects need to be identified.

Specific recommendations and additions or deletions to the work scope

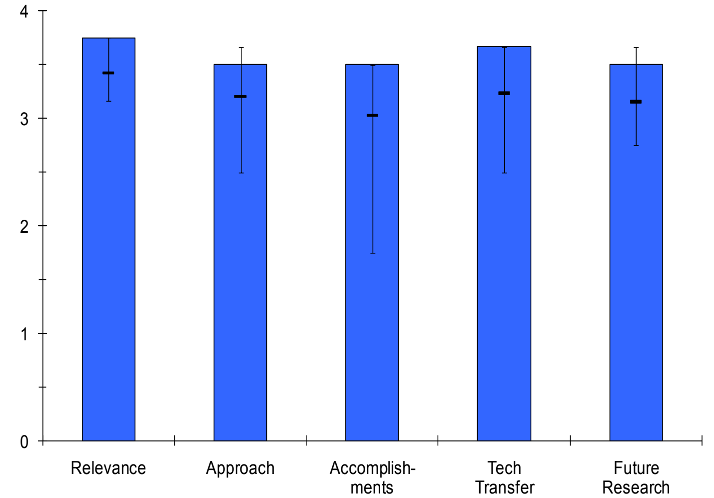
- The scope appears correct. I look forward to future progress reports.
- Since 2-D image data is used in full-area diagnostics, there may be value in adding the software for a 2-D autocorrelation routine for identifying non-random defect sources in a real manufacturing environment.
- It would be valuable to be able to model a relationship between the measurements of defects in MEA production runs vs. final cell/stack costs in $/cm^2 or $/kW. Presenter stated that they hope to do this. The model needs to be capable of adapting to different manufacturers' processes.
- Are developers looking at other fuel cell types besides PEM? Solid oxide fuel cell may be amenable to transmission diagnostics.

Project # MF-02: Reduction in Fabrication Costs of Gas Diffusion Layers
Colleen Legzdins; Ballard Material Products

Brief Summary of Project

The objectives for this project are to 1) reduce the fabrication costs of gas diffusion layer (GDL) products and demonstrate the means of achieving six sigma quality standards at high-volume manufacturing, 2) produce high-performance GDLs at lower cost in the near term, and 3) verify the design of a new production facility incorporating new GDL process technologies to meet automotive volume requirements at the DOE 2015 cost target of $30/kW for the fuel cell system (GDL cost target = $4/kW).

Overall Project Score: 3.6 (4 Reviews Received)



Question 1: Relevance to overall DOE objectives

This project earned a score of **3.8** for its relevance to DOE objectives.

- The methods outlined to reduce GDL costs and develop online quality control are very important; if successful, they will immediately feed and expand parent company's markets.
- It was not entirely clear whether the manufacturing improvement processes being looked at were scalable to commercial levels. Some discussion of manufacturing volume range would be helpful.
- The presentation was well laid out to identify various processes being targeted.

Question 2: Approach to performing the research and development

This project was rated **3.5** on its approach.

- This reviewer would have appreciated more details on the online tests.
- What metrics are being used to measure improvement? Without revealing manufacturing details, could frame the measurement as percent reduction in number of coats, increase throughput by X%, etc.
- How are the online tests being used for quality control? Are they being related to actual performance data?
- Good discussion on involvement of manufacturing personnel and integration with existing processes / techniques.
- Good review of processes being identified for cost improvements.
- A process flow diagram of the GDL manufacturing process that identifies the process steps that have the greatest impact on overall cost would have been helpful.
- It was difficult to understand the relative benefits of the various process steps being discussed. Does ink-mixing impact cost more than ex situ testing? It probably does not.

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

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

- Without a reference of numerical improvement (e.g., X% decrease in time to make ink), it is harder to gauge actual progress.
- This reviewer would like to know what, if any problems were encountered during the tasks and how they were overcome. Otherwise, the project appears to be on track.
- The coating weight scan is a great advance.

- While this is the first year of the project, it appears many key components are ahead of schedule.
- Outstanding progress relative to being a new project.
- The team has isolated two key manufacturing line processes elements whose improvement has the potential to significantly reduce costs.
- In-line measurement and product property variation versus performance study is an excellent plan as feedback to optimize key manufacturing line process elements under investigation.
- Accuracy evaluation relative to international standards for surface topography measurements shows good understanding of metrology.
- Excellent overall consideration of the vast array of measurement technologies available in all aspects of the manufacturing process. Great understanding of the factors that affect measurement performance.
- Since it is early in the project, few results can be expected yet.

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

This project was rated **3.7** for technology transfer and collaboration.

- The main partner appears to be parent company Ballard Power Systems.
- Good addition to now include NREL/M. Ulsh in addition to Pennsylvania State University.
- It appears that Pennsylvania State University is the only substantive partner external to Ballard Material Products. To be successful in this project, Ballard is very dependent upon its ability to apply established in-house processes and protocols for other Ballard product lines to the new GDL product.
- It appears that collaboration teams are identified and apparently working well.
- This reviewer is not entirely clear what the different roles are for each collaborator.

Question 5: Approach to and relevance of proposed future research

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

- The project is “on plan,” and future actions are appropriate to achieve objectives.
- Again, Ballard's progress will be predicated on its ability to transfer protocols and processes for other Ballard products to the new GDL product.
- Future research is very aggressive. This is great.
- Most of the project is yet to be performed. "Future Work" beyond this project should be easier to identify once more results start coming out of this project.

Strengths and weaknesses

Strengths
- This program covers a full line of coating processes (i.e., ink delivery, reduction of steps) and online measurement of various parameters.
- The project has full control of web (carbon paper) manufacture.
- Ballard's good track record as a manufacturer of products using similar materials and processes is a strength.
- The manufacturing process element improvement is good.
- Online, in situ measurement is a strength.
- Structure and manufacturing processes are identified well.

Weaknesses
- This reviewer would like to see more metrics on improvement for the various tasks and subtasks, even if they are relative or normalized.
- The relative impact on the cost of each process step is not clear. They are probably clear to the PI, but they were not communicated during the presentation.

Specific recommendations and additions or deletions to the work scope

- Is there room to add modeling of the impact of defects on MEA performance to determine what value of a defect is critical? For example, how would you relate the roughness scan to performance and a specification?

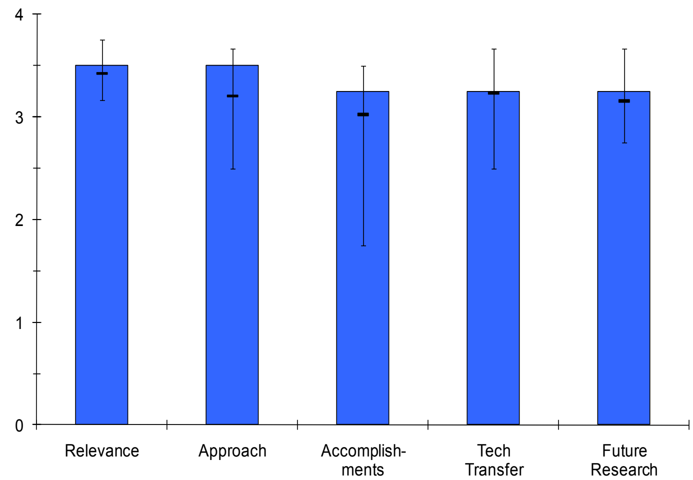
Project # MF-03: Modular, High-Volume Fuel Cell Leak-Test Suite and Process

Ian Kaye, Ru Chen, and Matt Mendez; UltraCell Corporation
Peter Rieke and Dale King; Pacific Northwest National Laboratory
Gordon Splete; Cincinnati Test Systems

Brief Summary of Project

The objectives for this project are to 1) design a modular, high-volume fuel cell leak-test suite capable of testing in excess of 100,000 fuel cell stacks per year (i.e., 50 fuel cell stacks per hour), 2) perform leak tests inline during assembly and break-in steps, 3) demonstrate fuel cell stack yield rate to 95%, 4) reduce labor content to 6 minutes, and 5) reduce fuel cell stack manufacturing cost by 80%. Phase I of the project will focus on analysis of the manufacturing process, stack failure modes, and leak-test methods; prototype design and fabrication; and leak-test suite design. Phase II will include pilot production line modification; leak-test suit fabrication, integration, and verification; and a limited production test run.

Overall Project Score: 3.4 (4 Reviews Received)



Question 1: Relevance to overall DOE objectives

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

- This was a good presentation, and it appears to have good progress at 20% level.
- This is a key area in terms of fuel cell performance and durability.
- This project is very relevant to the fuel cell manufacturing initiative at DOE. A means of quickly determining whether or not an assembled stack is leak-free would be a significant contribution. The as-assembled UltraCell fuel cells have inconsistent quality with significant variations in yield from batch to batch. This test fixture appears to be designed specifically for UltraCell; therefore, even if it is successfully developed, it may not be universally applicable.
- This is very relevant to the DOE objectives for cost and reliability improvements in fuel cell power systems as they are evolving in the early portable market.

Question 2: Approach to performing the research and development

This project was rated **3.5** on its approach.

- This is a good use of the flexo-tiltometer, particularly in the identification of the use of bolts. The material costs seem expensive.
- I have been impressed with the manufacturing expertise of the people that UltraCell has brought into the program. Great background and understanding of how to interject quality control principles into the manufacturing process, first with Deming and then with Six Sigma.
- The approach is to use the manufactured stack as part of the sensor network. The presentation indicates that the yield for finished stacks is quite variable. This being the case, testing finished products may result in considerable wastage. Testing materials and/or stacks during assembly, rather than after, would appear to be a better approach. If this is not possible, use the resources to improve the yield of the fuel cell stacks to begin with. However, the project would have more significance if a test fixture could be developed to check the health of stacks before they are completely assembled. Once the yields become more consistent, the approach of

developing a test fixture appears sound. The specifications for the test sensor are being continually refined as defects and/or leaks in assembled stacks are discovered. This is a good thing.
- Combining manufacturing process analysis, stack failure modes and effects analysis (FMEA), and leak test development is a good mix for leveraging investment into improvements in system cost, reliability, and production rates.
- For high-rate stack leak checking, investigator's approach provides what appears to be a robust set of methods to do the job. From a presentation answer, it looks like the diagnostics of pressure distribution, compression, and leak current is, or will be, implemented on every cell during assembly. This is great, if true.

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

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

- This is a good use of partners and evaluation of technologies.
- The potential of the learnings from this project to successfully transfer to other fuel cell technologies is uncertain.
- Progress is pretty good for roughly six months of work completed before the presentation needed to be submitted. A greater discussion of the analysis of the manufacturing process would be beneficial, particularly since the analysis could show the path to better yields.
- Good test results that translate into good test hardware and protocols for testing as-built stacks.

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

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

- Very well done.
- UltraCell has brought together a good team.
- Collaboration appears to be going well, particularly between UltraCell and PNNL.
- Project lead is a significant fuel cell system provider. The collaboration with PNNL will benefit from their background in fuel cells and systems.

Question 5: Approach to and relevance of proposed future research

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

- On track for go/no-go decision.
- The future work plan is good and builds on past successes while learning from failures.
- The leak-test prototype brassboard planned for FY 2009 should quickly show the value of an ultimate 50 pph (i.e., 50 fuel cell stacks per hour) test system from this project.

Strengths and weaknesses

Strengths
- UltraCell's focus on quality control in the manufacturing process is a strength.
- Very well thought out and organized project.
- The implementation of test methods into company's production line as they are developed provides a rapid translation of a DOE project into a realistic industry benefit.

Weaknesses
- The potential of the solution from this project to transfer to other fuel cell technologies seems weak.
- It is not clear how the development of this test suite will be used to improve stack yield. The process analysis needs to be explored.

Specific recommendations and additions or deletions to the work scope

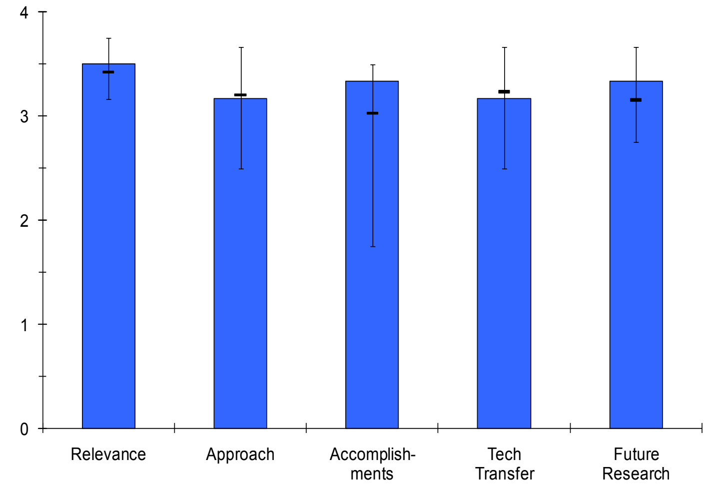
- Perhaps some interaction with an organization with expertise in improving the manufacturing process would be helpful.

Project # MF-04: Manufacturing of Low-Cost, Durable Membrane Electrode Assemblies Engineered for Rapid Conditioning

F. Colin Busby; W.L Gore and Associates, Inc.

Brief Summary of Project

Overall Project Score: 3.3 (6 Reviews Received)



The overall objective of this project is to develop unique, high-volume manufacturing processes that will produce low-cost, durable, high-power density 3L (3-layer) membrane electrode assemblies (MEAs) that require little or no stack conditioning. Objectives include 1) developing a manufacturing process scalable to fuel cell industry MEA volumes of at least 500,000 systems per year, 2) developing a manufacturing process consistent with achieving the \$15/kW$_e$ DOE 2015 transportation stack cost target, 3) the product made in the manufacturing process should be at least as durable as the MEA made in the current process for relevant automotive duty cycling test protocols, 4) the product developed using the new process must demonstrate a power density greater or equal to that of the MEA made by the current process for relevant automotive operating conditions, and 5) the stack break-in time should be reduced by at least 50% compared to the product made in today's process, and break-in strategies employed must be consistent with cost targets.

Question 1: Relevance to overall DOE objectives

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

- This project addresses the lack of high-rate manufacturing processes for MEA fabrication. It is very relevant to the DOE Fuel Cells Subprogram objectives and is important to enable the cost of MEAs to meet the DOE targets.
- Project goals are laudable and relevant to DOE goals for improving proton exchange membrane (PEM) MEA production. If the remaining tasks for this phase can be accomplished, there should be a valuable lab-scale production prototype for lower-cost production.
- The project is addressing cost issues associated with MEAs, but there is conflicting information regarding whether durability is to be improved or simply maintained.
- Relevance to overall program was well defined in the presentation. There was an obvious attempt to tie the project goals to DOE's overall goals.

Question 2: Approach to performing the research and development

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

- The approach is logical and has identified the areas in which improvements are sought. Reduction in materials (e.g., eliminating the backing layer and direct coating) and wastage is key, as is understanding MEA failure mechanisms during fabrication and conditioning. Gore plans to address both issues in this project. W.L. Gore & Associates is anticipating a 25% reduction in material cost; reductions in conditioning cost will also be considered.
- There are numerous diverse subtasks related to reducing cost and improving durability. All are worthy of doing, but not sure if the project plan is an optimization of these activities.

- Phase 1 cost modeling nearly completely relies on a thinner membrane (still with ePTFE [expanded polytetrafluoroethylene] reinforcement?), direct coating for one electrode, and removal of backers in process. Will this be demonstrable in any of the production prototypes supposedly developed and built in the remainder of CY 2009?
- The approaches for both mechanical property and conditioning modeling are appropriate.
- More details concerning the cost modeling approach should have been provided.
- The approach is well formulated.
- The approach seems well thought out. More detail on the downselect of cost-reduction processes that will be modeled would be nice; however, there was not enough time in the presentation or room on the submitted materials to cover all the material. This was not the presenter's fault.

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

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

- Progress on this project is reasonable. It is scheduled to end in December 2009. The schedule appears to be quite aggressive and may need to be extended. Preliminary results from the cost model indicate the possibility to reduce 3-layer MEA manufacturing cost by 25%. However, it is not clear if this reduction will meet the DOE MEA cost target because a baseline cost was not presented.
- The mechanical testing and property data generation is valuable to the remainder of the project.
- The integration of modeling and data for a new conditioning model should prove very useful in designing a new MEA and manufacturing method.
- The cost model indicates the potential for 25% MEA materials cost reduction, which when added to potentially reduced conditioning costs, would help in meeting DOE goals.
- Membrane durability testing shows good progress although it is unclear if continuous and cyclic testing were performed within one test sequence or separately (either consecutively or in parallel).
- More details concerning the cost reduction effort should have been presented. It could be clearer how the potential cost savings will be realized.
- There is some risk that modifications to production processes to reduce cost will not maintain performance or durability relative to the baseline. Risk mitigation approaches should be examined.
- This is early in the project, so accomplishments are understandably "slim" so far.
- More definition on the "failure criteria" baseline would be helpful. The benchmarks and the trade-offs between cost and quality were not clear. Would slightly less quality yield higher cost savings, but still be acceptable? It probably just needs a bit more explaining.

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

This project was rated **3.2** for technology transfer and collaboration.

- Collaboration is strong between Gore, UTC Power, and the University of Connecticut. Each brings appropriate skills to bear on the problem.
- This looks like an appropriate and good collaboration.
- The team incorporates experienced partners, but the overall effort does not seem to be terribly integrated. (It almost seems like three separate projects under one umbrella).
- The responsibilities of each team member were clearly spelled out.

Question 5: Approach to and relevance of proposed future research

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

- The work plan is well laid out and focuses the remaining resources on the appropriate activities, such as on the conditioning model development and on the installation of continuous lab-scale equipment.
- The planned future work on completing and testing the models is important in meeting goals for future MEA and process designs. The prototype design, build, and test phases for lab-scale production equipment will be the

ultimate validation for the designs and modeling. There should be some iteration and contingency time included in the plan.
- The planned work for new production processes/cost reduction seems appropriate.
- In other areas, the future work needs more detail concerning decision points and the relationships/interactions between different project aspects.
- Since it is early in the project, there was understandably not a lot of detail on future work. Program plans, however, were clearly explained.

Strengths and weaknesses

Strengths
- Very good team that includes industry leaders. Baseline MEA meets the DOE durability targets (9,000 hours with no sign of failure) so that membrane development will not consume resources that can be spent on the manufacturing process development.
- Good planning for the modeling and experiments required to make decisions on new MEA manufacturing processes. The resulting models and database will be helpful in other future projects regarding improved cell designs and manufacturing.
- An experienced team working on important potential MEA cost reduction avenues is a strength.
- Key collaborators are in place for research, modeling, and testing, which is a strength.
- Rapid conditioning emphasis is excellent.
- Good team and well planned project. The concept of modeling before implementation is the way to go.

Weaknesses
- The schedule may be too aggressive. It is hard to know if a 25% reduction in MEA cost will meet the DOE cost targets.
- The project scope is probably more ambitious than remaining schedule allows.
- Weak (or unclear) interaction and coordination of seemingly disparate team member efforts is a weakness.
- Nothing really problematic was identified in this project.

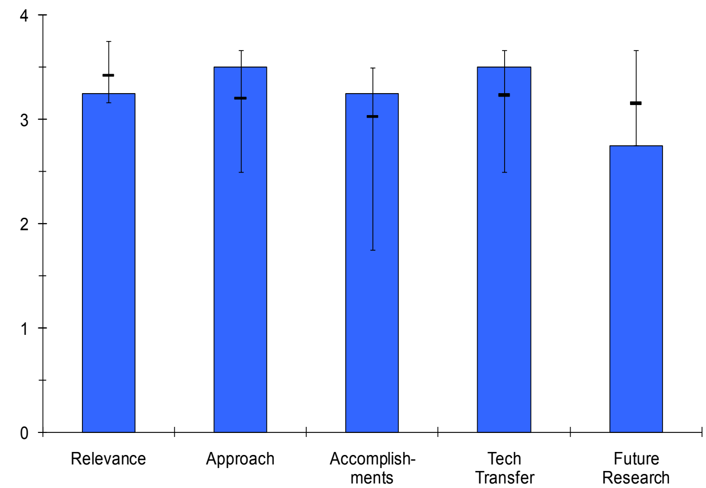
Specific recommendations and additions or deletions to the work scope

- Regardless of proprietary considerations, some indication of the cost of the baseline MEA should be provided.
- Consider a change of scope or extending the remainder of this project.
- Make an addition to the project to develop/evaluate, integrate, and demonstrate process control strategies.

Project # MF-05: Adaptive Process Controls and Ultrasonics for High Temperature PEM MEA Manufacture

Raymond Puffer; Rensselaer Polytechnic Institute

Overall Project Score: 3.3 (4 Reviews Received)



Brief Summary of Project

The overall objectives of this project are to 1) achieve greater uniformity and performance of high-temperature membrane electrode assemblies (MEA) by the application of adaptive real-time process controls (APC) combined with effective in situ property sensing to the MEA pressing process and 2) greatly reduce MEA pressing cycle time through the development of novel, robust ultrasonic bonding processes for high-temperature (160-180°C) proton exchange membrane (PEM) MEAs.

Question 1: Relevance to overall DOE objectives

This project earned a score of **3.3** for its relevance to DOE objectives.

- The project is relevant to the DOE Fuel Cells Subprogram.
- High temperature PEM MEAs will likely play a major role in fuel cell system commercialization, and adapting manufacturing and quality assurance methods relevant to PA-PBI (phosphoric-acid-doped polybenzimidazole) membranes and MEAs will provide an important contribution to DOE's and industry's commercialization goals.
- Adaptive process control has the potential to markedly increase MEA manufacturing quality and therefore reduce costs.
- The project would have more relevance if it was not limited to high-temperature MEAs, and there is some uncertainty regarding the ability to scale up the ultrasonic process to larger cells.

Question 2: Approach to performing the research and development

This project was rated **3.5** on its approach.

- The project hopes to improve the uniformity and performance of UltraCell's high-temperature MEAs through adaptive process control over the hot pressing cycle. A second objective is to reduce the cycle time for the pressing operation through the use of ultrasonic welding techniques. UltraCell has had difficulty in achieving consistent performance from its fuel cells as seen in Project MF-03. It is not clear that this effort will improve the consistency of the fuel cells. A better understanding of the cause of the performance variability is needed.
- Adaptive process control and design-of-experiments strategies are well thought out.
- Model validation using miniature thermocouples in ultrasonic (U/S) and thermal pressing may be a challenge.
- U/S welding and sealing of MEAs would be a major improvement for production of PBI MEAs. This looks very promising.
- Design of experiments is an excellent approach for determining the influence of various fabrication parameters.
- Potential cost savings analyses should be performed earlier in the overall project.

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

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

- The project is new and demonstrated the feasibility of ultrasonic welding with a cycle time of less than one second as compared to about one minute for thermal bonding. Details on the modeling task are lacking in the presentation.
- U/S welding and sealing of MEAs prior to the use of APC looks promising.
- It will be important to identify the reasons for the slight departure of the ohmic region of the polarization curve. It looks like either a resistive change from interfacial or bulk resistivity, mass transfer reduction from diffusion layer compression, or both. Good that there will be extensive experimentation for optimization of U/S processing and identification of process control parameters.
- This early-stage project is showing promising early results.
- No indication yet of potential cost savings from ultrasonic fabrication process. Also, performance and durability of MEAs made with an ultrasonic process needs to be confirmed.
- Not clear if adaptive process control can be successfully implemented in fabrication process if cycle time drops to less than one second.

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

This project was rated **3.5** for technology transfer and collaboration.

- Solid list of industry and academic partners are on this team.
- The partners appear to have effective collaboration. BASF Fuel Cells is an important team member because they supply the high-temperature MEAs for UltraCell.
- An outstanding, complementary list of collaborators.
- For an early stage project, the level of team collaboration and coordination is adequate.

Question 5: Approach to and relevance of proposed future research

This project was rated **2.8** for proposed future work.

- While this seems like a strong team, the long intervals between future milestones are of concern – more than one year between the second and third phase. The time plan does not explain why this interval needs to be greater than a year.
- The project appears to be long when considering the hoped for results.
- The future research looks good. In Phase III, the APC work could require significant iterative development and should be planned for.
- The scope of future work is appropriate, but there is little indication of the timing of and interaction between future work elements. Decision points are not clearly defined.

Strengths and weaknesses

Strengths
- Good team organization. The ultrasonic welding technique could be applied to low-temperature MEAs if it proves successful at reducing cost.
- Very good organization and collaboration.
- Excellent approach to the work plan.
- This early-stage project is showing promising results.

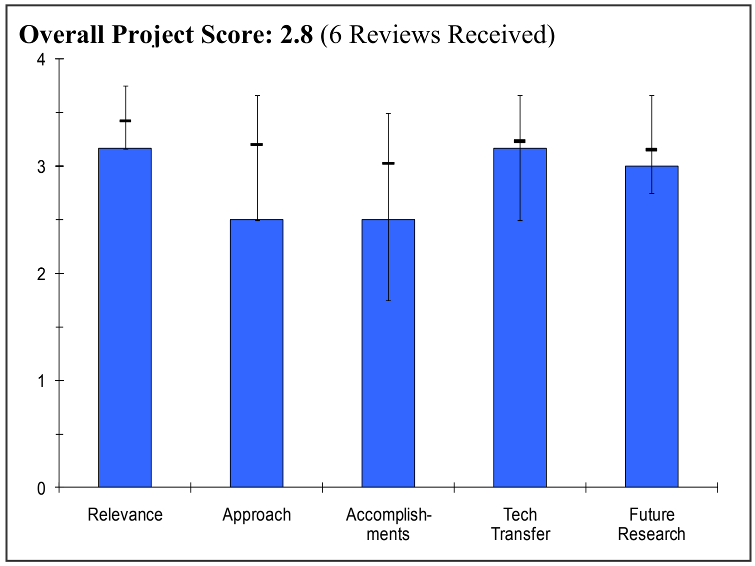
Weaknesses
- The project needs additional effort in assessing potential cost reductions

Specific recommendations and additions or deletions to the work scope

- Concentrate more on UltraCell's lack of consistent performance. Perhaps add scope or reduce project duration.

Project # MF-06: Development of Advanced Manufacturing Technologies for Low Cost Hydrogen Storage Vessels

Carter Liu; Quantum Fuel Systems Technologies Worldwide Inc.
Bruce A. Johnson; The Boeing Company



Brief Summary of Project

The overall objective of this project is to manufacture Type IV hydrogen storage pressure vessels, utilizing a new hybrid process with the following features: 1) optimal elements of flexible fiber placement and commercial filament winding and 2) reduced production cycle times by adaptations of high-speed "dry winding" methodology. The aim is to achieve a manufacturing process with lower composite material usage, lower cost, and higher efficiency.

Question 1: Relevance to overall DOE objectives

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

- High-pressure compressed hydrogen is one of the primary methods of transport and storage of hydrogen, and economically acceptable methods of manufacture need to be pursued.
- The project is very relevant to the DOE Fuel Cells Subprogram as it seeks to reduce the cost of high-pressure hydrogen storage tanks, which is the only technology currently available for storing hydrogen on board a vehicle. Reductions in cost and weight are important even if the volumetric storage density will not be improved much.
- Uncertain valuation of combined processes of fiber winding and advanced fiber placement. The significance of weight savings may not warrant the additional process costs.
- Tank improvements employing advanced fiber placement and fiber winding are apparently an incremental improvement from the existing composite tanks used in vehicles.
- The project is relevant to DOE objectives but there is little indication that cost reductions can be realized from the somewhat varied efforts within the project.
- This is borderline "Good/Fair." It looks as much like a product development/research project as it does a manufacturing process project. Fiber placement and dome design, plus evaluation of liner polymers, does not seem as related to manufacturing as to product improvement.
- Cost goals were not clearly defined. There was discussion of reduction of the fiber required, but it was not clear what cost that represents.

Question 2: Approach to performing the research and development

This project was rated **2.5** on its approach.

- A number of significant weaknesses in the program description are evident.
- Little attention is paid to test evaluation of the composite structures fabricated. Specifically, how will they be tested? What instrumentation will be employed? Will the tanks be tested to operating pressure, burst or cycles?
- No evidence of stress analysis was given to assure the new winding patterns will be practical and give sufficient safety factors. The contributing organizations are experts in these areas; however, no evidence of addressing these deficiencies was given in this presentation, and the PI did not adequately address questions posed at the end of the presentation.

- The approach brings together leaders in the field of fabrication with composite material sets. Fiber placement has been thought to be a viable approach to reducing the amount of expensive carbon fiber in filament-wound storage tanks. Developing a cost model is absolutely necessary to determine whether or not this approach makes sense. The project will also examine a long-shot approach to tank fabrication being developed by LLNL.
- The hybrid fiber winding and advanced fiber placement process effort and tape fabrication processes seem to be significantly different from each other enough, that they may have been better served in separate projects.
- The approach to performing the work is generally rational and appropriate for addressing barriers.
- The liner work could provide assistance in mitigating cylinder thermal limitations due largely to fueling thermodynamics.
- The LLNL work is insufficiently characterized, and it is not clear how it integrates into the overall project.
- It almost seemed like three separate projects under one umbrella. Possibly, it is just because there was limited time for the presentation, but the interdependence between the three partners' work was not clearly demonstrated.
- There was little discussion of testing protocols for assuring that structural integrity is maintained with new fiber wrap placements (except for dome area).

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

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

- The program is in the very early stages, and significant accomplishment would not be anticipated.
- The project was about six months old when the presentation materials were due, so progress has not been great. At the time the presentation was due, the cost model should have been largely developed according to the schedule provided. If this was so, some details of the model and any preliminary results should have been presented – at least a baseline against which to compare reductions achieved through this project. Reaching the go/no-go decision point with adequate data upon which to make the decision is key to the project.
- The assessment of scalability for fiber placement is important for project, but it is not evident how much of an assessment there is to the capability for scaling for dome-end fiber placement.
- Quantum's filament winding accomplishments listed (slides 7, 8) look like their traditional winding process. Was there an additional accomplishment during this reporting period?
- For an early-stage project, some progress is being made.
- The combination of filament winding and fiber placement trades material cost for capital and processing cost, and it is not clear if any cost savings can be realized. Additionally, the filament winding process is characterized as having high repeatability, a high level of automation, low labor cost, high accuracy, and a relatively fast process cycle time. What precisely is going to be improved?
- It is too early to tell. Even with modeling it is hard to see if material and weight savings will exceed equipment investment (the inclusion of the cost model is excellent consideration but needs figures to ascertain the benefit).
- This is early in the project so a lack of demonstrable progress is understandable.

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

This project was rated **3.2** for technology transfer and collaboration.

- The team assembled has the technological expertise to carry out the program adequately.
- This is a good team. Boeing has tremendous experience in fabricating composite structures for the airline industry. They are attempting to adapt and scale down the processes to tank fabrication requirements. The LLNL work could provide a large payoff if successful.
- The hybridization of Quantum's history in filament winding with Boeing's fiber placement looks like an opportunity to develop a new standard for composite tank design. LLNL's contribution with a high-risk, high-payoff approach of tape fabrication can increase the project's likelihood for success. PNNL's modeling and compatibility studies are helpful.
- Boeing is an experienced and knowledgeable partner that appears to be fully engaged.
- The LLNL work does not seem well coordinated.
- Each of the partners' roles in the project was described adequately. The interdependence of the work (as mentioned above), however, was not entirely clear.

Question 5: Approach to and relevance of proposed future research

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

- The future plans need to be adjusted, such as to clarify stress analysis, safety margin, and test methodology.
- Most of the work in this project is yet to come. The plans going forward look reasonable and logical.
- It would be very helpful to the DOE program if the "Go/No-Go decision → demonstrate process can reduce material usage and cost" step was moved ahead of the June 2010 Merit review. At least some qualitative assessment of the potential for weight and cost reduction using the hybrid process should be completed by then.
- While the elements of future work are identified and seem appropriate, there is little indication of the interaction between some of the elements, and timing is unclear. Decision points are not clearly defined.
- Most of the project has not yet occurred. Future work/milestones were described sufficiently.

Strengths and weaknesses

Strengths
- Demonstration of advanced composite tank winding manufacturing methods is a strength.
- Good team makeup.
- Teaming is strong. Good and relevant histories for composites and tanks with Quantum, Boeing, and LLNL.
- PNNL hydrogen compatibility study can translate to other polymer/composite hydrogen pipeline development done elsewhere.
- A solid team with good interaction and coordination.
- This project could provide incremental improvements in cost and manufacturing of Type IV pressure vessels.

Weaknesses
- Demonstration of understanding of analysis of stresses, safety factor, and required testing protocols is weak.
- Investigators need to demonstrate that there can be a significant value to the DOE Hydrogen Storage Subprogram that can result from the addition of advanced fiber placement process to the filament winding method.
- It is not clear that costs can be reduced (and therefore barriers be addressed).
- Is this project correctly categorized as manufacturing, or should it be product development research?

Specific recommendations and additions or deletions to the work scope

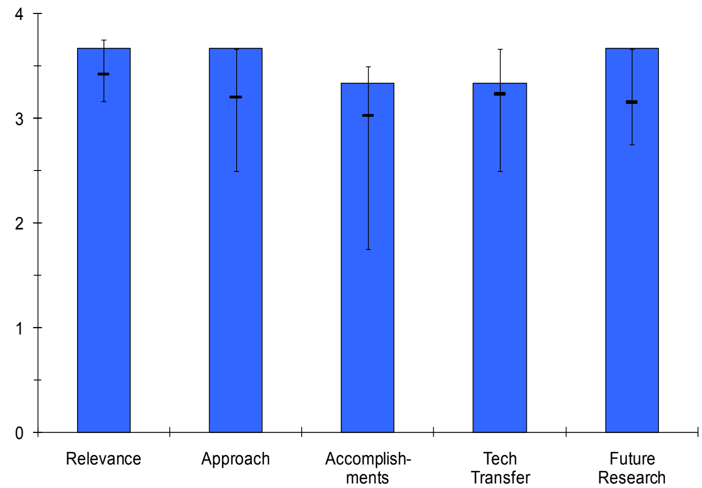
- Detailed stress analysis in dome and transition areas to compliment advanced manufacturing method development should be added to the project.
- Quantum should be required to provide a true baseline cost estimate and accurate projections regarding the advancements possible in this program.
- If there is a significant increase in safety factor at constant weight using the hybrid process, would that have a greater value than a reduction in weight at constant pressure? (Are they helping improve real or perceived safety of 700 bar automotive tanks?)

Project # MF-07: Digital Fabrication of Catalyst Coated Membranes
Peter C. Rieke and Silas A. Towne; Pacific Northwest National Laboratory

Brief Summary of Project

The overall objectives of this project are to 1) demonstrate basic process steps in the digital fabrication of catalyst-coated membranes (CCMs) and membrane electrode assemblies (MEAs), including ink formulation and delivery with industry standard print heads, catalyst layer quality and mechanical durability, and electrochemical utility; 2) define advantages and disadvantages of digital fabrication including the reduction of large run MEA fabrication cost, versatile and agile process line, and the integration of new technology; and 3) identify the unique advantages of digitally fabricated CCMs, including Z gradation in composition.

Overall Project Score: 3.5 (3 Reviews Received)



Question 1: Relevance to overall DOE objectives

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

- The effort is relevant to program goals and has the potential to be a significant process improvement and cost reduction.

Question 2: Approach to performing the research and development

This project was rated **3.7** on its approach.

- The approach to the work is generally appropriate and should address identified barriers.
- An initial assessment of economics is needed.

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

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

- Early results are promising, but the need for multiple passes/layers to achieve desired deposition thicknesses could impact potential cost reduction.
- The potential ability to control layer deposition in three dimensions has significant implications for MEA optimization.
- The ability to sustain or improve operational performance and durability of MEAs using new fabrication processes needs to be demonstrated.
- The technical barrier relating to low levels of quality control, specifically "Adaptation of print industry quality control process to MEA fabrication." was not achieved. It was not the fault of the PI, but rather an underfunding of the effort. The intent to address this barrier was on target, and the plan was appropriate.
- The presenter admitted that performance data of printed CCM product versus conventional product was suspect for numerous reasons. Without a reputable validation, the final product cannot necessarily be declared a success. It would not cost much, if anything, to send the CCM product to a well-validated testing lab like General Motors, Hawaii Natural Energy Institute, or LANL.

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

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

- The project team is balanced and seems reasonably well coordinated.
- Given current business conditions, General Motors' commitment to the project could be a risk factor, and the team should investigate potential alternate team members.
- Collaborators chosen were right on target. General Motors could have been more involved especially in performance testing.

Question 5: Approach to and relevance of proposed future research

This project was rated **3.7** for proposed future work.

- The proposed future work is largely appropriate, but more emphasis needs to be placed on potential cost reduction.

Strengths and weaknesses

Strengths
- There are early promising results, and this is a solid team.
- All the right players are involved in this project.
- This is a great plan and results show a potentially great outcome.

Weaknesses
- More emphasis on estimates of potential cost reduction is needed.

Specific recommendations and additions or deletions to the work scope

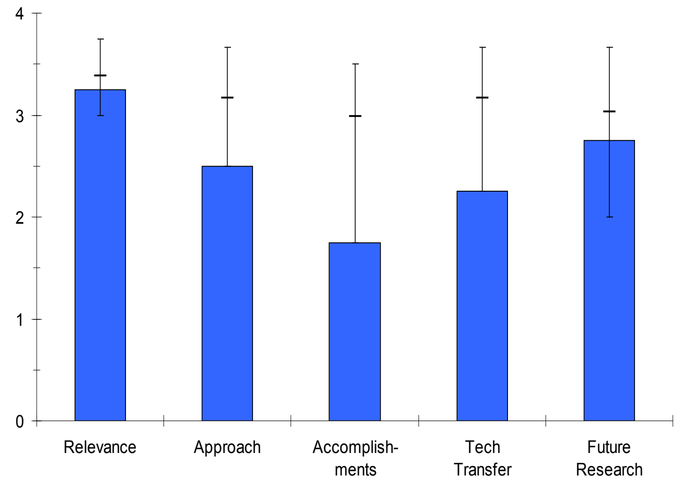
- The inkjet process could have application to solid oxide fuel cell fabrication as well, and at least a preliminary assessment should be incorporated.
- The results look very promising. Funding should be secured to bring the project to closure.

Project # MFP-01: Inexpensive Pressure Vessel Production through Fast Dry Winding Manufacture
Andrew Weisberg, Salvador Aceves, Blake Myers, and Tim Ross; Lawrence Livermore National Laboratory

Brief Summary of Project

The overall objective of this project is to reduce long-term hydrogen vessel cost to \$4/kWh (\$800 for 6 kg vessel) through innovative winding technology. LLNL has a patent pending tape fabrication technology that retains high fiber strength through continuous fiber path control. LLNL can reduce costs through high-speed dry winding operations.

Overall Project Score: 2.4 (4 Reviews Received)



Question 1: Relevance to overall DOE objectives

This project earned a score of **3.3** for its relevance to DOE objectives.

- Finding methods to reduce the overall cost of carbon fiber wound vessels will contribute tremendously towards achieving DOE objectives.
- Significant increases in winding speed are projected from the dry wind method, but no evidence supporting the supposition are given to support this claim due to proprietary information.
- This was a very good presentation with good analysis and identification of return on investment (ROI) from an invention.
- Assuming the loosely described effort yields feasible results, the project could provide some cost reduction; though at this time, it is not clear how significant the reduction could be.

Question 2: Approach to performing the research and development

This project was rated **2.5** on its approach.

- The concept of using tape versus a cumbersome curing method is intriguing. This approach could eliminate the costly winding and curing process and improve the overall repeatability and quality of the winding process.
- Due to proprietary information limitations, sufficient information to evaluate the approach to be taken for this program could not be given.
- The project is well done and on track.
- The approach is not clearly defined, possibly due to intellectual property (IP) concerns at the time of review.

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

This project was rated **1.8** based on accomplishments.

- The PI did not answer critical questions such as the following:
  - How does the adhesion process work? Is it complicated? Is it costly?
  - Does this process change the way the vessels will be wrapped in the future? Will it require more or less fiber?
- Since a calorimeter is used to determine the enthalpy change of the bonding process, is there still a curing process similar to that of contact cement? Is he using the same resins? Is he using self-setting resins? What is the cost? What are the material interactions?
- The PI should be able to tell us the high-level process procedure without revealing the recipe specifics.
- This program has just started, and little progress could be made. The preliminary development of a calorimeter to assess dry tape bonding has been made.

- The project team has made good progress.
- Accomplishments are not identified, possibly due to IP concerns at the time of review.

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

This project was rated **2.3** for technology transfer and collaboration.

- Quantum, Boeing, and PNNL are good partners. The first two are big consumers of carbon fiber technologies in varied industries.
- While part of a well-rounded team, there is little demonstrated evidence of collaboration with team partners.
- A good evaluation of the project.
- This effort seems to be operating in isolation at the moment.

Question 5: Approach to and relevance of proposed future research

This project was rated **2.8** for proposed future work.

- This project is non-responsive due not revealing the basic premise of the process.
- Demonstration of IP-protected technology will determine utility of the proposed process. Comparison testing of conventional composite layups with the dry tape method needs to be more clearly detailed.
- The future work is not adequately described, nor is there much confidence that the effort will address identified barriers.
- "Exotic procurement efforts" are identified, but without any contingencies or risk mitigation.

Strengths and weaknesses

Strengths
- The potential high-speed composite lay up method proposed may significantly reduce manufacturing cost.

Weaknesses
- Secrecy of the high-level process makes it difficult to judge strengths or weaknesses.
- Technical description of methods could not be given due to IP limitations.
- An evaluation of the proposed method was not clearly demonstrated.
- Due to IP concerns, insufficient details were available to adequately review this project. In the future, please consider withholding from review projects in similar circumstances.

Specific recommendations and additions or deletions to the work scope

- Even without IP in place, the PI must discuss the high-level process idea of how this tape is to work. He must establish a gap chart and a set of metrics against traditional winding techniques and track his progress against that.
- The PI should clearly define comparison methodology for dry tape vs. conventional methodologies to determine utility of the proposed technology.
- The team should define a pathway for implementation into large-scale articles with team members.

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