Fuel Cells

Summary of Annual Merit Review Fuel Cells Subprogram

Summary of Reviewer Comments on Hydrogen Fuel Cells Subprogram:

In general, reviewers agreed that the projects covered the appropriate technology areas and were clearly focused on addressing key technical barriers and meeting program targets. Reviewers applauded the program's use of go/no-go decisions in project management and recommended that all projects incorporate these as part of their work plans. They also emphasized the importance of establishing cost and performance targets that are *customer-based*. The reviewers recommended increased emphasis on high-risk, high-payoff R&D to achieve scientific and technical breakthroughs. In particular, they recommended high-risk work on novel new materials and catalysts.

Several reviewers questioned the funding of industry-led projects that appeared to support product development that would provide benefits to only the funded company. There was concern that a significant portion of the results would be proprietary and therefore not benefit the industry as a whole. In this regard, these reviewers recommended increasing funding to universities and National Laboratories for collaborative R&D with industry, and decreasing funding to industry-led projects. Reviewers repeatedly emphasized the critical need for researchers to work in close collaboration with technology developers and manufacturers for identification of requirements and testing.

Reviewers stressed the importance of fuel cell component durability and the need for longer-term (> 1,000 hours) tests for materials. In this regard, reviewers recommended that, wherever possible, projects should incorporate component/material durability tests (with identification of failure mechanisms) under operating conditions defined by OEMs or system developers. More testing of materials and fuel cell systems under "real" conditions is needed to gain a better understanding of the effects of fuel and air impurities and other environmental stressors on fuel cell performance. In related comments, reviewers agreed that demonstrations are extremely important to facilitate technology commercialization and to gain hand-on experience in real-world applications.

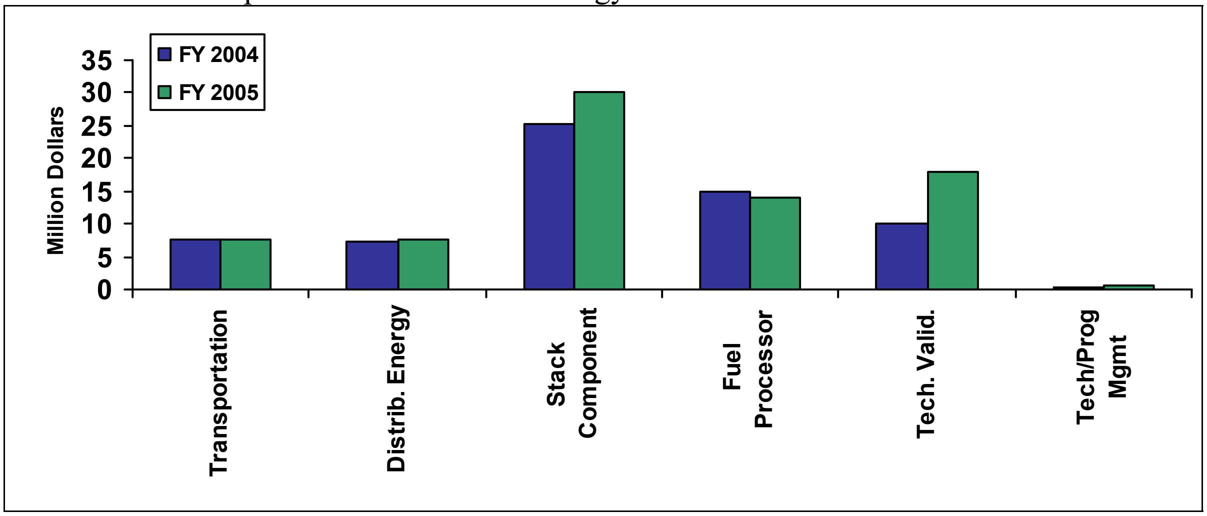
The reviewers were generally critical of continuing further R&D in support of on-board reforming, and were encouraged by DOE's go/no-go review of this research area. In August 2004, DOE announced its decision to discontinue funding of on-board fuel processing R&D based on extensive technical evaluation of the status, progress, and potential of on-board fuel processors.

To evaluate similar projects (especially materials, membrane and catalyst projects), reviewers recommended that the principle investigators present their results using common metrics. Reviewers also suggested a systematic, integrated approach to screening and evaluation of novel materials and catalysts to facilitate the comparison of results.

Reviewers agreed that cost modeling is an absolutely necessary activity to provide an independent assessment of the likely cost of PEM fuel cell technologies. And finally, several reviewers found that the level of funding for portable applications is very low, and suggested that the funding level be improved if DOE intends to support meaningful work in this area.

Fuel Cell Funding by Technology:

The fuel cell program contributes to the President's Hydrogen Fuel Initiative and to the DOE goal for energy security by supporting research, development, and technology validation activities that address stationary, transportation, auxiliary power unit, and portable power applications, including fuel cell stack components, fuel processors, and balance-of-plant components. The President's 2005 Budget Request (subject to Congressional appropriation) addresses the National Academy's Report recommendations and provides greater emphasis on fuel cell stack components as well as technology validation efforts.



Majority of Reviewer Comments and Recommendations:

- **Materials Research:** New materials for improved fuel cell stacks and system components and lower costs are essential. Put more effort into identifying materials that are stable at high temperature rather than optimizing materials that are unlikely to be stable at high temperatures.
- **High-Temperature Membranes, HTM:** Develop common metrics/requirements for HTM and their stability/durability for easy comparison. Understand water transport and water freezing behavior. Look at performance at lower temperature which reflects start and warm-up conditions (60-80C) and at low-humidity testing. Development of high-temperature MEAs is critical and supports RD&D plan objectives.
- **Improved Catalysts:** Continue developing non-platinum or low-platinum catalysts to reduce fuel cell cost. Investigate long-term catalyst durability. Identify approach to develop mass production processes.
- **Low-Cost, High-Durability Membranes, MEAs:** Focus on higher-temperature systems. Address robustness of MEA. Improve understanding of MEA failure mechanisms.
- **Balance of Plant:** Start-up time/energy, durability, and scale-up are important considerations. Fuel processor tolerance to high sulfur/CO/coke is crucial. Balance of plant is dependent on stack design and drive cycle requirements. Sensors—consider mechanical

strength, tolerance to occasional exposure to fuel and air impurities, and how to incorporate into fuel cell platform. Low-cost, durable, lightweight, and compact air delivery machines are key to viable fuel cells. Microchannel reactors offer size and cost reductions.

- **Analysis:** Thermal/water management and HTM are critical areas. Models help set development approaches and identify key parameters. Ensure key analysis assumptions are based on industry input. Extend analyses to real-world operation to further guide technical targets and work.

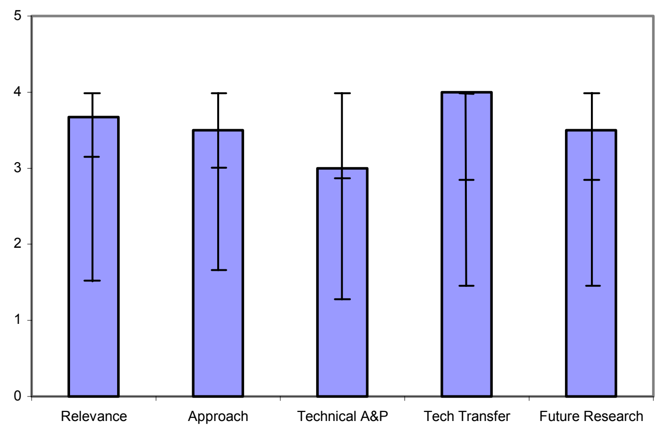
General comments for the fuel cell program included: 1) understanding the requirements of the auto industry for fuel cell system and individual components as well as impact of real world conditions on performance; 2) long-term durability/performance is a critical barrier to commercializing fuel cells; and 3) National Laboratories, universities and other organizations should work with a few non-proprietary systems to enable open publishing of results to benefit the entire fuel cell community.

Project # FC-1: Fuel Cells Sub Program Review
Davis, Patrick, DOE, Team Lead; Nancy Garland, DOE, Presenter

Brief Summary of Project

The purpose of this Fuel Cells Subprogram overview is to describe subprogram goals/objectives, budgets, barriers/targets, approach to R&D, technical accomplishments, interactions and collaborations, solicitations and awards, and future directions. As such, it sets the stage and put into context the R&D and analysis projects, which will be presented in this subprogram area during the Annual Merit Review.

Overall Project Score: 3.53



Question 1: Relevance to overall DOE objectives

This project earned a score of **3.67** for its relevance to DOE objectives.

- Fuel cell research is key to accomplishing the President's Initiative. The fuel cell program is well aligned towards meeting the challenges. The area of on-board reforming is probably a weakness in that it is not a good "bridge" technology until an infrastructure is developed. It is encouraging that the viability of this will be evaluated in June '04 , so further significant expenditures in this area can be avoided.
- Perhaps could have emphasized other go/no-go decisions (not just the on-board fuel processing) a bit more, as such decision points are now becoming normal operating procedure.
- Presentation was delivered along technical difficulties and was a bit hard to follow; otherwise good description of activities.

Question 2: Approach to performing the research and development

This project was rated **3.50** on its approach.

- This program is definitely focused on addressing the key technical barriers for implementation of fuel cells.
- Cost goals Direct HFC and Reformed HFC system. Systems are same at $45/kW. This is a mistake and distorts decision making. RHFC should allow higher cost since DHFC needs infrastructure.
- Good job of balancing desires of industry with long-term science needed to truly advance technology.
- Challenges adequately identified and discussed. Approach: "focus on high risk R&D" does not happen. Team is very conservative, funding traditional approaches from groups who have been funded by DOE for years. The bulk of funded efforts (>75%) are "same old" work.
- Need more rational approach for screening/directing evaluation of novel materials. Each program has similar goals, but no common figures of merit to compare results.
- This program has demonstrated very high standards on facing challenges and implementing go/no-go decisions.

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

This project was rated **3.00** based on accomplishments.

- Progress is generally very, good, but slow progress in certain areas such as cost and durability highlight the significance of how challenging the technical barriers are. It is important that targets are "customer based" if the President's Initiative is to be successful.
- Progress is good but breakthrough required - high-risk, high-payoff research must receive appropriate funding/priority.
- Efforts in portable systems ("consumer electronics") are ridiculously inadequate, almost to the point of being a distraction. Why are there still any efforts in on-board fuel processing? No auto company today is considering this approach!
- It is very well focused and is constantly re-evaluating the challenges, targets -- and addressing them. Managed very well and in a very effective manner.

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

This project was rated **4.00** for technology transfer and collaboration.

- Inclusive and extensive R&D network established.

Question 5: Approach to and relevance of proposed future research

This project was rated **3.50** for proposed future work.

- Future research should focus away from on-board reforming, with additional emphasis on stack durability and cost reduction of the entire fuel cell system.
- Very good plans - need to make sure they are living documents. Coordination with SC program important.

Strengths and weaknesses

Strengths
- This program has a strong tech team that has a high level of expertise and a good understanding of the challenges.
- Program has been up and running for several years. Targets and approach have been continually refined based on research findings and policy/market forces.
- Most of the funding to industry supports product development that will primarily (in some cases only) benefit the individual company. These efforts are not R&D, but pure and simple product development. This is grossly unfair, particularly since VERY few new companies are funded. I recommend increasing University and National Lab funding and decreasing or better ending funding to Industry for R&D. The only exception should be specific and defined demonstration projects.
- Would like to express appreciation for the work Valri Lightner has done as project manager -- very efficient, analytical, and responsive.

Weaknesses
- Sound system - well you knew that!

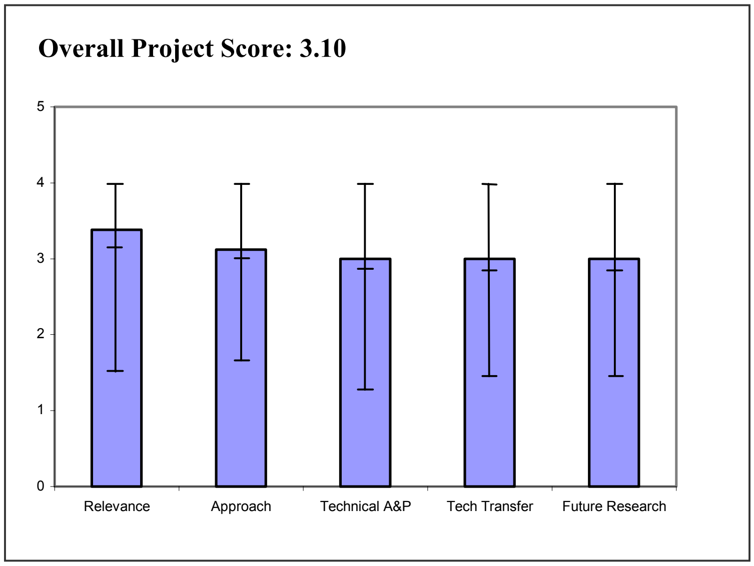
Specific recommendations and additions or deletions to the work scope

- The program should move away from on-board reforming
- In the mix of academia/national labs/industry, I think DOE's FC programs should have a little more emphasis on academia, or academia and National Lab will need long-term commitment to get new people or academic and industry partnership. More academics should be engaged in materials research. More inorganic chemists working on non-precious metals ORR catalysts. More on CU biomimetic. More on MeOH oxidation catalyst. More synthetic organic chemists (academic) engaged on polymer electrolyte. Ideally more funding, but take from industry allocation if necessary.
- Presentation offered good overview. Well managed program.

Project # FC-2: Integrated Manufacturing for Advanced Membrane Electrode Assemblies
DeCastro, Emory; De Nora North America

Brief Summary of Project

De Nora North America and its team are (1) developing new cathode alloys and ELAT structures that allow an overall cell performance of greater or equal to 0.4A/cm^2 at 0.8V or 0.1A/cm^2 at 0.85V operating on hydrogen/air with precious metal loadings of 0.3mg/cm^2 or manufacturing technology; (2) developing a membrane which operates at 120 C and 25% RH; and (3) taking advances from (1) and (2) to integrate into pilot manufacturing, aimed at delivering a 1-5kW stack with performance consistent with the previous objectives.



Question 1: Relevance to overall DOE objectives

This project earned a score of **3.38** for its relevance to DOE objectives.

- Although operation of a fuel cell at 120C is the overall goal of the high temperature membrane activity, the fuel cell will need to operate at a range of temperatures throughout the drive cycle. As such performance at 80C, 50C, and 10C should also be reported.
- Project team has a thorough understanding of PEMFC science and the requirements for commercialization.
- The project appropriately addresses electrode and membrane performance and durability which are the keys to commerciality of fuel cells.
- The cathode catalyst and structure work is directly aligned with DOE cost and performance goals.
- Lower Pt loadings will contribute to lower material costs.
- The project is clearly focused on problems of critical importance to the achievement of the cost and performance goals necessary to develop practical fuel cells. The work targets two of the most difficult barriers, namely low cost catalyst electrodes and new membranes capable of high temperature performance.

Question 2: Approach to performing the research and development

This project was rated **3.12** on its approach.

- The approach for high temp membrane development is good. Electrochemical stability should be evaluated. It is not clear that new technology is being developed in the cathode catalyst activity.
- The project and the sub-contractors are well coordinated.
- The approach is well-focused.
- Ink-based approach seems to be promising and unique.
- Approach to catalyst and structures good. Gradient control during materials fabrication should help optimize the system.
- No new catalyst was reported. It is not clear whether IBAD will be useful for catalysts/preparations because the loadings are too high.

- The researcher should try to develop other material than carbon-based GDLs.
- This is a well integrated program containing electrode, membrane and stack development so that feedback can occur from the exploratory or material work to the scale-up. It is a concern that the membrane work is high temperature and the electrode work is low temperature. The connection of the high temperature membrane work to the electrode development appears to be absent and needs to start.

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

This project was rated **3.00** based on accomplishments.

- Monomer selection is good.
- Good progress is being made in very complex inter-relationships between performance, durability, and cost.
- Catalyst work appears close to target, but it is unclear if this is superior to other state-of-the-art electrocatalysts. Hi-T membrane work shows promise.
- Some results are at a very early stage and hard to evaluate. The project shows improvements over time.
- Extension of fine gradient approach to electrode an important accomplishment. "Machine fabbed" alloy ELAT is a step forward.
- Good progress in lowering Pt loadings (particularly in the anode). Results provide scientific understanding of material performance. Durability tests are needed.
- It is a little difficult to measure progress in the membrane area with the alphabet soup of classifications, specifically, it is difficult to evaluate if the chemical and structural features of the membranes that lead to successful materials are being fully explored. The low loading catalyst work is making progress but not fast enough.

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

This project was rated **3.00** for technology transfer and collaboration.

- Good coordination between the various participants is evident.
- Very good multi-disciplinary approach. Good/excellent private industry - university collaboration. A little better explanation of how all the various parties contribute, where the work lies on the critical path etc. would be helpful.
- Work is being published. Patent applications filed on polymer electrolytes.

Question 5: Approach to and relevance of proposed future research

This project was rated **3.00** for proposed future work.

- Add ex-situ catalyst durability testing.
- Would like to see more measured results reported, especially with short-stack testing.
- The project should not focus on broad questions of the structure-function relationships in catalysts.
- Focus part of the effort to improve Pt (or catalyst) utilization.
- Future work looks fine but need to co-ordinate the new high tech membrane work with the electrode work, particularly with respect to understanding how the membranes interact with the electrode's surfaces and particles. The modeling will need some base data and the work needs to show more of the polymer characterization e.g. rheology, dielectric etc. For example, the case shown when the unfilled membrane fails and the filled one does not, can be easily explained by increase of Tg above

the test temperature due to presence of the filler. Basic rheology test would have shown this. Please make sure the polymer people are talking (and listening) to the electrochemists and vice-versa.

Strengths and weaknesses

Strengths

- Excellent overall technical approach.
- Very strong integrated multi-disciplinary team and it is being well coordinated.
- Membrane development activity is good.
- Fine-gradient electrode and GDL work is well done and could be a significant advance.
- Attention to the appropriate fuel cell components is made and effort is expended at reasonable levels for all aspect of the work flow from basic understanding to stack building.

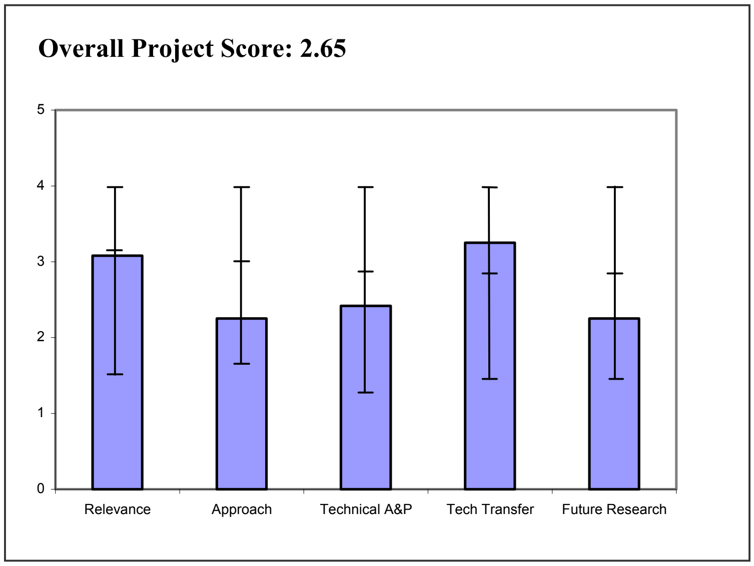
Weaknesses

- Progress could be improved.
- Need more information on catalyst durability/stability.
- Both catalysis and membrane tasks are too diverse.
- No information was reported about the stability of Pt alloys.
- The program might be becoming a little difficult to coordinate. Many players on-board and the review needs to emphasize better how all the participants play in the program.
- Weakness to be addressed is the incorporation of the new membranes into the electrodes. Need to understand mechanical needs as well as thermal and chemical needs. One would think that the chemical instability issues would be at the most severe in the electrodes, so some work with the new membranes in this mode is critical.

Specific recommendations and additions or deletions to the work scope

- CCM and other electrode approaches should be considered to enhance membrane performance.
- 0.4 A/cm^2 is the quarter-power target for the cathode catalyst development activity. Continue to test and report results at higher current densities which will be required to achieve catalyst and membrane cost targets. "GM Format" is an appropriate way to show this.
- Acquire and report data at 80C, 50C, and 10C to reflect automotive conditions. Membrane will likely be saturated at lower temperature conditions.
- New membranes into the MEAs urgently needs to be done.

Project # FC-3: Development of High Temperature Membranes and Improved Cathode Catalysts
Meyers, Jeremy; United Technologies Corp.



Brief Summary of Project

In the area of high-temp membranes United Technologies Corp. (UTC) Fuel Cells is optimizing candidate membranes for operation at 120C, 50% relative humidity (RH) and characterizing membranes for suitability in high-temperature fuel cells including ex-situ testing (conductivity at various humidity; water uptake; tensile strength) and in-cell tests (performance at 120C and 50% RH, 1.5 kPa; 100 hours stability tests; fuel crossover; elemental analysis of the exhaust water). For improved cathode catalysts, they are selecting the most promising alloy catalysts for evaluation in fuel cells, optimizing fabrication processes, conducting testing to evaluate performance and stability (in liquid cell), and comparing performance of submitted catalysts to that of TEC10E50E (TKK's 46.7% Pt/C).

Question 1: Relevance to overall DOE objectives

This project earned a score of **3.08** for its relevance to DOE objectives.

- All aspects of the project are relevant to DOE goals and objectives.
- High temperature membranes are critical to reducing heat exchanger size and reducing balance of plant needed for water management and CO reduction. Catalyst work important for cost reduction.
- Fuel cell operating condition is unique and different from DOE/FreedomCAR requirement. 120C 25% RH is appropriate.
- Project team understands important issues.

Question 2: Approach to performing the research and development

This project was rated **2.25** on its approach.

- There is insufficient recognition of low-humidity requirements for high temperature membrane testing.
- High temperature membrane and catalyst research areas require fundamental development. UTC's approach of evaluating materials from other organizations leverages their expertise in MEA synthesis and fuel cell testing, but does not necessarily direct sufficient fundamental analysis to each material regarding failure modes.
- High temperature membrane down-selected but target wasn't achieved.
- Not developing new polymers, just testing polymers from others. Appears to be a "bench marking" effort. Alloys for catalysts tested are well known in the literature.
- Catalysis work is realistic and the strong point of this project. More emphasis is needed on utilization issues.

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

This project was rated **2.42** based on accomplishments.

- The catalyst loading of the alternative catalysts is not clear. A direct comparison of the alternative catalysts is present only in table and not on performance curves.
- Results presented relative to industry benchmarks not against DOE goals. Catalyst shows greater activity but Pt/C not plotted on durability or performance plots.
- Need to explain why TKK catalysts shows good performance.
- All the membranes evaluated are well known as are their strengths and limitations.
- Strong, clear presentation.
- Membrane down-select yielded very disappointing results.

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

This project was rated **3.25** for technology transfer and collaboration.

- Team includes industry and university participation as well as UTRC. There is National Lab involvement although small.
- UTC evaluated materials from a range of research organizations, leveraging the resources of Phil Ross's laboratory.
- Not working with companies that will really commercialize these materials as MEAs, e.g. Gore, Dupont or 3M.
- Well-coordinated multi-party effort.

Question 5: Approach to and relevance of proposed future research

This project was rated **2.25** for proposed future work.

- Membranes have been down-selected for further work.
- Next steps in membrane area appear to represent new starts with introduction of composites and ionic liquids. Catalysis work builds on existing work. Presentation did not show connection between next steps and past work.
- Need to investigate durability of alloy catalyst. Project goal and approach should be reconsidered.
- There is no evidence presented that materials work should continue.
- Continuously benchmark the result so as not to lose focus.

Strengths and weaknesses

Strengths

- Leverages UTC experience in building, testing and evaluating fuel cell stacks. Evaluates advanced materials in near atmospheric pressure stack technology.
- Catalyst analysis activity.
- Stack and system testing and design.
- Strong team and well integrated.

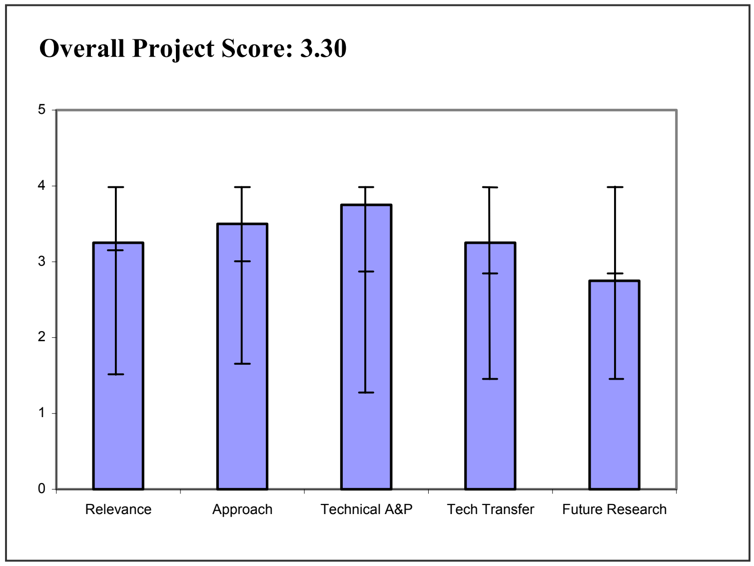
Weaknesses

- Lack of low-humidity membrane testing.
- Causes of failure and lower performance of down selected membranes was not discussed.
- Lack of polymer chemistry and characterization, specifically conductivity testing.
- Half-cell testing is not necessarily reliable.
- Lacks new ideas.

Specific recommendations and additions or deletions to the work scope

- Analysis of materials and sources of performance differences is not included. These activities should be added to advance science.
- It is not recommended to continue this project without meeting target at the technology down-selection phase.
- Scale down and/or end effort soon. We need new materials, not more tests on what is already out there.

Project # FC-4: Advanced MEAs for Enhanced Operating Conditions
Debe, Mark; 3M



Brief Summary of Project

3M is developing high performance, lower cost membrane electrode assemblies (MEAs) qualified to meet demanding system operating conditions of higher temperature and little to no humidification, with less precious metal catalysts, and higher durability membranes than current state-of-the-art constructions. Objectives include: durable, lower cost MEAs for operation in the range of 85 < T < ~ 120C (develop next generation, thin film, ultra-thin layer catalyst electrodes (NSTE); optimize PFSA based ionomers modified for enhanced durability at low RH; match MEA components for enhanced performance under demanding conditions; utilize roll-good fabrication processes for lower cost) and development of MEAs for operation in the range of 120 < T < 150C (new PEM's that do not rely on standard modes of aqueous proton conduction); understanding relationships between materials, proton conductivity, T and RH; screening materials and fabrication processes.

Question 1: Relevance to overall DOE objectives

This project earned a score of **3.25** for its relevance to DOE objectives.

- Although operation of a fuel cell at 120C is the overall goal of the high temperature membrane activity, the fuel cell will need to operate at a range of temperatures throughout the drive cycle. As such performance at 80C, 50C, and 10C should also be reported.
- Misunderstanding of DOE/FreedomCAR requirement, of membranes 120C is high temp requirement and at the same performance as low temperatures should be targeted. Check DOE/FreedomCAR requirement. 120 to 150C development are not necessary.
- Development of high performance, low cost MEAs is critical.
- The project is focusing on two of the critical barriers of the Fuel Cell Program. The combination of basic research with development and manufacturing is excellent and can hardly be improved upon.

Question 2: Approach to performing the research and development

This project was rated **3.50** on its approach.

- Membrane approach is good. NSTE for catalysts is interesting.
- Task 1 is well thought out. Task 2 is good but does not seem as comprehensive as Task 1.
- In general - well thought, but a bit unfocussed.
- Good integration of the electrode and membrane aspects. Use of combinatorial methods is good for screening and provides progress. Perhaps a little more fundamental work may be needed to understand the direction that is leading. Good mix of academic and National Lab participants.

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

This project was rated **3.75** based on accomplishments.

- Good performance, particularly at mass transport region.
- Good progress demonstrated in development of NSTF catalyst and membranes for 85<T<120C towards meeting project targets.
- Several valuable achievements.
- Progress in both catalyst and membrane development is very significant. Difficult to tell how soundly based is the understanding due to proprietary nature of the activity. Extent of the advances indicates good understanding of the technical problem and the science needed to solve them.

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

This project was rated **3.25** for technology transfer and collaboration.

- Good team of university/National Lab collaborators with excellent coordination.
- Several technical accomplishments are reported within this one project. Technology transfer and application are evolving.
- Roles the partners are clear and necessary. Management of activities is well organized.

Question 5: Approach to and relevance of proposed future research

This project was rated **2.75** for proposed future work.

- Need to investigate the durability (automotive lifetime) of the catalyst alloy.
- A considerable amount of effort is focused on developing high temperature (>120C) membranes for stationary applications. Not sure all objectives can be accomplished.
- Like to see the polymer work explained more fully next time. It looks to be very interesting. Also this reviewer does not understand the no-ink part of the MEA fabrication. The polymer has to contact the electrode surface. Explain how this is done.

Strengths and weaknesses

Strengths
- Continue using LBNL as an independent 3rd party for validation. Verify the gain in specific activity of PtCA and PtCD.

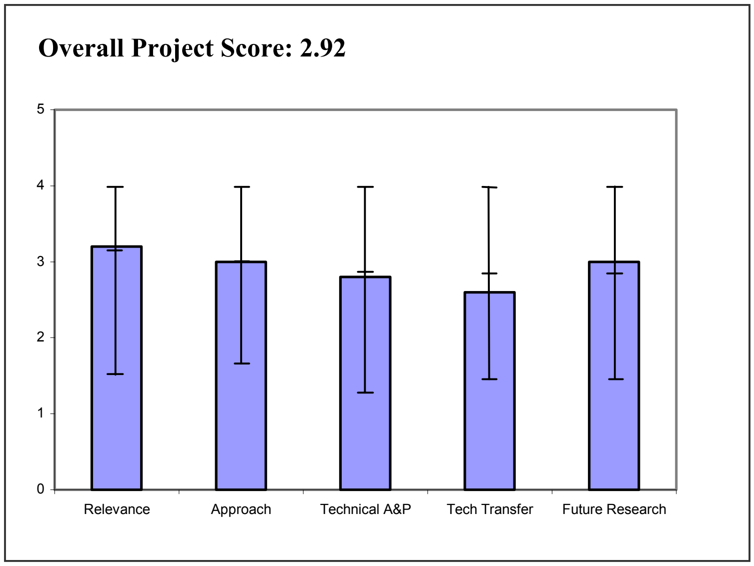
Weaknesses

Specific recommendations and additions or deletions to the work scope

- MEA stability test should be conducted under conditions representative of automotive usage profiles. Longer chemical and thermal stability tests are necessary to verify automotive lifetime requirement.
- Continue making technical innovations available to third party industrial firms.

Project # FC-5: Development of High-Performance, Low-Pt Cathodes Containing New Catalyst & Layer Structures
Atanassova, Paolina; Superior

Brief Summary of Project



This is a four year project led by Cabot Corporation to develop and apply combinatorial powder synthesis platform based on spray pyrolysis for discovery of high performance low-Pt cathode electrocatalysts for PEM automotive fuel cells. This project will use the platform for electrocatalyst composition discovery and microstructure optimization under conditions that can be scaled for commercial powder production, and will deliver high-performance cathode electrocatalysts and MEAs with lower Pt content to meet the DOE target of 0.6 gPt/kW in 2005. Specific objectives include: completing the development of rapid testing equipment – DuPont Fuel Cells; starting high throughput synthesis of ternary alloy compositions in a discovery mode; further optimizing MEA electrode structure; testing long-term stability of new electrocatalysts; and delivering electrocatalysts and test MEAs to stack manufacturers.

Question 1: Relevance to overall DOE objectives

This project earned a score of **3.20** for its relevance to DOE objectives.

- Effort aligned with DOE cost, durability and performance targets.
- High volume manufacturing method could reduce catalyst cost.

Question 2: Approach to performing the research and development

This project was rated **3.00** on its approach.

- Test conditions are clearly presented. Novel catalyst composition will be identified by combinatorial screening. MEAs with the novel catalysts will also be screened by combinatorial screening. The task progression is logical.
- GDL surface roughness is an issue. Consider using CCM approach for MEA evaluation.
- The approach needs to be confirmed by long-term tests of the catalysts produced.
- Not truly "combinatorial" method. Still must make "inspired" guesses about what metals to use.
- Rapid-throughout combinatorial screening and "production-capable" spray pyrolysis combine for strong approach.

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

This project was rated **2.80** based on accomplishments.

- Many catalysts samples have been prepared and the equipment has been qualified. There is a clear comparison with Pt catalysts. Most of the samples exhibited better performance than Pt.
- Electrochemical data should be more clearly presented. Catalysts loading are still higher than DOE targets.
- Very limited results shown. Not clear how general spray pyrolysis method is used for catalyst preparation.
- Automatic catalyst/ink/MEA preparation up and running. Process uniformity is very good.

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

This project was rated **2.60** for technology transfer and collaboration.

- Team includes GM and DuPont. No National Labs or universities were mentioned.
- Role of Dupont unclear.
- Interactions with mostly unspecified MEA developers, FC developers and OEMs reported.

Question 5: Approach to and relevance of proposed future research

This project was rated **3.00** for proposed future work.

- CSMP is logically holding to their plan.
- Need to investigate durability of catalyst alloy. Baseline for MEA optimization is too low.
- Development of rapid MEA screening system and combination with rapid-throughput catalyst preparation will be a significant accomplishment.

Strengths and weaknesses

Strengths
- Catalyst and MEA analysis testing.
- A useful tool for combinatorial synthesis has been developed.
- More catalyst optimization than "discovery."
- Approaching "production-capable" catalyst, ink and MEA preparation.

Weaknesses
- A lacks long-term verification of the test results.

Specific recommendations and additions or deletions to the work scope

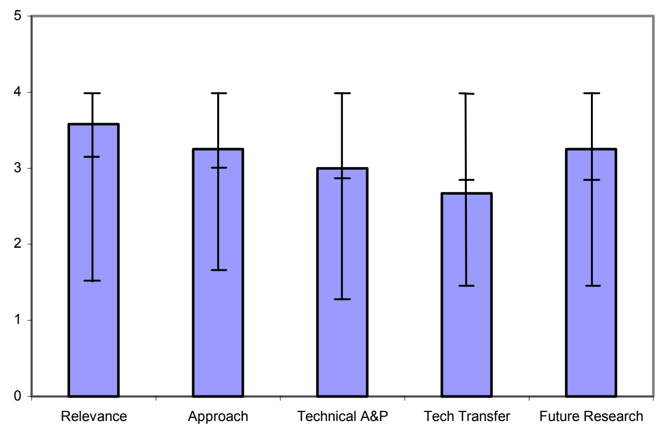
- GDL surface roughness could be an issue. Consider using CCM approach for higher quality MEA evaluation.
- Should focus more on optimizing catalysts known to have some promise using spray pyrolysis method. Increase effort in characterizing what is synthesized.

Project # FC-6: High-Temperature Membranes
Zawodzinski, Tom; Case West Reserve University

Brief Summary of Project

This Case Western Reserve University (CWRU) project is developing membranes for 120ºC minimally hydrated polymers to achieve H^+ conductivity approaching that of well-hydrated PFSAs at 80ºC. CWRU will also focus on new polymers and other scaffolds carrying sulfonic acids or other superacids with 25% RH at operating temperature as suggested by GM, and improve durability. CWRU will also focus on membranes for >150ºC operation which replace water with 'proton mobility facilitators' and non-volatile molecules to effect proton transfer.

Overall Project Score: 3.15



Question 1: Relevance to overall DOE objectives

This project earned a score of **3.58** for its relevance to DOE objectives.

- High-temperature membranes are a key focus of DOE. Consideration of water freezing behavior in the membrane is important and fairly unique in DOE programs.
- This is among one of the most important also most challenging technologies to enable the PEM fuel cells in transportation (Low RH). It is very critical to support this kind of research.
- This program is driving down to the fundamentals of High-Temp membranes rather than just testing out new materials. High-temperature membranes could be game-changing for automotive and stationary products.
- Understanding the water transport mechanism is key!

Question 2: Approach to performing the research and development

This project was rated **3.25** on its approach.

- Understanding of functional structures is being developed by diagnosis and analysis, physical chemistry, and synthesis trial. The approach should provide basic insights for all HTM researchers. Techniques for augmenting proton/water conduction are being investigated.
- HT membrane development for this group is still at the stage of early exploration and screening. Degree of participation in HTMWG is not clear. The approach to HT membranes is very broad and covers many of the currently known approaches.
- The only team that is taking a molecular scale approach to rationally design the new material.
- Need to identify metrics for membrane and its stability (durability). Technical approaches well covered; present considerable technologies.
- A rational approach to high-temperature membranes. Very good approach to screening. Do not need FC demonstration/MEA optimization at this stage.
- Clearly addressed.

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

This project was rated **3.00** based on accomplishments.

- Significant results are imminent.
- Excellent characterization techniques for proton transport were used including NMR and thermal analysis. Very limited performance data of fuel cells. No data at 120ºC or higher.
- The sweeping approach this team takes necessitates patience.
- Good work, unlocking limitations.

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

This project was rated **2.67** for technology transfer and collaboration.

- With the exception of the High-Temperature Membrane Working Group and VA Tech, no collaborations are mentioned.
- The activities proposed are only limited to academic community. No collaboration with industrial FC developers.

Question 5: Approach to and relevance of proposed future research

This project was rated **3.25** for proposed future work.

- As far as membrane, MEA, and GDL are concerned, it is a right approach. However, no fuel cell tests were planned. Whether or not the HT membrane or MEAs are good or not relies on the fuel cell performance.
- Need to identify clear path to the goal.
- This is good effort laying the groundwork for future breakthroughs. Need to limit MEA fabrication/testing and stay focused on membrane characterization.

Strengths and weaknesses

Strengths
- The project includes approaches to develop a fundamental understanding of high-temperature membrane (conduction) processes with translation of the understanding to approaches to meet DOE targets. Upcoming work includes input from "new faces from the polymer chemistry community" outside of the fuel cell community.
- HT membrane materials synthesis expertise; some good material characterization techniques. Interesting proton transport studies by NMR.
- Very good grasp of the big picture; excellent job at educating the community about the challenges.
- Membrane and polymer analysis.
- Figures of merit for comparison of emerging technology (ion concentration vs. conductivity) = great way to compare and uncover fundamental limitations of chemistry.

Weaknesses
- No optimization or screening activities of HT membrane development are defined.
- Many results, e.g. conductivity, NMR relaxation were conveyed verbally; this makes the presentation very difficult to be appreciated. Need show more data, not more concepts. Timing/pace of the presentation needs be improved. Latter half has more substantial stuff, but is glossed over casually.

- Project management.
- Prematurely doing FC testing. Need figures of merit for chemical/mechanical stability. Common chart for all HTM projects. Membrane conductivity vs. RH and temperature, water uptake vs. RH and temperature, change in properties after immersion in boiling water.

Specific recommendations and additions or deletions to the work scope

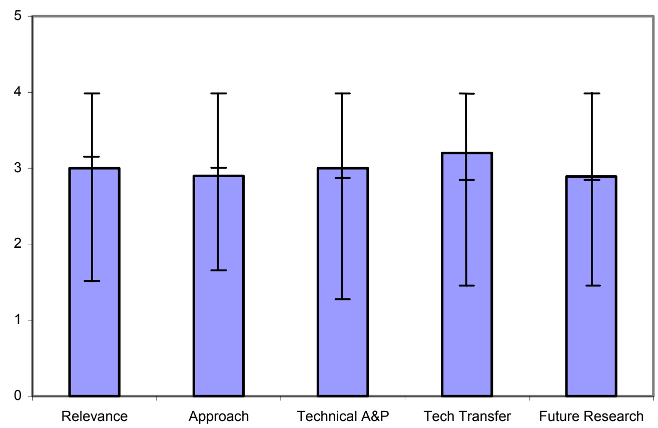
- The fundamental R&D should be continued. More focus on HT membrane developments instead of electrodes, GDL, etc.
- Need to convince people to continue to support this team by really demonstrating one system with tangible, superior results in the next reviews.
- This project is one of the most important projects for automotive FC development. Clear path to the project goal should be identified.
- DOE should demand common figures of merit for all HTM projects for easy reference. Drop MEA/cell testing. Progression should be: basic science, screening of polymers, screen of membranes, MEA fabrication and optimization, cell/stack demonstration.
- The approach to "design membranes" provides an excellent opportunity to overcome some of the obstacles.

Project # FC-7: Electrodes for Hydrogen-Air PEM Fuel Cells
Uribe, Francisco; Los Alamos National Laboratory

Brief Summary of Project

This project contributes to the DOE effort by developing an efficient, durable, direct hydrogen fuel cell power system for transportation. Specific goals of the project include: lower Pt-catalyst content in the MEAs, improved Pt-catalyst utilization, develop low-cost, high surface area support materials that either "replace" precious-metal supports or improve Pt activity for ORR, evaluate catalyst durability, evaluation of the effects of fuel and air impurities on FC performance, additional ways to mitigate negative effects of impurities, and continued collaborations with Industry and other National Laboratories.

Overall Project Score: 3.00



Question 1: Relevance to overall DOE objectives

This project earned a score of **3.00** for its relevance to DOE objectives.

- All aspects of the work are relevant. The effects of impurities on cell performance are important.
- Addressing the major issues limiting fuel cell application.
- Development of new materials may not be able to be done on budget effectively. Baseline testing is key capability and contribution -- durability and impurities.
- Objective of this project is unclear. Define clear objective, and it should be to develop "robust" electrodes/catalyst for automotive usage.
- Addressing the impurities issue is important. Validation and testing of new materials made.
- This is a very important program and it is generating very important data regarding PEMFC operation with gas contaminants and impurities.
- This effort on developing electrodes for hydrogen air fuel cells is absolutely critical for the realization of the initiative. It responds to the objective. It is a very thorough discussion involving much collaboration with other National Laboratories and companies such as DuPont, GM and UTC Fuel Cells.
- Determination of the effects of air and fuel contaminants on PEMFC performance is critical to the development of the technology.
- FC developers are already aware of most of these impurity effects.

Question 2: Approach to performing the research and development

This project was rated **2.90** on its approach.

- The results presented seem to be measurements of data taken of components (catalyst) prepared by others, such as Brookhaven National Laboratory. Approaches to making improvements are scarce.
- Systematic conventional approach.

- Life tests. Impurity effects and mitigation important, well done.
- Need to consider more systematic approach, such as design of experiments (DOE).
- Lots of important observations on separate topics. Needs more focus on one topic - migration or impurities and relative importance of each.
- The PIs are demonstrating that a successful PEMFC product must operate in the real-world where clean laboratory conditions do not exist.
- The technical barriers are outlined in terms of stacked materials and manufacturing costs, durability and electrode performance. Each was discussed in a logical manner.
- Excellent approach, overall. Effect of scrubbers for cleaning impurities from fuel or air should either be done thoroughly (i.e. effect on system size and complexity) or eliminated from project scope. Carbide supports will be oxidized at the cathode potential.
- Project objectives are too broad/diverse-need to rationalize.

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

This project was rated **3.00** based on accomplishments.

- The data presented are important but resolution of the issues identified is not described.
- Significant progress in all areas but only obstacles identified.
- Progress on track with original milestones. Efforts on low cost catalyst support materials may not be most effective use of time by this group. Studies of electrode changes with time are excellent.
- Excellent findings on important topics. Round robin testing should produce important information on testing reproducibility.
- Progress seems too slow.
- The accomplishments were very good and showed the negative and irreversible effects of low SO_2 and H_2S levels on performance. Stability up to 1000 hours was demonstrated. Relatively low-cost small particle materials for supported platinum monolayers were demonstrated.
- Good information on impurities. Further measurements required. First-time someone talks about NaCl, great
- Much progress has been made this year, especially in the impurity area and in the collaboration with BNL.
- Results verified known problems - need to explore innovative alternatives to use of filters - undesirable for automotive application.

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

This project was rated **3.20** for technology transfer and collaboration.

- The team includes universities, industry, National Labs, and the US Fuel Cell Council (USFCC).
- Catalysts made at BNL but generally not addressed.
- Some of the interactions listed were only presentations -- not serious interactions.
- Collaboration with BNL provides useful information.
- Many major players including the aforementioned DuPont, GM, UTC as well as several National Laboratories and universities were included in the technology transfer.
- The numerous collaborations and invited presentations attest to the high level of interest in this project.
- Collaboration with USFCC is valuable - industry needs test protocol for establishing/measuring impurity levels of H_2 specification because existing specifications are inappropriate.

Question 5: Approach to and relevance of proposed future research

This project was rated **2.89** for proposed future work.

- Future work logically follows.
- More of the same.
- Most items listed are very specific and important and should be done. Continued formulation of new catalyst supports should be dropped - put resources on other items.
- Need to identify clear path to the goal.
- No slide with future work except the round robin testing - but was included in the printout.
- The PIs must get the message out to the developers that the PEMFC system must operate in the “real world” where gas contaminants and other impurities are present.
- The future work will further quantify the influence of SO_2 poisoning and cleaning and will further evaluate the low Pt content catalyst in long-term tests. Evaluation of Ru migration during long-term operation will be studied and the effort will participate in round robin testing of the new catalysts.
- The causes of ruthenium crossover should be determined (if DOE decides the fuel may contain CO i.e. reformate rather than "pure" hydrogen).
- Focus on establishing "mechanisms" of irreversible effects and degradation in long term tests.

Strengths and weaknesses

Strengths
- Systematic, highly resourced project. Progress made on identifying problems.
- Testing and MEA characterization are strengths that make sense, much more than materials development. Understanding performance decay processes.
- Electrode performance analysis.
- Addressing various aspects of the MEA durability.
- Fundamental sound and broad-based.
- Collaborations, fuel cell fabrication and testing capabilities and experience.
- Low Pt loading results are encouraging but need more long term tests with imposed variable load and temperature (both high and low) profiles (automotive drive cycles).

Weaknesses
- The effect of SO_2 is reported but methods to reverse the effect are not proposed. Using a filter to remove the SO_2 does not address means to deal with filter failure or breakthrough such as air bleed that is used to mitigate CO poisoning.
- Project doesn't seem to be evolving to useable, high performance fuel cells.
- Inadequate staffing or resources to actively pursue new materials development. Rate of progress and ability to relate properties to scale-up processes will be lacking.
- Process.
- Can benefit from more focused systematic study on effects of one factor that is considered to be most important.
- Some conclusions represent too much the scientific side -- e.g. a SO_2 filter means an extra part for the FC system - adds more complexity.
- Need more focus on long term > 1,000 hr impurity effects - not just short term performance.

Specific recommendations and additions or deletions to the work scope

- Given the sulfur problem, I don't think that the problem can be solved by saying "make cleaner fuels".
- More characterization and performance/lifetime testing, done in serious collaboration with manufacturers of materials. Less focus on new materials development, like catalyst supports.
- This project is important for automotive fuel cell development. And this team is capable. It is necessary to take more systematic approach to identify tolerance of each impurity substance.
- Focus on the effect of impurities on FC membranes.
- Though last year's reviewer's comments mentioned addressing a solution for mitigating the sulfur dioxide problem, this project should either focus on the electrochemical issues and not gas clean-up or greatly expand the scope (and funding) to include an extensive study of air and fuel impurity removal.
- Fully exploit use of TEM techniques to derive degradation mechanisms due to time and/or fuel impurities.

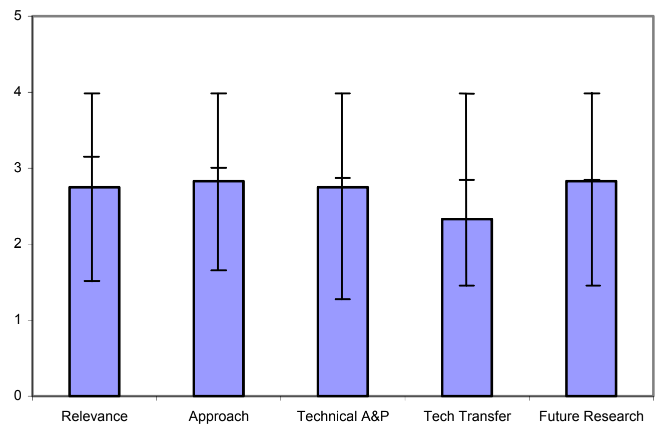
Project # FC-8: High-Temperature Polymer Membranes

Myers, Deborah; Argonne National Laboratory

Brief Summary of Project

Argonne National Laboratory (ANL) is working to develop a proton-conducting membrane electrolyte for operation at 120-150 ºC and low humidities to meet DOE's technical targets. The project is investigating dendritic macromolecules attached to polymer backbones, cross-linked dendrimers, and inorganic-organic hybrids. Specific goals include determination of: thermal stabilities and conductivities of samples, preparation and characterization of inorganic-organic hybrids, and fabrication and testing of MEAs with high-temperature membranes.

Overall Project Score: 2.70



Question 1: Relevance to overall DOE objectives

This project earned a score of **2.75** for its relevance to DOE objectives.

- The objectives of this project are clear to meet the specific DOE's goals.
- Budget too small to have serious impact in required time. Only membrane work, not integrated with other MEA components.
- Well aligned with goals of HT membranes.
- This is a fundamentally oriented project that attempts to assess the architectural aspects of novel membranes, including organic-inorganic hybrids.

Question 2: Approach to performing the research and development

This project was rated **2.83** on its approach.

- It is a good approach to use sulfonated dendrimers blended with colloidal silica gel, although the concept is not new.
- Excellent/brilliant idea to focus on dendrimers.
- Good work, but very narrow focus resulting from limited resources. Not able to study catalysts/PEM ORR issues.
- Why no conductivity data at target 120ºC/25% RH? How stable over the full range of %RH -- is the data only hysteresis?
- Again, highly fundamental studies of branched spherical macromolecules with high surface charged densities with the hope that it may facilitate proton transfer, even at low water concentrations.
- Certainly a sound academic research effort.

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

This project was rated **2.75** based on accomplishments.

- A higher sulfonic group density than Nafion is achieved. A sulfonated organic component blended with silica was made (although it is not clear that the sulfonated organic components are the dendrimers or Nafion.)
- Impressive conductivity result at low RH. Others work years to reach to same level.
- Rate of progress per unit of $ or resources is good - but resource funding too low. Initial samples just being characterized for conductivity at temperatures <100 ºC even though target is >120ºC.
- Benchmark at 120ºC/25% RH. Only two cases "G2 and G3" - a more systematic study in structural modification would be preferred.
- A model dendrimer system has been prepared. Inorganic-organic hybrid membranes have been prepared and initial films were tested by blending these new materials with about 70% Nafion. Some results indicate that the hybrid has higher conductivity than the Nafion control up to 80ºC.
- Chemical/physical properties are far away from DOE goals; e.g. 4 days of testing mentioned as stable.

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

This project was rated **2.33** for technology transfer and collaboration.

- The level and degree of collaboration with CWRU and Toyota is suitable.
- Only one serious interaction with CWRU.
- Suggest expanding work at CWRU to include MEA fabrication.
- PIs have applied for a U.S. patent and are establishing collaboration with Toyota.
- Not presented.

Question 5: Approach to and relevance of proposed future research

This project was rated **2.83** for proposed future work.

- The future plan is reasonable. More fuel cell performance tests are needed either internally or through the collaborations
- Use the proposed work to further develop structure/conductivity relationships
- Future work will continue to characterize these dendrimers and to fabricate and test MEAs using the subsequent membranes. It is not apparent that the epi-chlorohydrin polymers will have sufficient stability for the fuel cell operation. However this will be no doubt ascertained.
- The future plan is well based on current accomplishments.

Strengths and weaknesses

Strengths

- The use of sulfonated dendrimers. The concept of sulfonated dendrimers blended with inorganics like silica. The sulfonated dendrimers have higher density of sulfonic groups than Nafion.
- Very exciting program all around.
- High quality technical personnel.
- Interesting approach with great potential based on "kW" equivalent weights (high meq/g).
- Good fundamental study.

Weaknesses

- The progress is significant, but the pace is slow. Water solubility is a problem for the membrane materials that are being developed. No real membrane based on dendrimers/SiO_2 has been made. No fuel cells tests.
- Is any of this conductivity sustainable with time? Would benefit from complementary work on mechanism, thermal stability, fuel cell electrode interface compatibility.
- Inadequate staffing to make needed rapid progress with these new material sets. Film forming issues may be significant. Lack of plan for overview to anticipate issues with fabricating full MEAs with these new PEM materials.
- Needs better correlation between dendrimer structure and structural modifications and the final "function" of conductivity, stability, and mechanical stability.
- Unlikely exact system will be useful.

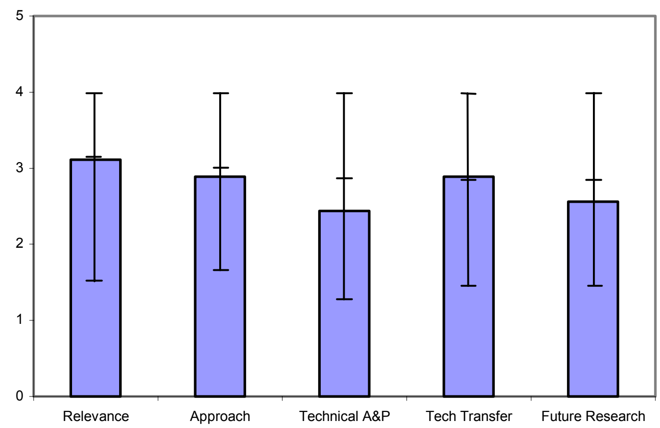
Specific recommendations and additions or deletions to the work scope

- Quickly make the membranes based on their future work. Evaluate by fuel cell performance tests and characterized by different electrochemical techniques. Do some durability tests (all tests should be done under high temperature and different RH conditions specifically. Pay attention to the conditions of low RH.)
- Nafion at 20% RH conductivity is about 5 to 7 mS/cm -- the dendrimer G2/G3 (80%) result at 20% RH is about 22 mS/cm, which can be explained by the fact that its ion exchange current (IEC) is 4 x that of Nafion. The question is if and how to further improve conductivity to meet the DOE goal?
- Work with outside membrane company to evaluate film-forming issues. Try to leverage research effort by collaborations on areas of weakness.
- More testing at higher temperatures (conductivity, stability).

Project # FC-9: Development of Polybenzimidazole-based, High-Temperature MEAs
Staudt, Rhonda; Plug Power

Brief Summary of Project

Overall Project Score: 2.78



This Plug Power project will identify and demonstrate an MEA based on a high-temperature polybenzimidazole (PBI) membrane that can achieve the performance, durability, and cost targets of both stationary and automotive fuel cell applications. Key objectives include: (1) complete initial screening of potential PBI-based chemistries and structures and downselect top 5 - 10 candidate materials based on chemical and physical properties; (2) initiate rapid screening of candidate PBI materials in 50 cm^2 MEAs,; (3) initiate detailed electrochemical characterization of MEAs made with selected PBI polymers; (4) initiate evaluation of low cost acid-absorbing materials for phosphoric acid management within the system; (5) initiate design and development of bipolar plates with PBI-specific flow fields; and (6) initiate development of a PBI membrane-based MEA with advanced electrode structures providing high catalyst utilization and performance exceeding that of Nafion.

Question 1: Relevance to overall DOE objectives

This project earned a score of **3.11** for its relevance to DOE objectives.

- Application to stationary is clear. Not sure how this can be used in automotive, specifically in a freeze and thaw cycle.
- PBI and its doped composites appear to be leading candidates for stationary power activities. However, there are many questions related to the development of a suitable MEA with appropriate electrode structure that will allow performance greater than the state-of-the art materials, e.g., Nafion. The technical targets are outlined with respect to DOE. The team includes Plug Power, Celanese, Rensselaer and Albany Nanotech, a small company.

Question 2: Approach to performing the research and development

This project was rated **2.89** on its approach.

- Screening will result in down selection, ultimately to one membrane for stack testing. Data to date indicate that the PBI system has serious acid retention and mechanical stability issues - presentation lacked discussion of solutions.
- The approach is good. Candidate polymers have been screened and characterized. An attempt to develop low cost membranes has been made.
- The results of this project could lower the cost of PAFC by making stacks easier to assemble. Acid storage is simplified and improved.
- Synthesis of new polymers should not be the focus of this project. The focus should be on catalysis and acid management - the key technical issues.

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

This project was rated **2.44** based on accomplishments.

- Poor acid retention and poor creep under constant load have been identified as significant problems. The PBI system has been projected to 40,000 hours life.
- One of a very few high temperature membrane approaches that shows promise. Improved performance and acid retention have been shown.
- The technical accomplishments include 5 PBI compositions, each with unique chemical structure. Membranes have been made. High molecular weight film-forming systems were developed and all of the phosphoric acid contents for these systems were greater than previously reported.
- Too early to judge if candidate materials will be successful.

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

This project was rated **2.89** for technology transfer and collaboration.

- A good team includes industry and universities but no National Labs.
- Collaboration with RPI, Celanese and Plug appears to be working well and is a key component of the project.

Question 5: Approach to and relevance of proposed future research

This project was rated **2.56** for proposed future work.

- Stated future work does not address resolution of the serious technical issues described.
- The research should focus on the most critical characteristic of this membrane to evaluate its real potential for fuel cell applications.
- High initial creep will need to be addressed.
- Achieved 3.3 gPt/kW (2 atm,0.5v, 1.2A/cm^2, 2mgPt/cm^2) - this is higher that PFSA. Suggest devoting resources to see if g/kW can be further reduced, otherwise, it will be difficult to achieve the cost target.

Strengths and weaknesses

Strengths
- Celanese, PBI manufacturer, is a part of the team.
- Previous work on this area helped to focus project.
- Future work will continue the evaluation of materials and membranes and test selected candidates in single cells.
- Significantly higher temperature demonstrated vs. other PEM approaches. Will deliver thermal system advantages of high temperature.
- Many materials have been screened.
- Solid team.

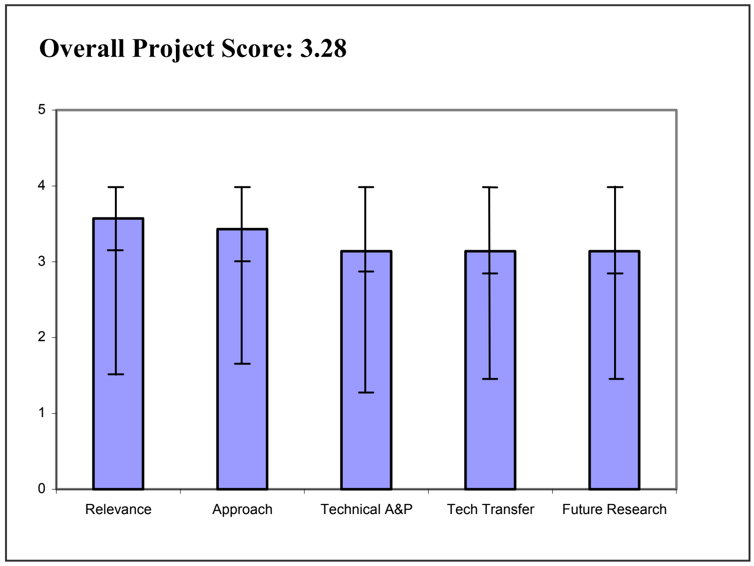
Weaknesses
- Lacks discussion on polymer structure characterization, (Task 2) and relationship between structure and membrane properties.
- Improve description of contribution from individual collaborators. Is this all new data since 8/03? Saw presentation with Fuel Cell Gordon Conference - June 03 which also showed PBI improvements

- Show progress (status) compared with the DOE targets.
- More discussion on issues of start-up, electrode performance and electrolyte management.

Specific recommendations and additions or deletions to the work scope

- Recommend speaking/working with PAFC developer who could help with acid management, flow field design and cathode catalyst optimization using Pt ternary alloys.
- Applicability to auto is claimed. Sensitivity of MEA to liquid water is admitted. Begin stack evaluation with auto drive cycles even with a non-optimized version of MEA and to develop water management approaches. Otherwise, this fuel cell will be limited to stationary applications.
- Focus on acid storage and stack assembly issues.
- Continue focus on electrodes electrolyte management and start-up. Reduce effort on flow field development and polymer synthesis.

Project # FC-10: Enabling Commercial PEM Fuel Cells with Breakthrough Lifetime Improvements
Bauman, Jayson; DuPont



Brief Summary of Project

This DuPont project will utilize both experiments and modeling to develop an understanding of potential mechanisms than can lead to membrane failure, including: H_2O_2 formation; radical formation; attack of polymer weak sites; material properties degrade; localized stress which promotes cracks/fissures; and crossover failure occurrences. Mitigation strategies such as peroxide prevention, peroxide decomposition, polymer stabilization, membrane reinforcement, and edge seal design and optimization are being investigated to improve membrane durability. The project will optimize each and incorporate them, in total, into fuel cell products.

Question 1: Relevance to overall DOE objectives

This project earned a score of **3.57** for its relevance to DOE objectives.

- Membrane durability is being examined and improved both chemically and physically.
- Peroxy radical mitigation is good objective and relevant to DOE/FreedomCAR objectives.
- Durability is a key barrier to commercializing current PEM Nafion-based fuel cell technology.
- PEM lifetime is critical to the success of DOE's Hydrogen Program.

Question 2: Approach to performing the research and development

This project was rated **3.43** on its approach.

- Physical reinforcement and chemical stabilization approaches are being developed. Accelerated testing is based on extensive and verified UTC Fuel Cell experience.
- Good combination of MEA structure and material development.
- The approach is outstanding, involving materials synthesis, accelerated aging test, analysis, stack testing, materials characterization and cost analyses.
- "Cost not greater than Nafion" target probably not adequate.
- Good comprehensive approach to all important aspects of membrane life.

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

This project was rated **3.14** based on accomplishments.

- 6 months ahead of schedule for stack testing. Eliminated end groups susceptible to chemical attack. Mechanical strength doubled and made isotropic. Some adverse effect on cost and performance observed.

- The accomplishments were not well documented, perhaps because of the relatively recent timing of this project. An accelerated test has been developed, however, it appears to be based on the same peroxide reagent type testing that has been done for some time.
- Early results are showing benefits.
- Progress is encouraging that Nafion can achieve durability goals.
- Significant progress made on resistance to peroxide attack. Would be beneficial to show correlation between OCV and mechanical degradation.

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

This project was rated **3.14** for technology transfer and collaboration.

- Large degree of collaboration with systems integrators. If successful, they will have an easy path for integration into fuel cell manufacturing.
- A good team has been assembled to go from raw materials all the way to full power plants. This allows validation of improvements.

Question 5: Approach to and relevance of proposed future research

This project was rated **3.14** for proposed future work.

- Will examine ways to effect performance and cost.
- Future efforts should include more on cost estimate of membrane.
- Encouraging, broad base of activities.
- Consider how techniques developed can be applied to advanced membranes.
- Future plans look reasonable.

Strengths and weaknesses

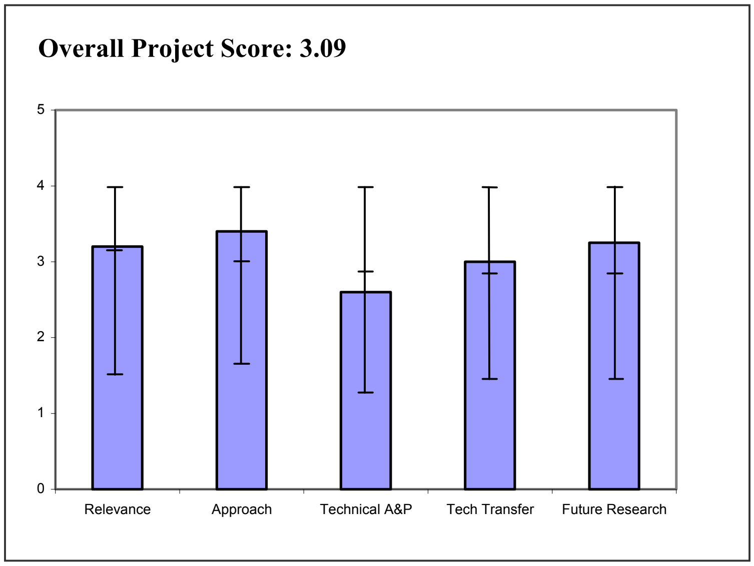
Strengths
- Addressing both chemical and physical solutions. The accelerated testing protocols are well-established.
- Team is strong.
- Characterization of MEA. Material development.
- Membrane durability factors well identified and mitigating strategies in hand.
- Multi-attribute, multi-disciplinary approach with testing to quantify improvement of each change.
- Safety appears to be an integral part of the project.

Weaknesses
- Pinpoint discrete progress thus far.
- Degradation factors associated with membrane/electrode/catalyst interface also needs consideration.

Specific recommendations and additions or deletions to the work scope

- Establish correlation coefficients for accelerated testing and project to real life expectations.

Project # FC-11: MEA and Stack Durability for PEM Fuel Cells
Hicks, Mike; 3M



Brief Summary of Project

During this project, 3M will determine root causes of MEA failure modes and develop an MEA with enhanced durability and maintained performance, that is manufacturable in a high volume process, meets market required targets for lifetime and cost, and is optimized for field-ready systems. The system demonstration will be for >2000 hrs. Focus will be on MEA component development, MEA characterization and diagnostics, and defining system operating window.

Question 1: Relevance to overall DOE objectives

This project earned a score of **3.20** for its relevance to DOE objectives.

- Well conceived and well focused.
- Objectives focused more on stationary than transportation application. Stationary fuel cells may plan a role in developing a hydrogen economy, and may prove some learning of value to transportation applications.
- MEA durability is critically important.
- MEA and stacked durability for automobiles, stationary power, as well as even portable systems is clearly a large issue.

Question 2: Approach to performing the research and development

This project was rated **3.40** on its approach.

- Excellent approach.
- Seem to be good, but need more detail explanation of technical approach for polymer materials, electrolyte and lifetime prediction models.
- A reasonable, well defined approach that may not be developing anything new but tests an already developed 3M proprietary polymer.
- Uses 3M's proprietary perfluorinated sulfonic acid ionomer, which is claimed to have improved oxidative stability over the baselined Nafion system. Aging tests developed to correlate single cell data with MEAs.

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

This project was rated **2.60** based on accomplishments.

- Technical progress very good.
- Stack and MEA seem to be too sensitive and limited to narrow operating conditions. It is not an appropriate approach to narrow the operating condition.

- It is claimed that the membrane GDL and cathode catalyst systems show improved oxidative stability. Peroxide measurement is used extensively and believed to be the key to understanding degradation. Membrane, GDL and cathode stability have been evaluated.

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

This project was rated **3.00** for technology transfer and collaboration.

- Excellent collaborations with industry, etc.
- 3M has collaborated with Plug Power, CWRU, and the University of Miami (modeling).

Question 5: Approach to and relevance of proposed future research

This project was rated **3.25** for proposed future work.

- As described work will be valuable. Progress to date is less than anticipated.
- Their proposed future work is to continue the MEA component development, establish decay mechanisms and accelerated lifetime predictor tests, and study the interaction of these parameters to MEA durability.

Strengths and weaknesses

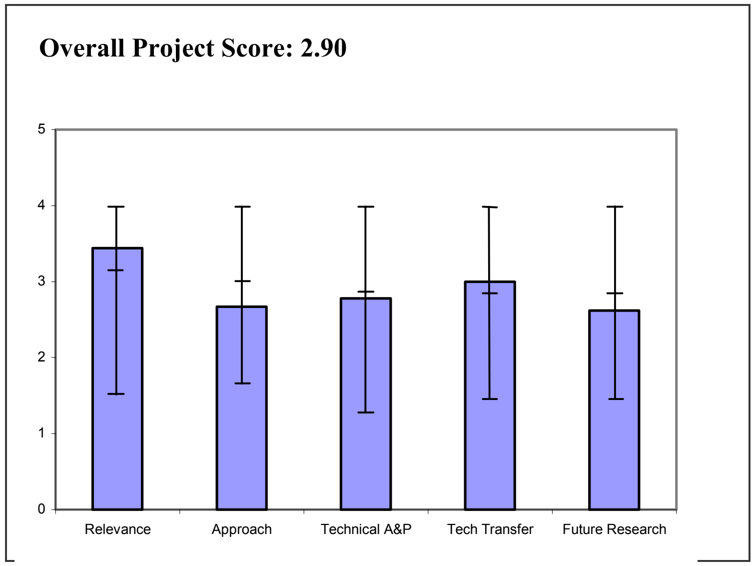
Strengths
- Well presented and managed project. The program should enhance significantly enhance fuel cell reliability. The 3M novel membrane development.
- Characterization of electrolyte material.
- MEA production at high volume. Understanding of factors associated with MEA durability.
- Major player in the field.

Weaknesses
- Robust approach.
- Internally focused project.
- Specifics are a bit difficult to discern.

Specific recommendations and additions or deletions to the work scope

- Focus on critical barrier of catalyst support degradation.
- Evaluate according to automotive requirements.

Project # FC-12: Development of a Low-Cost, Durable Membrane and Membrane Electrode Assembly
Gaboury, Scott; Atofina Chemicals



Brief Summary of Project

The objective of this Atofina Chemicals project is to develop low-cost, high-durability membranes by optimizing chemistry and process, validating scale up, developing MEAs based on these membranes, optimizing MEA for new membrane, validating MEA performance, and validating the MEA performance in single cells and in stacks.

Question 1: Relevance to overall DOE objectives

This project earned a score of **3.44** for its relevance to DOE objectives.

- Progress in a novel membrane is essential.
- Durability target is relevant to DOE and FreedomCAR targets. Performance target should include operation from high temp (120C) through low temp (10C) for automobile requirements. Low hydration conditions should also be evaluated.
- PVDF membrane has the potential to reduce costs but the total cost will also depend upon the cost of the electrolyte for which no information is given.
- The goal is to develop lower cost, higher durability membranes and to develop MEAs based on these membranes and to validate the performance in single cell and short stack testing.
- Lower cost high-durability membrane development is one of key objectives of the DOE program.

Question 2: Approach to performing the research and development

This project was rated **2.67** on its approach.

- Testing progresses from membrane to MEA to stacks.
- Atofina has an excellent track record in novel materials development.
- The membrane properties that provide superior durability to Nafion are not understood.
- MEA optimization with new membrane material is probably necessary, but starting that before you have a membrane comparable to Nafion may be premature.
- The approach is to blend an electrolyte with Atofina's Kynar PVDF polymer, which by itself is known to be quite stable in the fuel cell environment. In order to produce conductivity, the blended materials must be generated. The chemistry of the blend will be much different from Nafion, so, the approach to forming MEAs is recognized appropriately as being different.
- The electrolyte is not described. Kynar is not fully fluorinated and may actually not be more durable than Nafion. Stability of PVDF membranes in Li-ion batteries is irrelevant.
- Test temperatures are too low.

Question 3: Technical accomplishments and progress toward project and DOE goals
This project was rated **2.78** based on accomplishments.

- Nafion performance is within reach.
- Stable corrosive environment.
- First year progress is slow.
- Need to identify reason for poor performance and failures. Optimization of MEA before membrane is better performance improves may be premature. - need a better membrane first.
- Polarization curves appear competitive with existing materials.
- Performance in cells much lower than Nafion especially at lower humidity.
- Focus on more automotive related testing.

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

This project was rated **3.00** for technology transfer and collaboration.

- Team includes GA Tech, Johnson-Matthey, and UTC Fuel Cell, although UTCFC's role was not described.
- Good collaboration - high throughput screening should be helpful.
- Atofina has interacted with Johnson-Matthey and Georgia Tech to leverage their new materials. Some of their results look quite interesting.
- Johnson-Matthey is a major supplier of Pt salts and Pt catalysts.

Question 5: Approach to and relevance of proposed future research

This project was rated **2.62** for proposed future work.

- Logical and according to plan.
- In the future they will continue to develop the membrane technology based upon the Kynar chemistry and the blend polyelectrolyte chemistry. They plan to continue long-term testing and scale up the process.
- Fairly flexible approach.
- High temperature operation should be evaluated.

Strengths and weaknesses

Strengths
- Well conceived, well managed program.
- Kynar PVDF is an innovative material for this application.
- Strong polymer group.

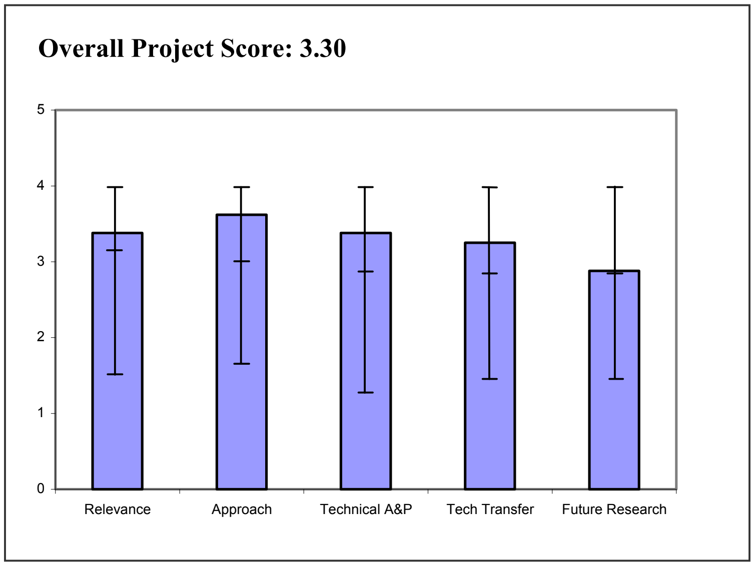
Weaknesses
- Need to identify mechanisms/causes of failure in durability tests. No information given on the electrolyte, so it is difficult to assess system. Not clear that root causes of problems are known, so cannot judge whether plans should address those problems.
- Approach may not translate to high temp conditions.

Specific recommendations and additions or deletions to the work scope

- Membrane and MEA robustness should be evaluated as well as durability. Robustness is necessary for automotive application.
- Detailed studies of failure modes and decay mechanism should be included.
- Focus screening based on higher temperature operations.

Project # FC-13: New Electrocatalysts for Fuel Cells
Ross, Phil; Lawrence Berkeley National Laboratory

Brief Summary of Project



For this project, new catalysts for both anodes and cathodes are being developed following a unified concept of PGM-based bimetallic nanoparticles with a "grape" structure (a PGM "skin" with base metal core). The choice of PGM and core metals for the anode and cathode will be based on computational screening of PGM core-shell nanostructures using newly developed (under BES funding) Monte Carlo simulations. Lawrence Berkeley National Laboratory (LBNL) will also: (1) pursue new synthetic chemistry to synthesize nanoparticles with a "grape" structure, (2) continue focus on Re as metal core with Pt and Pd as PGM, (3) optimize AuPd as alternative to Pt in anodes, and (4) conduct fundamental studies of the crystallite size effect for the oxygen reduction reaction in acidic electrolytes on carbon supported Pt and Pt alloy nanoparticles.

Question 1: Relevance to overall DOE objectives

This project earned a score of **3.38** for its relevance to DOE objectives.

- Project is highly focused and specific to one of the barriers.
- Great fundamental studies, provide guidance for choice of alloy materials.
- Working to reduce PM loading is crucial to reducing fuel cell costs. This type of work is very important.
- Better catalysts are needed for success of the program.
- Cost target is not mentioned.
- Relevant to better understanding of ORR kinetics.
- The fundamental technology which addresses the limits of current electrochemistry understanding is necessary to move fuel cells/hydrogen use to practical use.

Question 2: Approach to performing the research and development

This project was rated **3.62** on its approach.

- Technical approach is good but I question if this method can reduce the catalyst cost?
- World leading research capabilities and staff. Focus on fundamentals is important and critical for National Labs.
- Focus is sharp and needs to continue.
- Approach is good, but focus on specific key technical barriers should be clearer.
- Approach not well-outlined. Excellent fundamental results need to be incorporated into approach. How do results indicate new approach to prevent leaching? Does leaching of Co, Fe, etc. stop after 1st layer is removed?

- Professor Ross is a well known leader in this field. He demonstrated many fundamental concepts involving sandwich surface structures of Pt-Ni nanoparticles as well as core shell structure. Very fundamental studies of the surface electronic properties were reported. Thin film RDE methods were utilized for kinetic measurements.
- Seems good. It is necessary to identify how to develop mass production process for this electrocatalyst for fuel cells.
- A combination of catalyst characterization techniques, catalyst species, and modeling that has combined resources (BES) is very productive.

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

This project was rated **3.38** based on accomplishments.

- Progress continues to be made on engineered catalyst particle structures.
- The progress this year seems to be most significant - number of important confirmations and findings.
- Project is progressing, but it is not clear that this project will result in overcoming technical barriers.
- Excellent leverage of BES funding with Monte-Carlo simulations. Rejection of Pt in core of Pt-Re alloy is important finding. Only group really characterizing catalyst structure at the atomic scale.
- Thin film RDE methods were optimized for characterizing the 3M nanostructure Pt catalysts. The activity for ORR is close to that obtained on well known polycrystalline Pt.
- Activity is enhanced for Pt skin effect.
- "Grape" structure can significantly reduce the amount of platinum in fuel cells if the catalyst is durable over many hours in fuel cell environment.
- Very good presentation of data and inclusion of description of test conditions. Performance tests certainly appropriate for fuel cell relevance. Incorporation of 3M catalyst is very good decision.

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

This project was rated **3.25** for technology transfer and collaboration.

- Collaborations are ongoing with GM, UTC and 3M, as well as the Max Planck Institute in Germany and the University of Liverpool in the UK.
- Work with major players in fuel cell commercialization is right approach.
- Great validation studies.
- Project collaboration is good with several industry and university partners. The maturity of this project's technology looks to be enough into the future that technology transfer to an OEM or supplier cannot be evaluated.
- Working with GM and 3M and 2 universities. Good progress in establishing RDE as catalyst characterization tool.
- Significant interactions with leading fuel cell developers. Transferring characterization techniques to developers.
- Very capable collaborators chosen and overlap with industry is good for transfer of knowledge. Interaction with investigators who have different viewpoint or capabilities could be very rewarding.

Question 5: Approach to and relevance of proposed future research

This project was rated **2.88** for proposed future work.

- Fair rating only because future work was not discussed. Suggest more emphasis on fundamental understanding than on how to make materials.

- Continue combination of modeling and fundamental studies on the alloy/Pt morphology and performance.
- Not really covered in the presentation or list of slides. Not clear on how fundamental results are being used to guide new catalyst research.
- The future appears to hold further studies in analogous areas.
- No discussion of future research directions. Assume LBNL will continue to work on characterizing suitable "grape" structured catalysts.
- While the direction of work is clear, what the future plans for taking advantage of information to advance cathode catalyst structure/composition to better materials was not made clear.

Strengths and weaknesses

Strengths
- Capabilities for fundamental understanding of catalysts.
- Project is apparently making progress towards a reduction in PM loading.
- High quality basic science being applied to understanding importance of catalyst structure.
- Material synthesis
- Good interactions with major fuel cell developers - GM and 3M to improve basic understanding of ORR on specific catalysts unique to each. Good return on investment.
- Excellent experimental facilities and techniques. Combination of theory and experimental practice on a range of catalyst candidates provides very good direction and understanding of interacting processes.

Weaknesses
- Size of effort. Should employ more post-docs.
- It is not clear whether the progress will actually lead to overcoming some of the technical issues to implementing these types of catalyst.
- Not clear on direction of work to produce new catalysts with improved activity and endurance. Next steps for improving Pt-Co?
- Seems to be a certain amount of selectivity in choice of experiments and candidate species that support the chosen theory and model. Chooses to extol findings presented 20 years ago.

Specific recommendations and additions or deletions to the work scope

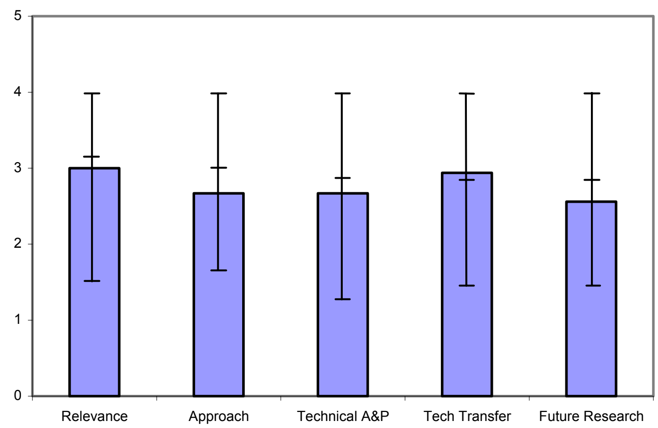
- I would like to see this group get involved with obtaining basic understanding of very low Pt or non-Pt containing catalysts. (e.g., w/Karen Swider-Lyons)
- Keep going. But, it is necessary to consider how electrode can be fabricated in large production basis. Actual cost perspective should be identified.
- What are next steps in reducing "grape" structure concept to practice? How does this catalyst perform in operating fuel cells?
- A concerted effort to carry out a set of experiments, using alloys that are candidates and do not follow theory, to help understand strengths or gaps in the hypothesis. Perhaps working with another theorist or model who has a different viewpoint would provide a little less biased description of catalyst behavior.

Project # FC-14: Low-Platinum Catalysts for Oxygen Reduction at PEM Fuel Cell Cathodes
Swider-Lyons, Karen; Naval Research Laboratory

Brief Summary of Project

The Naval Research Laboratory (NRL) will target DOE goals to achieve 0.02 g Pt/rated kW before 2010 by focusing on lowering Pt in fuel cell cathode. NRL is using \ oxide-based supports for Pt and other metals to leverage oxygen dissociation by oxides, metal-support interactions with Pt, and ionic mobility of oxide supports. 2004 objectives include: "perfecting" electrochemical methods, rigorously characterizing active and inactive catalysts, devising mechanism(s) to explain catalyst activity, and designing new active and stable catalysts.

Overall Project Score: 2.77



Question 1: Relevance to overall DOE objectives

This project earned a score of **3.00** for its relevance to DOE objectives.

- It is definitely relevant to reduce the cost of MEA. However, it is not clear if there is any economic benefit of attempting to reduce levels from the point of view of long durability if novel nanotechnology is not used.
- Narrow focus. Addresses one aspect of catalysts needs.
- Very relevant. Needs to stay focused at the fundamental science level.
- The development of low platinum catalysts would be great boon to the fuel cell initiative.
- Supports goals to reduce the cost of fuel cells and to conserve Pt.
- Very well aligned with the goals of the program.
- Cost target is not given.
- Lower Pt loading in line with HFCIT objectives.
- Fills need for work on conducting oxide supports, both to enhance catalytic activity and as a possible alternative to carbon.

Question 2: Approach to performing the research and development

This project was rated **2.67** on its approach.

- Technical approach is good but, I question if this method can reduce the catalyst costs?
- Good approaches for low-Pt ORR catalysts to be characterized by XPS, XANES and electrochemical methods. Would like to see more fuel cell performance testing results. The role of MO_x is not clear.
- Not clear yet how these supports can provide advantages over carbon. Could benefit from modeling, e.g. LBNL embedded atom approach.
- Come a long way! Work is now focused. Approach is good but needs to address broader MEA-electrode elements. Oxide substrates hard to understand how they will work.
- Goal has been to use material selection to choose stable active hydrous oxides/phosphates from selected portions of the period table. Thus this is quite a fundamental study also from the Naval

Research Lab. The approach has been to evaluate the rotating disk electrode systems and to prepare MEAs for fuel cells with traditional anodes. Physical characterization involves spectroscopy, thermal analysis, microscopy and surface analysis.
- Approach is good and some minor issues with data analysis at last year's review appear to have been resolved.
- Good choice of materials.
- Seems good, but need more detailed criteria for down-selection of material for this application. What could be the metric? Also, it is necessary to identify cathode corrosion problem and the solution should be incorporated in the approach.
- Poorly expressed rationale for studying platinized "hydrous oxides".
- Improved focus on materials that are likely to be stable. Combination of performance testing and detailed characterization is just what is needed on such an exploratory topic. Still need improvements in testing - too heavy loading of active materials on disks.

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

This project was rated **2.67** based on accomplishments.

- Pt-SnO_x is a promising catalyst. Good results from characterizations by XPS and XANES. Decent understanding of the catalysts mechanistically.
- Progress relative to this project's history is good, but progress relative to overcoming barriers is very low.
- Progress good. Work on mechanisms and fundamentals. Need to see some tie to actual electrode applications so as to get degradation mechanisms understanding as they impact structures.
- Accomplishments include the generation of various hydrous tin oxides with various metals and some enhanced ORR activity for analogous gold or palladium on the tin oxide supports.
- Making good progress with low cost catalytic materials.
- Good progress.
- Chaotic, sloppy presentation. Very few concrete results. Did not look like a year's work at the level of effort stated. No sign in results that this is a promising direction.
- Some improvement in testing and interpretation over last year - still needs further improvement. Data on both Pt - particle and Pt-in-oxide-lattice catalysts provides contrasts that could lead to important insights. Data could still be better presented (e.g. compare activities over a range of potentials, not just one).

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

This project was rated **2.94** for technology transfer and collaboration.

- Good balance of technology transfer/collaborations among academia and industrial organizations like GM. More collaboration with fuel cell developers are encouraged.
- Big improvement over past years.
- Team is doing better job with externals. Time to get this material into other's hands for feasibility testing.
- Possible mechanisms for the activity were reported.
- Appears to have broad range of collaborations and is working with industry to commercialize technology.
- Well-communicated interactions with good groups.
- What collaboration? GM is trying to correct their sloppy procedures. That's not collaboration.

- Outside interactions are appropriate for an exploratory project. Project takes advantage of outside contacts to grow in productive directions.

Question 5: Approach to and relevance of proposed future research

This project was rated **2.56** for proposed future work.

- Good plan for future work. Develop deeper understanding of the catalysts mechanistically. More fuel cell testing results. Develop ORR kinetic models. More collaborations with fuel cell MEA developers like W. L. Gore, Umicore, Johnson Matthey, DuPont, 3M, etc.
- Not clear that the progress to date justifies an expectation that this approach will ever be able to make improvement in low Pt loading in real fuel cell environment.
- Would like to see more mechanistic work, especially involving OOH mechanism/species. Oxide support optimization and model development.
- Future efforts will continue the study of this important area.
- Going nowhere.
- Planned classes of materials to be studied seem appropriate. Acknowledged need to get ink preparation under control to allow outside labs to reproduce results. Should make sure internal testing procedures give clean kinetic data - don't overload disks.

Strengths and weaknesses

Strengths
- An example of new catalyst design and fabrication through scientific understanding and suitable utilization of catalyst characterization techniques.
- Team has expanded and now has a broader skills set to address more fundamental issues. Team is more focused than years past.
- Electrochemical and physical analysis on electrocatalyst for fuel cells.
- Good choice or research area. Improved methodologies and interpretation of data.

Weaknesses
- More evidence should be provided in order to support the claim of the MO_x's roles in the catalyst mechanistically. No kinetic data. Very little fuel cell testing information.
- Unrealistic assessment of the entitlement performance of this technology approach.
- Selected aspects of talk were too vague. Increase quantitative analyses. Beef up thermodynamics/kinetics elements.
- Can strive further to present data in more standard format to better allow comparison of materials under condition that are both largely under kinetic control and could be analogously tested in a fuel cell. Still need to work on electrode preparation procedures and testing.

Specific recommendations and additions or deletions to the work scope

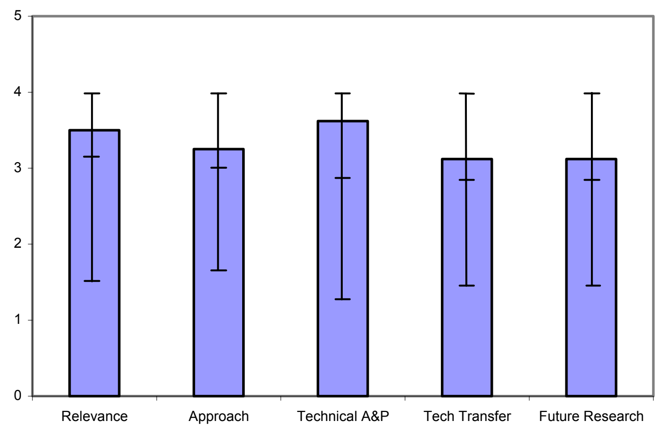
- Should seriously consider if this approach has the viability the P.I. proposes.
- Keep going. But, it is necessary to consider how electrode can be fabricated on a large production basis. Actual cost target should be identified.
- Terminate as soon as possible.

Project # FC-15: Low-Platinum Loading Catalysts
Adzic, Radoslav; Brookhaven National Laboratory

Brief Summary of Project

The purpose of this Brookhaven National Laboratory (BNL) project is to develop low platinum-loading electrocatalysts. The objectives are to demonstrate the possibility of synthesizing novel electrocatalysts for O_2 reduction with monolayer level Pt loadings, further characterize the $PtRu_{20}$ electrocatalysts for H_2/CO oxidation and long term tests, and to gain understanding of the activity of Pt monolayer and the $PtRu_{20}$ electrocatalysts.

Overall Project Score: 3.32



Question 1: Relevance to overall DOE objectives

This project earned a score of **3.50** for its relevance to DOE objectives.

- Very specific focused approach addressing one barrier -- Pt reductions.
- Very relevant for the DOE goals.
- Important area.
- Directly addresses precious metal loading, durability and CO tolerance target for anode and cathode catalysts.
- Work is relevant. Project goals aligned.
- Good, but CO tolerance should be reconsidered to meet hydrogen system as a primary purpose (not reformer system).
- Program continues to make progress toward reducing the Pt content of the fuel cell. May have already exceeded DOE target.

Question 2: Approach to performing the research and development

This project was rated **3.25** on its approach.

- Requirement of Pd or Ru sub-particle dilutes cost advantage of this approach.
- Is this method applicable to other metals/metal oxides as support to Pt? Can this approach be used for making large quantities of catalyst?
- The development of lower platinum loading systems using two different methods for platinum monolayer deposition.
- Excellent combination of fundamental characterization (CV's, XANES microscopy) combine with critical fuel cell-relevant testing at both materials level and in MEAs (with LANL) to provide guidance for further development.
- Approach is methodical and was built upon prior work. Sound fundamental basis. Fundamental yet practical.
- Program has good understanding of fundamentals. Applies fundamentals to successfully develop technology.

Question 3: Technical accomplishments and progress toward project and DOE goals
This project was rated **3.62** based on accomplishments.

- Given the $250K funding. Demonstration of stability very important. Basic understanding of ORR inhibition by unions.
- Validation studies at LBNL very important continued collaboration.
- Stability tests at LANL show no loss of voltage after nearly 900 hours. It is proposed that the durability target of 2000 hours can be reached with this electrocatalyst. With respect to the cathode, the platinum monolayer has been demonstrated to be an active catalyst for oxygen reduction. Further complex mixed-metal electrocatalysts were synthesized and their activities are being examined. Further surface analysis studies have also been carried out.
- Very exciting results for monolayer Pt on Pd and Pt/Pd/C catalysts for ORR. Continued work on PtRu anode catalysts also making good progress in durability and mechanism elucidation.
- Progress is good and practical testing at LANL applauded. Focusing on correct "elements" of potential catalyst.
- High activity observed. What is durability?
- Program continues to show success after success. Movement to cathode catalyst is most exciting.

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

This project was rated **3.12** for technology transfer and collaboration.

- For size of program, interactions with LANL have been productive.
- Collaborations with Los Alamos have been developed, and interactions with Plug Power have been initiated.
- Excellent work with LANL to conduct MEA and durability studies for technology transition. Several other potential collaborations under discussion, including Plug Power.
- Probably could increase a bit.
- No real collaborations listed except for LANL.
- Has key groups from industry and academia.

Question 5: Approach to and relevance of proposed future research

This project was rated **3.12** for proposed future work.

- Studies of PtOH effects on ORR could be critical. More work on CoPd.
- Expand effort on AuNi immerscible alloys -- good approach other materials?
- For the future, hydrogen oxidation will be studied using the platinum sub monolayers. Oxygen reduction will be further studied in conjunction with LANL.
- Pt/AuNi/C work promising and should be pursued. Pt/Pd/C continued effort and LANL tests are a must do.
- Well thought out. Covers all aspects of catalyst/development of electrodes.
- Future work not clearly specified in sufficient detail.
- Well focused objectives and based on past performance, it should be successful.

Strengths and weaknesses

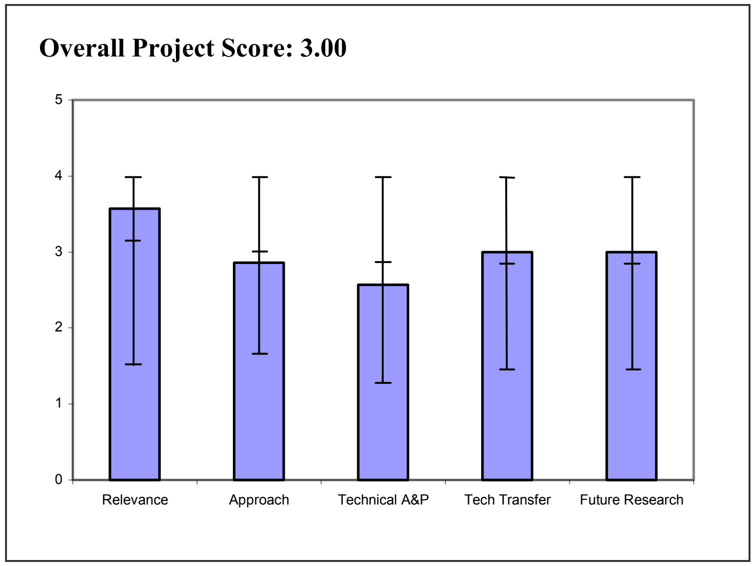
Strengths
- World class investigators.
- Very thorough approach to designing catalysts based on understanding the complex relationship between the catalyst components at the materials level and how that influences reaction mechanisms.
- Solid approach. Good follow-through from theory to application. Very practical yet seems to know what fundamental risks remain.
- Material development.
- Research leader is tops in field.

Weaknesses
- May not have critical mass for adequate rate of progress.
- Should expand a bit further (tech transfer).
- PI tried to put too much information into presentation. Needs to focus presentation on key results that support objectives and goals of program. PI is doing good work on this program but his presentation was so hurried and long that the good work was not obvious.
- Low budget compared to $750K for 1st year projects for non-precious metal catalysts.

Specific recommendations and additions or deletions to the work scope

- Work with LBNL to understand commonality of the approach, i.e. "skin" effect. Why not more focus on PdCo system, instead of Au nanoparticle supports for Pt?
- Keep going.
- This program is under-funded. Most successful effort of DOE for reducing catalyst loading but low budget. DOE should consider integrating with industrial counterpart.

Project # FC-16: Development, Characterization and Evaluation of Transition Metal/Chalcogen Based Cathode Catalysts for PEM Fuel Cells
Campbell, Stephen; Ballard Power Systems



Brief Summary of Project

Ballard Power Systems intends to develop a non- precious metal cathode catalyst for PEM fuel cells, which is as active and as durable as current PGM-based catalysts at a significantly reduced cost. Their plan includes development of composition and structure, process development (can be scaled up), and evaluation/ demonstration in fuel cells and stacks.

Question 1: Relevance to overall DOE objectives

This project earned a score of **3.57** for its relevance to DOE objectives.

- The non-precious metal cathode catalyst would of course make a major difference to progress in fuel cell development.
- Development of non-Pt cathode catalyst for PEMFC is critical for reducing stack cost (to improve market penetrability) and minimize/reduce U.S. dependency on a non-domestic resource.
- Non-Pt electrocatalysts are critical for commercial implementation of PEM fuel cells.
- Lowering the cost and eliminating the use of precious metals are critical to the commercial realization of PEM fuel cell power systems.

Question 2: Approach to performing the research and development

This project was rated **2.86** on its approach.

- Logical approach culminates in short stack test. Process development is required just to test the materials.
- The approach has been to study optimum catalyst compositions (metal, chalcogen) and the structure using a well-defined thin film material on glassy carbons. Thus, this is also a relatively fundamental study.
- Technical experimental approach is good but lack of a theoretical modeling effort could hamper catalyst development. Not clear that selected metal chalcogens will be better than Ru chalcogens.
- Questionable whether data obtained on thin film "model" catalysts can be easily transferred to "nano-dispersed" catalysts - possibility of missing "magic" formulations. Focus on structural/nano-structural characterization is important.
- Chalcogens have been tested for oxygen reduction in the past (Alonso Vante, 1987-1995). How is this approach different?
- Does not build on previous R&D in this area based on discussion. Technical feasibility not shown.

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

This project was rated **2.57** based on accomplishments.

- Considering the very recent start (4-5 months), progress is reasonable although, so far, the only progress is staffing up and equipment procurement and set-up.
- Too early to evaluate.
- Apparently, the project has only recently started so not too many accomplishments were claimed, except that the research staff is in place and working. The glassy carbon substrates have been machined, and initial baseline data have been obtained and the coating of the thin films is in progress.
- New project (less than 2 months). Very difficult (not fair) to judge effectiveness towards achieving objectives. Appears that research plan for collaborators is in place.
- Too early to assess, in general equipment/apparatus set-up not considered accomplishments.
- Very little progress relative to other DOE-supported cathode catalyst projects initiated at the same time.
- Program just getting started and progress to date is minimal.

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

This project was rated **3.00** for technology transfer and collaboration.

- Would like to see National Lab involvement for catalyst requirements. University involvement is only for characterization and not for catalysis or materials choice.
- Collaborations with Los Alamos have been developed, and interactions with Plug Power have been initiated.
- Appears that most of R&D effort is being conducted by university collaborators. Role of Ballard in catalyst development effort is not clear.
- Ultimate transfer of technology via demonstration in Ballard stack is excellent approach. Need more collaborations with U.S. universities and National Labs (U.S. $$).
- Several collaborations are in place and the transfer to fuel cell manufacturing will be easy since this is a Ballard Project.
- Appears to have put together good team.

Question 5: Approach to and relevance of proposed future research

This project was rated **3.00** for proposed future work.

- Substantial data were promised "imminently."
- In the future it is planned to do in situ fuel cell optimization using down selected powder catalysts. Obvious variables to be studied will be investigated.
- Technical plan is well structured to allow for rapid screening of catalyst performance. Concerned that they will not be able to make down selection of catalyst by end of 1st year.
- Doesn't appear to have fast track approach to achieve "home run." Need to validate thin-film approach for screening catalysts.
- The research plan is sound.
- No specifics or pathway discussed. Written as a "wish list."

Strengths and weaknesses

Strengths
- Characterization of catalyst for fuel cell.
- Good approach using well-defined "model" catalysts to gain insight into the catalytically active center.
- Experience and commercial position of Ballard for commercialization and technology validation.
- University collaborations and ease of transfer of technology to fuel cell manufacturing.

Weaknesses
- Doesn't adequately address potential differences between catalysts on glassy carbon and on porous carbon powders. Process development is a major part of this effort rather than catalyst characterization and testing. The project will be a failure if they cannot make the catalysts on the porous carbon. Maybe involvement of an experienced catalyst-maker company would save time and money and reduce risk.
- Need to confirm that the "model" catalyst is truly representative of actual catalyst (not necessarily a weakness). Lack of theoretical modeling effort could hamper catalyst developers. Lack of effort focusing on catalysts durability/stability, especially prior to stack performance and assessment testing.
- Long-term path for feasibility demonstration. Basis for selection of trans-metal chalcogens not clear to this reviewer. Universities apparently in critical path for development (long-term).
- No distinction from past work on this type of electrocatalyst.
- Not apparent the researcher understood topic area.

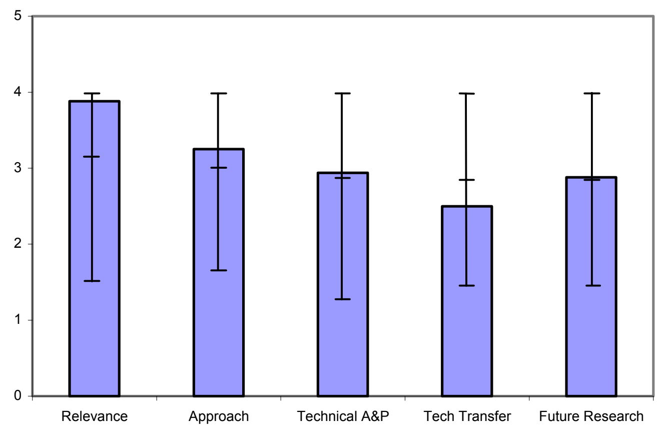
Specific recommendations and additions or deletions to the work scope

- Keep going.
- Need to determine acceptable volume increase and required catalyst activity relative to "state-of-art" Pt/C catalyst to meet DOE targets. Need to quantify performance criteria for selecting catalyst for stack performance and assessment testing (Phase 3-Task 8).
- Incorporate go/no-go decision into work plan. Need to demonstrate technical viability before proceeding to subsequent phases.
- Restructure program to get better definition of technology, hard (go/no-go) goals. Consider stopping program until restructured.

Project # FC-17: Novel Approach to Non-Precious Metal Catalysts
Atanasoski, Radoslav; 3M

Brief Summary of Project

Overall Project Score: 3.09



This 3M project will develop and demonstrate non-precious metal NPM cathode catalyst to lower cost (50% less vs. target of 0.2g Pt/peak kW) and to reduce the dependence of PEM fuel cell catalysts on precious metals. Additionally, they will identify opportunities for system cost reduction, through breakthroughs in key areas of the fuel cell, the catalyst and application of cost-effective processes for MEA fabrication, closely associated with the development of the new catalyst. Sample tasks include investigation of Fe-N-C as a model catalytic site, test 1- and 2- step synthesis processes, and fabrication and characterization MEAs.

Question 1: Relevance to overall DOE objectives

This project earned a score of **3.88** for its relevance to DOE objectives.

- Supports goals to reduce the cost of fuel cells and to conserve Pt.
- Development of non-Pt cathode catalyst for PEMFC is critical for reducing stack cost (to improve market penetrability) and minimize/reduce U.S. dependency on a non-domestic resource.
- Important to commercialization of PEM fuel cells. 50% cost reduction relative to Pt seems to be a very conservative goal.
- There exists a need for non-precious metals or very low loaded precious metals in fuel cells.
- Lowering the cost and eliminating the use of precious metals are critical to the commercial realization of PEM fuel cell power systems.
- Development of non-platinum or non-precious metal catalysts for fuel cells is critical to cost reduction and poison-resistance of electrodes. This project, if successful will provide a means to overcome a major barrier.

Question 2: Approach to performing the research and development

This project was rated **3.25** on its approach.

- Approach seems to have potential to make non-precious metal catalysts.
- Good integration of theoretical and experimental research. Still too early to evaluate effectiveness of approach.
- Developing new vacuum deposited catalysts using 3M technology, including its unique nano-structured thin film substrate. A second approach has also been to develop recent insights based on non-platinum ORR catalysts for PEMFCs.
- Leverages 3M's existing technology base for catalyst/MEA production. Rapid feedback loop with electrochemical testing.

- Not clear this a repeat of previous macrocycle R&D. Presenter did not seem to be aware of catalyst activity limitations.
- Nice combination of experimental and theoretical approaches. I have some reservations that the modification of the edges of graphene sheets to incorporate N and Fe will result in a high enough density of catalytically active sites given that the edge sites constitute a small portion of the total number of sites.
- The project is building upon in-house capabilities and new developments in the literature to attempt to prepare new catalysts using high throughput manufacturing capabilities. The project is integrated with the high surface area nano-structures discussed in FC-4. One would wish to see a little more fundamental work on analysis of the nature of the catalyst. Perhaps some SIMS to see if structures can be identified. Also what would be the difference between these catalyst structures and say, a polyvinylpyridine layer with Fe bound to it? It would be interesting to compare. One is a bit concerned about the catalytic activity and whether it will be sufficient to compete with Pt. If not, how does the nano-structuring of the carbon support affect this?

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

This project was rated **2.94** based on accomplishments.

- Although early in the project, PI seems to have reasonable plans in place to meet objectives of the project.
- Too early to evaluate.
- Very good effort to date in establishing theoretical and experimental program. Progress to date does not suggest technical barriers will be overcome but effort to date is commendable.
- Produced a model iron-nitrogen-carbon system as a model catalytic site. They have demonstrated a one-step synthesis for the proposed target structure and have formed and characterized MEAs for the new catalysts. They have begun to model the incorporation of these systems in the catalyst layers. Various data were produced to support that hypothesis.
- It seems a bit early to expect exciting results, but significant improvement is necessary. Identified alternative processes for producing catalysts with high pyridine nitrogen.
- Showing some results of repeat of literature work from GRI, cited V. Jahlan.
- Excellent progress for the short duration of the project. Next year will be much more critical.

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

This project was rated **2.50** for technology transfer and collaboration.

- No discussion of collaboration or interactions.
- Only collaboration identified is Jeff Dahn for fast screening methods. Assume PIs will collaborate informally with industry/academics when appropriate.
- Collaborations with Los Alamos have been developed, and interactions with Plug Power have been initiated.
- Built-in tech transfer. Collaborations with universities. Probably should consider validation at National Labs.
- Presentation did not mention transfer and collaborations. Industry group is strong.
- A subcommittee with Jeff Dahn was mentioned, otherwise there is very little collaboration/technology transfer evident.

Question 5: Approach to and relevance of proposed future research

This project was rated **2.88** for proposed future work.

- R&D to identify active catalyst sites and understand reaction mechanism is critical; theoretical effort is essential.
- In the future they will further study the appropriateness of the nitrogenated carbon precursor as a catalyst system. They will attempt to use surface analytical techniques to identify the nature of the most active site. Modeling will be continued and the limitations of the boundaries of the project will be identified.
- PI seems to have good future plan, increased testing, characterization, broader scope of formulations, etc.
- Average plan. Little discussed on electrochemical aspects.
- Not really clear about future plans and time-frames. No specific milestones given, e.g. how much catalytic activity will constitute success? What surface area will be required? How about stability and durability? When will these tests start.?This aspect of project needs improvement.

Strengths and weaknesses

Strengths
- Characterization of catalyst for fuel cell.
- Good integration of experimental and modeling program.
- Good balance between sample preparation process development, and electrochemical testing. Good technology validation/commercialization path; Fe-C-N catalyst formulations demonstrated to be valid path for non-PM catalysts.
- Unique approach.
- Builds on in-house capabilities and adds to other programs already on-going. Builds on new insights into catalysts.

Weaknesses
- PI spent too much time discussing the time line for future actions which cut short the time available to discuss accomplishments, future plans or collaborations. It is suggested that the PI devote more time to accomplishments and future plans.
- Initial electrochemical activity test results are not encouraging -- need to determine if poor-performance is due to the catalyst or other factors. Need to determine density of active sites - is it achievable?
- Significant performance improvements needed, although this is a new project.
- Researcher did not appear to know history in this area.
- Low density of potentially catalytic sites and poor activity thus far.
- Future plans not well laid out. No specific target provided and effect of high surface areas not developed.

Specific recommendations and additions or deletions to the work scope

- Keep going. Need to determine acceptable volume increase and catalyst activity required relative to "state-of-art" Pt/C catalyst to meet DOE targets.
- Validate at National Labs (when performance levels warrant).
- Using projected catalytic activity, researchers should calculate the catalyst loadings to achieve performance compatible with Pt catalyst.

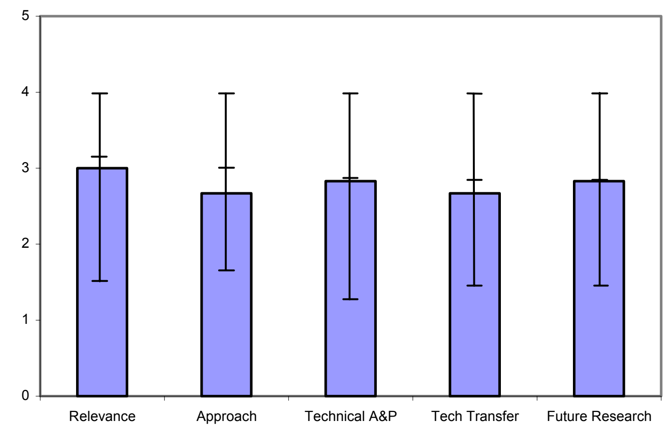
- Add better planning for next year. Need specific milestones. Not clear from this presentation.
- The project is co-coordinated with FC4 and FC11 but only contains one specific collaboration with Dalhousie for combinatorial screening. The presenter did not emphasize these aspects and this should be developed in the next year. The fundamentals underlying this work are being kept a little too unclear to justify the large amount of public funds. Clarify this for next year.

Project # FC-18: Novel Non-Precious Metals for PEMFC: Catalyst Selection Through Molecular Modeling and Durability Studies

Popov, Branko; University of South Carolina

Brief Summary of Project

Overall Project Score: 2.80



The University of South Carolina (USC) will synthesize novel non-precious metal electrocatalysts with similar activity and stability as Pt for oxygen reduction reaction (ORR). They will focus on high activity for ORR, mass production methods, corrosion resistance, low cost, and improving understanding of reaction mechanism of oxygen reduction on non-precious catalysts. Supporting tasks include theoretical molecular modeling, electrochemical characterization, structural studies (XPS, EXAFS, XANES), identifying the correlation among the catalyst composition, heat treatment and catalytic sites for oxygen reduction, and demonstrating the potential of the novel non-precious electrocatalysts as a substitute for Pt currently used in MEAs.

Question 1: Relevance to overall DOE objectives

This project earned a score of **3.00** for its relevance to DOE objectives.

- Very focused on one critical barrier.
- Work is relevant.
- Addresses cost, durability and performance issue for cathode materials.
- Interesting approach based on combination of fundamental studies and synthetic methods.
- Program addresses methods for NPM catalyst and is important.

Question 2: Approach to performing the research and development

This project was rated **2.67** on its approach.

- Approach is a "wish-list." Tasks listed are very large and difficult. For size of budget, doubtful critical gains can be met in allowable time.
- Technical feasibility needs include stability of catalyst and impact of poisoning of membrane.
- Combination of modeling and experiment may accelerate catalyst development. Cost comparisons probably not entirely accurate since some of the organometallics could come down in price if mass produced. Needs to incorporate some additional analytical techniques to really understand what they actually have.
- Approach is logical and consistent.
- Well structured approach that should answer key questions regarding performance capability of catalyst.

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

This project was rated **2.83** based on accomplishments.

- Large amount of data acquired for short time of project. Good sign. Good quality data.
- Good progress. Prior graphic suggests much understanding still in front of team.
- Many others have demonstrated issues with use of Fe; why are they using it? Results are very preliminary -- a lot of work still to be done. Need to move beyond only echem characterization to see if these systems are truly feasible.
- Good progress, benchmarking and comparative studies.
- Claims performance equivalent to Pt on RRDE. This should be quantified in "real" fuel cell.

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

This project was rated **2.67** for technology transfer and collaboration.

- For basic R&D like this, the academic interaction is good.
- Collaborative effort with CWRU and Northeastern, but they don't seem actively engaged in the effort at this point. Other interest (industry) not likely until proof of concept demonstrated.
- Collaborators are all excellent researchers and the interaction should provide good path/results from the studied materials.
- Good academic collaboration but needs industry group.

Question 5: Approach to and relevance of proposed future research

This project was rated **2.83** for proposed future work.

- Proposed work on target to meet goals of program. Ambitious plan for next 12 months.
- Too broad. Proposed future work doesn't indicate exactly what they plan to do based on current results. What will the initial modeling studies focus on (current MX/C materials, planned N-containing precursor material, etc.?).
- Good plan for future work.
- Addressing immediate issues.

Strengths and weaknesses

Strengths
- Broad spectrum of technical issues are being addressed by a solid team.

Weaknesses
- Past experience of fuel cell catalyst development might cause one to question whether just transition metals on carbon can achieve the targets.
- Difficult to understand sometimes. Should include a "take-home message" bullet on each slide in addition to the data plots. Approach seems primarily empirical - don't see how all the pieces (catalyst synthesis and testing, modeling, characterization) are going to be pulled together.

Specific recommendations and additions or deletions to the work scope

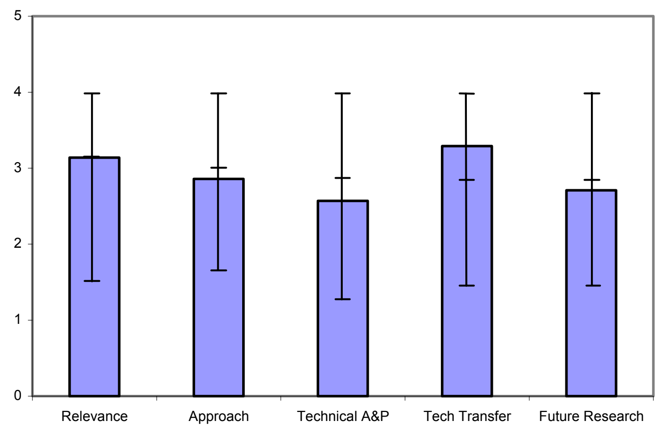
- Pick a class of materials and understand it before beginning a new area (MX/C vs. N-containing) or provide intermediate milestones to determine how long the effort in one class will go before a go/no-go target is either met or not.
- Surprised by claim non-precious metal catalyst with performance equivalent to Pt under RRDE conditions. Key question is whether the RRDE are relevant to fuel cells.
- Suggest prioritizing and focusing on fewer more critical tasks.

Project # FC-19: Scale-Up of Carbon/Carbon Bipolar Plates
Haack, David; Porvair Fuel Cell Technology

Brief Summary of Project

Porvair Fuel Cell Technology intends to develop material and manufacturing methods leading to a low-cost carbon/carbon bipolar plate. Objectives are to: evaluate and demonstrate performance within a fuel cell stack; evaluate potential cost of manufacture; develop low volume production capabilities; develop incremental, near-term cost reduction technologies; manufacture 10 kW fuel cell sealed plate demonstration stack; develop and implement comprehensive quality assurance plan; and develop a comprehensive cost model for high volume production.

Overall Project Score: 2.91



Question 1: Relevance to overall DOE objectives

This project earned a score of **3.14** for its relevance to DOE objectives.

- As FC market fails to develop as rapidly as projected, component scale-up projects become less relevant. More emphasis should be placed on component improvement.
- If $10/kW goal is achievable as stated in the presentation, with volume, this will be a significant cost reduction. 95% of current cost is labor; estimated assembly techniques should cut cost to acceptable levels.
- 10kW stack size is not appropriate for future demands, neither is automotive nor is stationary applications. Need to become larger.
- Project focused on developing cost-effective manufacturing method for bipolar plate, a key component of PEMFC system. Scale-up of promising technology developed at National Lab.
- Bipolar plates are an important topic.
- Novel preparation of a key fuel cell component, offering some unusual possible benefits.

Question 2: Approach to performing the research and development

This project was rated **2.86** on its approach.

- Approach has not been clearly communicated. What is definition of success?
- Initial plan to scale-up may have been able to demonstrate low-cost production of bipolar plates - with change in direction. It is not clear how the approach will meet targets.
- Logical move to get out of pilot plant goal of 300 plates/hr. Instead focusing more on effort of cost reduction R&D. However, automation of assembly might not be as straight forward for ensuring repeatability and quality on plates. Effort must be spent here.
- May be the right way to establish the process first, than having a look to adjust to the right size. But maybe it's too late after establishment of process.

- Current focus on cost reductions through near net shape forming and low cost machining options. Addressing important product quality issues including dimensional tolerance, electrical conductivity, hydrogen permeability. Pursuing development of components for sealed plate stack.
- Not clear that ongoing directions of project area is well-defined following abandonment of scale-up. Incremental improvement is not the best subject for government-sponsored research, but large cost-share is acknowledged.

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

This project was rated **2.57** based on accomplishments.

- The project has shown some improvements in production and improved product to leverage but it is not clear if the improvements are good enough to reduce costs and increase durability - need to do some testing showing correlations of better dimensional tolerance with costs -- other factors with durability. Stated that major costs are related to labor and low volume processing, but have not made progress in goals to high-volume processing as was the original goal.
- If data reported is factual, it appears the targets should be met. Dimensional tolerance important significant and impressive.
- Good progress made in achieving desired dimensional tolerance in pilot scale facility. Promising sealing technology demonstrated. Project manufacturing costs consistent with long term cost targets. Operating a pilot production line at up to 10 plates/hr; sold nearly 40K plates last year; original plan to develop 300/h facility would not be supported by current market.
- The tolerance is far too broad for a real application (slide 12).
- After good start in previous years, project seems to be drifting a bit. Start made on getting sealed plates evaluated, but no data shown yet.

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

This project was rated **3.29** for technology transfer and collaboration.

- Collaboration with best-in-class. UTC validates efforts in this program.
- Interaction with UTC Fuel Cells or ORNL will probably get improvement into a fuel cell, although probably only a fuel cell from one manufacturer.
- Extensive collaboration with UTC. Over 40,000 plates purchased last year and used in various product lines. Sealed plates lacking a customer but plans to assemble stack for testing.
- Minimum number of partnerships shown in this review presentation.
- Authors working closely with UTC in PEMFC demonstrations. Scale up of ORNL carbon technology.
- There is apparently already transfer to customers. Why is this funded through DOE?
- Good transfer of ORNL technology to primary customer. Good efforts to transfer to other customers assuming can be brought to fruition.

Question 5: Approach to and relevance of proposed future research

This project was rated **2.71** for proposed future work.

- How will cost reduction be realized?
- Details of future work lacking. Not working on scale-up, not sure what near term cost cutting technologies they are planning to pursue. Appear to be trying to optimize their current production conditions which can not meet DOE targets rather than a system which can meet the targets.

- Continuing cost reduction R&D. More studies into sealed plates is a must, and is addressed in the 10kW fuel cell deliverable. More study into scale up for volume would be nice to see.
- Clear, but small selection of future plans.
- Project appropriately focused on developing new manufacturing strategies that could incrementally lower costs. Authors have identified important development issues needed for viability of technology.
- Plan is good as long as momentum is regained.

Strengths and weaknesses

Strengths
- Showed great technical progress this year. Choice of subcontractors is excellent.
- Appears to be on target for DOE barriers for cost, durability and performance. Close collaboration with UTC/ORNL continuously keeps plates in testing for reliable use data. Dimensional tolerance improvement is impressive.
- Outstanding example of technology transfer from National Lab (ORNL) to industry. Working closely with fuel cell industry (UTC) to identify and meet technical requirements. Making product on scale consistent with needs; plates being sold to developers.
- Tech transfer; material has some unique properties.
- Project is appropriately focused.

Weaknesses
- Market not ready for 10,000,000 units, so scale-up not practical. Approach not well-defined.
- Program goals appear to have changed drastically from scaling up production to reduce costs from labor and low volume manufacturing (the main cost factors) to addressing smaller cost factors. The scale of the program does not appear to be scaled down with the goal.
- By removing the pilot plant deliverable it is possible problems could arise in scale up for volume.
- Meeting cost targets will be a challenge.
- We do not need sales and marketing presentations during the review.
- With abandonment of pilot-facility, won't really develop knowledge of whether cost could be made competitive.

Specific recommendations and additions or deletions to the work scope

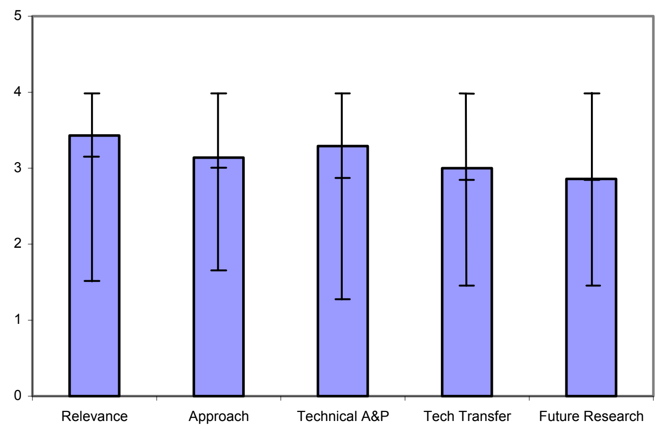
- Quality assurance program is pre-mature. Focus on product improvement (performance).
- Project focus seems to have changed from a major scaling-up effort to improving on an already developed technology at a small scale. Technology appears to be already fairly advanced. Stated they didn't scale-up because they couldn't see the volume to support the work at current costs. Suggest funding be delayed until the market is there for them.
- More study towards scale up of manufacturing volume.
- Push to see just how thin a sealed plate could be made.
- Nice progress with dimensional tolerance improvement. Please relate physical property data back to specific goals and/or project requirements.

Project # FC-20: Cost-Effective Surface Modification for Metallic Bipolar Plates
Tortorelli, Peter; Oak Ridge National Laboratory

Brief Summary of Project

Oak Ridge National Laboratory (ORNL), and National Renewable Energy Laboratory (NREL) are developing a surface treatment to protect metallic bipolar plates by thermal (gas) nitridation of Cr-containing alloys to form a pin-hole free Cr-nitride surface. Nitrided Ni-50Cr plates will be provided to collaborators for fuel cell testing that is more aggressive than the initial 0.7 V/1000 h. ORNL intends to form protective nitrides on cheaper alloys, such as commercial Ni-Cr base alloys and Fe-based stainless steels. They will scale up efforts and broaden industrial collaborations.

Overall Project Score: 3.14



Question 1: Relevance to overall DOE objectives

This project earned a score of **3.43** for its relevance to DOE objectives.

- Develop a low-cost bipolar plate critical to total FC cost. Metal offers durability in terms of shock/vibration. Identified lower cost alloy options.
- Helps to address cost reduction and durability goals of the program.
- Addresses cost and durability of bipolar plate technology.
- Very little progress shown in the past year.
- Project could improve reliability and durability of this metallic plates made from cost effective materials.

Question 2: Approach to performing the research and development

This project was rated **3.14** on its approach.

- Need to expand matrix of alloys investigated. Do more screening of a low (commercial and non-commercial) using lab methods. More basic work to develop "optimized alloy composition."
- Approach uses low-cost metal alloy plates and a surface nitriding process that should intrinsically cover the entire exposed surface. Industrially established procedure and inexpensive.
- Program must use thin sheet metal (0.003 or 0.004") for nitriding. Thin sheets will warp and look like a potato chip.
- Not clear it was wise spending time to "scale-up" the cost-impossible Ni-50 Cr material, though that may have been necessary to draw the interest of potential collaborators. Need to keep pushing hard on nitriding cheap stainless steels, even through any frustrations. Work towards uniform corrosion testing for the different materials - e.g., get polarization curves for modified passive layer -- not just acid analysis for metals.

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

This project was rated **3.29** based on accomplishments.

- Very good progress in terms of starting to look at new alloys. Promising results for success. Identified needs, but may not have resources to pursue.
- Initial results are promising.
- Excellent progress in overcoming changes of scale-up of nitride manufacturing process. Good progress in understanding influence of nitriding conditions on layer formations and optimization to reduce gaps. Promising results from ORNL/NREL collaboration on N-modified surfaces.
- In two years they have not tested plates in real fuel cell tests.
- Better attention to DOE targets than most others.
- Outstanding, especially in relation to the small budget.
- No new data (at least since Aug 03) shown for nitrided stainless steel - have the initial encouraging results not been repeated?

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

This project was rated **3.00** for technology transfer and collaboration.

- Participation of industry and other labs excellent. Working with FC manufacturing alloy sources.
- Seems to have reasonable mix of collaborations with industry, potential end users, and research activities.
- Findings by NREL on N_2 modification will be evaluated for transition. Samples will be sent to GM, LANL, DANA Corp, and FCE for fuel cell testing. Working with Gen fuel cell for plate stamping.
- Continue to address real-world test conditions. Company collaborations good. Not really responsive to real world testing -- comment from last year. Need to know test conditions, not just who doing it.
- Seem to be working well with a good range of people. Publishing in a timely manner.

Question 5: Approach to and relevance of proposed future research

This project was rated **2.86** for proposed future work.

- Expand matrix of alloys beyond those proposed. Consider other nitriding methods.
- Look forward to results with lower cost substrates.
- Plan will lead to validation of plates in fuel cell environment and for durability. Advances manufacturability with collaboration. Further optimization of nitriding procedures (theirs and NREL's).
- Should be continued.
- Longer-range tests (2005 analyses of plates from GM and LANL stacks) should be done on cheaper materials, not Ni-50Cr.

Strengths and weaknesses

Strengths

- Potentially good approach to low cost plates. Excellent work with array of partners. Start to expand alloy matrix.
- Mildly encouraging results on economically viable materials.

Weaknesses

- Need more basic work to understand process and then develop optimized alloy and nitriding procedures. Perhaps jumping to scale up too rapidly…although need samples for testing…catch 22.
- This is a high-cost and the process in not simple. Scale-up is a problem since parts will warp if not held down in place.
- Program still isn't adequately weaned from Ni-50Cr model material.

Specific recommendations and additions or deletions to the work scope

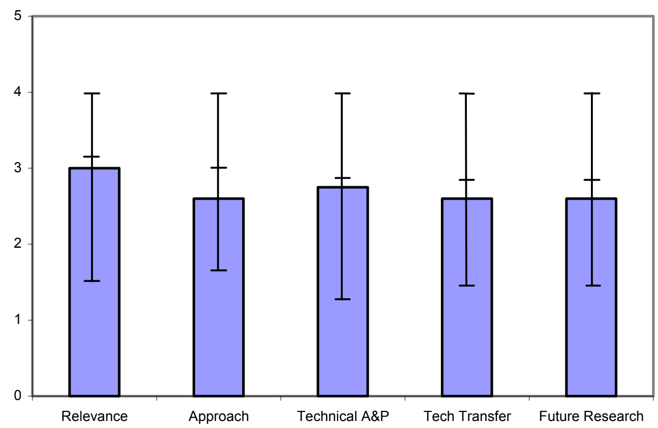
- Expand effort to more understanding and broader alloy matrix. Develop lab methods to screen samples more rapidly.

Project # FC-21: Platinum Recycling Technology Development
Grot, Stephen; Ion Power, Inc.

Brief Summary of Project

This Ion Power Inc. project will assist the DOE in demonstrating a cost effective and environmentally friendly recovery and re-use technology for PGM-containing materials used in fuel cell systems. The initial objectives include development of lab scale processes for the solubilizing catalyst coated membranes, development of lab scale processes for catalyst and ionomer materials, development of test methods to determine vitality of the recovered materials, and partnering with the key stakeholders in this technology area.

Overall Project Score: 2.71



Question 1: Relevance to overall DOE objectives

This project earned a score of **3.00** for its relevance to DOE objectives.

- Although Pt recycling is not one of the specific FreedomCAR goals, it will be an enabler if the vision of high volume fuel cell transportation is achieved.
- There is a clear need to develop the technology to recover platinum group metals from PEM MEAs. The need to recycle Nafion or similar ionomer is much less obvious.
- I do not see a link between recycling and stack durability.
- Necessary activity to understand entire lifecycle of fuel cell hydrogen technology.
- Platinum recycling is critical for life-cycle cost improvements for PEM.

Question 2: Approach to performing the research and development

This project was rated **2.60** on its approach.

- Novel approach.
- Relatively little specific information was provided on how the PGMs would be recovered, so it is difficult to judge the likely efficacy of the approach. Developing a recycle method that doesn't involve pyrolysis certainly a plus. Recycle of Nafion and building MEAs from completely recycled products is questionable. Contaminants are likely to collect in the membrane during FC operation, leading to an inferior recycled product.
- Approach lacks details - there was no mention of how they plan to recover materials.
- Methodology includes the collection of data and information that is valuable beyond recycle, and can provide valuable information about polymer degradation.
- Approach to "remanufacturing" vs. "recycling" seems to be a good way to keep costs down.

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

This project was rated **2.75** based on accomplishments.
- Too early to evaluate accurately.
- The project is fairly new, so results are not extensive.
- Process appears more expensive than materials recovered.
- Aging process needs verification.
- Anxious to see FC test results (polarization curves) of remanufactured and recycled catalysts and membranes.

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

This project was rated **2.60** for technology transfer and collaboration.

- Limited number of collaborations
- The authors are collaborating with DuPont to obtain new and aged materials for recycle studies, and with a faculty member from Delaware State Univ. External collaborations are not extensive, but probably not unusual for an industry-led project.
- Team needs fuel cell expert to guide testing, aging and analysis.
- Adequate for this task.
- Good industry collaboration w/DuPont as a partner.

Question 5: Approach to and relevance of proposed future research

This project was rated **2.60** for proposed future work.

- Continued work to understand the issues surrounding PGM recovery from MEAs is considered "good." A key question is whether recovery of ionomer material makes sense, from both cost and performance standpoint. No information was provided on the expected cost of ionomer recovery relative to that of new material produced in large volume.
- Needs to be more well defined.
- Planning on demo of recycled material in fuel cell may be too ambitious for group size and funding.
- The remanufacture and test of these materials is critical to detecting success.

Strengths and weaknesses

Strengths
- Seem to have good understanding of economic and environmental issues relevant to PGM recovery.
- Good plan. Good expertise.
- Excellent relevance to DOE goals. This project is on the critical path and needs to be successful.

Weaknesses
- Processing costs associated with ionomer recovery relative to new material cost not articulated. Because this is a relatively new project, progress is somewhat difficult to judge. Relatively little specific information on flow sheets etc. was provided, due to the proprietary nature of the work.
- Process economics look out of line with respect to materials recovered. Understanding of PEMFC weak. You cannot expect to recover Pt and reuse without reprocessing. Aging under load will change size of catalyst.

Specific recommendations and additions or deletions to the work scope

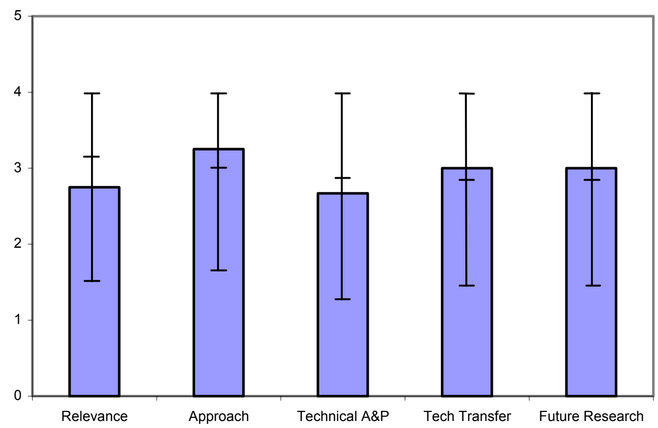
- Recycle of ionomer needs better justification than provided so far -- cost vs. benefits.
- May need to rescope due to dollar limit. May want to incorporate other MEA manufacturers at some point to illustrate range of applicability of process.
- (Milestone chart was too small to read, so comment below may be moot point.) Should add a go/no-go decision based on remanufactured materials achieving X% of original manufactured product, for example, ~ 80%.

Project # FC-22: Platinum Group Metal Technology Development
Shore, Larry; Engelhard Corp.

Brief Summary of Project

This Engelhard Corp. project will examine methods to recycle all precious metal-containing catalysts in a fuel cell "system." A primary objective is to develop a commercially-acceptable, environmentally-friendly process for recovering and recycling Pt and Ru from membrane electrode assemblies (MEAs) – by developing a process that does not emit pollutants (especially HF) and evaluating Ru recovery from MEAs. They will also develop a process for PM recovery from metal monoliths, and maximize precious metal (PM) yield from ceramic catalysts.

Overall Project Score: 2.93



Question 1: Relevance to overall DOE objectives

This project earned a score of **2.75** for its relevance to DOE objectives.

- Reclaiming precious metals is important, but this can be accomplished simply by burning MEAs; recycling involves more effort.
- Although Pt recycling is not one of the specific FreedomCAR goals, it will be an enabler if the vision of high volume fuel cell transportation is achieved.
- Future relevance to President's plan shown through TIAX study. However, how effective and environmentally friendly recycling methods are remains to be seen.
- Recycling is very important to the fuel cell mass production.

Question 2: Approach to performing the research and development

This project was rated **3.25** on its approach.

- Perhaps too many potential ideas. Better scouting is needed before commencement of work.
- Although Engelhard has extensive experience with recycling Pt from automotive catalysts, the approach seems rather complex. Also question the need for the deliverable of a pilot plant – may be premature to plan to build a plant given the current state of technology and timing for fuel cell programs and a H_2 transportation system.
- Working on multiple approaches, and then a down-select is an appropriate approach for creating new technologies. Raises chances for success with multiple concurrent approaches.
- Creative approach. Should consider environmental effects in addition to economic constraints.

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

This project was rated **2.67** based on accomplishments.

- Didn't see too much evidence of progress to date. Is Virginia Tech microwave destruction any different from burning?
- Too early to evaluate.
- Tough to say, very young project. Success has yet to be shown in detail. However, VT has achieved interesting preliminary results w/microwave approach.
- Coming along at a good rate.

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

This project was rated **3.00** for technology transfer and collaboration.

- Nice selection of development partners.
- No tech transfer/Engelhard looking for proprietary information. Multiple instances of collaboration with industry and universities, collaboration vital to their approach.
- Need to collaborate with fuel cell manufacturers to make sure recycling process can be implemented into front end engineering.

Question 5: Approach to and relevance of proposed future research

This project was rated **3.00** for proposed future work.

- What is contingency plan if no suitable reclamation technologies are found?
- Future research appears sound with appropriate approach. They should look to recycling Nafion as well as PM.
- Sounds reasonable so far.

Strengths and weaknesses

Strengths
- Recycling precious metals is very important, so success in this area is critical to enable fuel cell commercialization.
- Multiple approaches studied raises the opportunities for success. Already demonstrated platinum recycling >90% at low cost, however environmental concerns push for new approach.
- Innovative approach.

Weaknesses
- "Shotgun approach."
- What about impurities accumulating in the fuel cell stack?

Specific recommendations and additions or deletions to the work scope

- Recycling strategies need to be better evaluated before starting work; this can save time and give program better chance of success.
- Recommend adding Nafion recovery to scope.
- Approach is creative, keep it up but keep in mind environmental effects also.

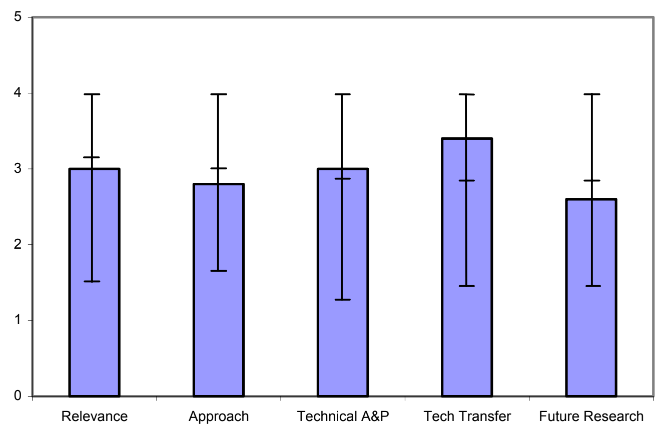
Project # FC-23: Advanced High Efficiency, Quick Start Fuel Processors for Transportation Application

Chintawar, Prashant; Nuvera Fuel Cells

Brief Summary of Project

Nuvera Fuel Cells' goal is to develop an automotive fuel processor for PEM fuel cells that is small and powerful enough for vehicle integration. Nuvera developed a new compact fuel processor technology called Substrate-based Transportation Autothermal Reformer (STAR). Its characteristics include substrate-based catalysts researched to reduce volume; developed new technology with leading catalyst companies; FP designed with substrate catalysts / custom heat exchangers; automotive volume achieved (75 liters), under-vehicle; "flat" aspect ratio (height < 9 in); automotive power achieved; and 200 kWth gasoline.

Overall Project Score: 2.96



Question 1: Relevance to overall DOE objectives

This project earned a score of **3.00** for its relevance to DOE objectives.

- Funding level omitted.
- Highly focused on application and DOE goals.
- Fuel for fuel cells is the critical issue. This hydrogen generator gives unprecedented ability to move between fuel and hydrogen.
- Efficiency of gasoline fuel processing and fuel cell is too low for commercial applications.

Question 2: Approach to performing the research and development

This project was rated **2.80** on its approach.

- Would like to see durability become a top priority.
- Startup time not met. Weight and energy requirements put additional burden on the fuel cell system.
- This presentation represents the culmination of years of detailed, quality engineering.
- Addressing key issues, such as durability.

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

This project was rated **3.00** based on accomplishments.

- Looks like durability limited to ~1000 hrs (ATR, WGS + PrOx) and needs are 5,000 hours. If durability of one component is improved, durability is still limited by others and could be a maintenance issue.
- Outstanding progress on volume.

- Outstanding progress on cost w/cost estimate at $15-20/kW.
- Collaboration good with government, academic and OEM, but FreedomCAR OEMs not interested.
- Information shared was plentiful. Impact of high sulfur fuel to design and performance was not discussed.
- The packaging is an important design advance.
- Start-up approach is reasonable.

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

This project was rated **3.40** for technology transfer and collaboration.

- U.S. automotive company partner would strengthen effort. Good partner list, could improve technical publications.
- Good interactions at industrial/National Laboratory levels.

Question 5: Approach to and relevance of proposed future research

This project was rated **2.60** for proposed future work.

- Durability is major issue. Need a plan for catalyst maintenance.
- Not clear what is proposed plan for future research and technical path (durability, start-up time, start-up energy) is not clear.
- This project moves into commercialization, the desired result to meet National goals.

Strengths and weaknesses

Strengths
- Looks like best integrated fuel processor system to date. Cost projections look promising.
- Size reduced to useful level.
- Ability to build on their experience base. Ability to work well together as a team.

Weaknesses
- Issues remain for commercialization, i.e., durability, start-up.
- PROX start-up still slow. CO concentration with PROX at optimal performance is still high using low sulfur fuel.

Specific recommendations and additions or deletions to the work scope

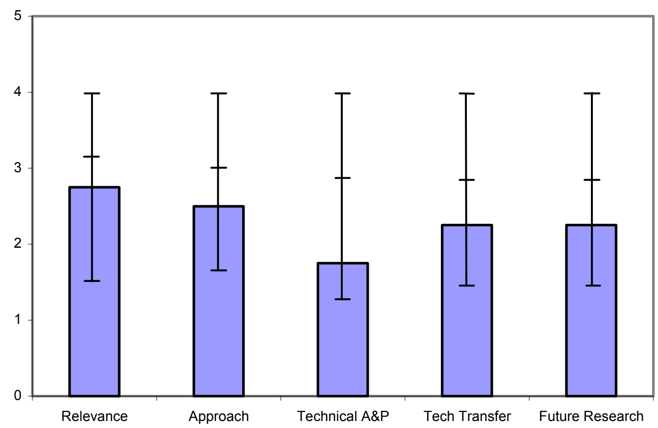
- Improve durability, without increasing catalyst volume and mass.
- Lack of time on test.
- LANL can provide technical approaches for rapid PROX start-up. This technology is within the DOE community. Don't count on higher CO tolerance. Exciting to have DOE-developed technology to enter EC market.
- Complete work in 2004.

Project # FC-24: Fuel Processors for PEM Fuel Cells
Thompson, Levi; University of Michigan

Brief Summary of Project

The University of Michigan project is to develop high-performance, low-cost materials including high capacity sulfur adsorbents for liquid fuels and high activity and durable Autothermal Reforming (ATR), Water Gas Shift (WGS) and Preferential Oxidation (PrOx) catalysts. Objectives are to design and demonstrate microreactors employing high performance catalysts, design and demonstrate microvaporizer/combustor, design and demonstrate thermally integrated microsystem-based fuel processors, and evaluate system cost.

Overall Project Score: 2.30



Question 1: Relevance to overall DOE objectives

This project earned a score of **2.75** for its relevance to DOE objectives.

- Project objective of low cost materials not demonstrated.
- Good goals. Need to get to the state of the art, and succeed there.
- This type of work is very important in order to understand how to efficiently produce hydrogen.

Question 2: Approach to performing the research and development

This project was rated **2.50** on its approach.

- Investigate the unit operations separately rather than bread boarding a small system (100 W). Advantage of micro-reactors (micro channel) is heat transfer, but system uses catalyst coated foams, negating advantage. Unclear how this scales -- size, volume, cost. Start-up time and energy are not addressed.
- Sound approach, but will need to address and demonstrate viable durability and weight, i.e. gravimetric power density. Viability of in-vehicle sulfur absorber needs to be confirmed by OEMs.
- Catalyst and sulfur removal seem commercial. Thiophenome is not removed with adsorbents.
- Poor quality testing with use of local gas.
- This project involves too many different aspects done by several different people/groups, making it difficult to focus on achieving the strongest results.

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

This project was rated **1.75** based on accomplishments.

- Sulfur outlet concentration too high at 300 ppb needs to be ~ 20 ppb.
- Little evidence that system integration is being achieved. No evidence of coking in ATR needs to be verified under repeated start-up/shut-down cycles.

- Data shown not encouraging (low conversion, etc.).
- The sulfur absorber prototype is not impressive when compared to system size and other work which has been done.
- Few details are provided on the microchannel work by which to gauge progress.

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

This project was rated **2.25** for technology transfer and collaboration.

- Partner list could be improved by interacting with a system integrator.
- Collaborations appear not to have yet been too beneficial.
- The overall project technology and goals are aligned, but the degree of novelty and size of demonstration limit the value.

Question 5: Approach to and relevance of proposed future research

This project was rated **2.25** for proposed future work.

- Future plans slide was for 2003. Start-up evaluation in a bread board system not relevant. 100W system so far from automotive cost estimates will be questionable. Suggest putting effort into the materials development.
- Need to progress to integrated system, measure start-up time, and project cost, size and weight.
- Completion of planned 1 kW bread board unit and complete evaluation would be acceptable.

Strengths and weaknesses

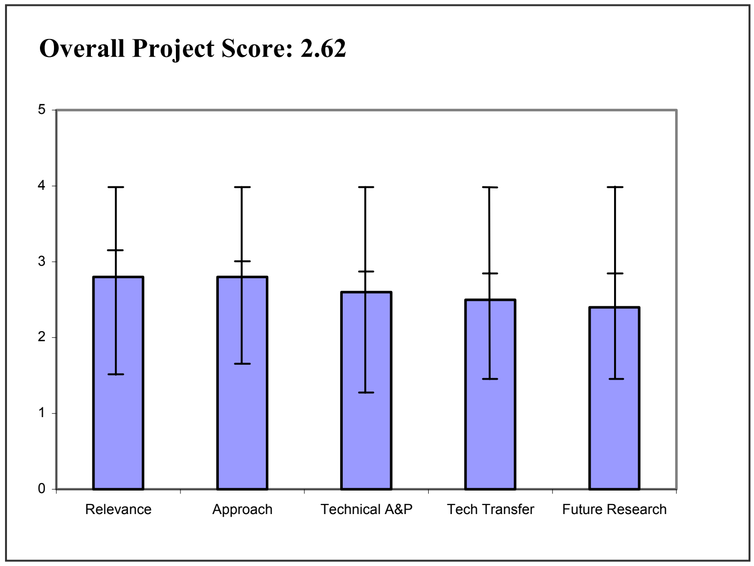
Strengths
- Key issues of fuel processing are addressed.

Weaknesses
- Do not see this as an integrated system. Behind other fuel processor developers.
- Computer modeling might be helpful.
- Too many varied activities are underway and the focus for specific advances that could add to the technical field are not apparent.

Specific recommendations and additions or deletions to the work scope

- Concentrate on new materials and material development.
- If durability is not going to be directly assessed, then ensure any projections are based on credible data, i.e., performance loss rate and/or material degradation measurements/mechanisms.
- There is no need to make larger hardware -- the 1kW would be just like the 100W, but bigger. Makes sense to redirect to address specific questions like durability, materials, etc. Needs better diagnostics and verification of data to models.
- Eliminate sulfur absorber work.
- Demonstrate unique technical contributions this finding has provided.

Project # FC-25: Plate Based Fuel Processing System
Yee, David; Catalytica Energy Systems, Inc.



Brief Summary of Project

Catalytica Energy Systems, Inc. is conducting this project to develop new catalytic reactor designs and reactor technology for processing gasoline to PEM quality H_2; developing improved catalyst materials compatible with these reactor systems; designing and fabricating prototype units for each reactor at the 2 to 10kW(e) scale; demonstrating steady state and transient performance; and evaluating rapid start up performance.

Question 1: Relevance to overall DOE objectives

This project earned a score of **2.80** for its relevance to DOE objectives.

- Question about automotive dedication to using on-board reforming. This system might be more suited to stationary hydrogen generation as start-up issues seem prohibitive.
- If go/no-go decision for on board reforming is no-go, then this work is slightly less relevant.
- This project is well-focused on meeting the performance criteria established by the Hydrogen Program for on-board reformation. Whether DOE will continue to support research on on-board reformation technologies is in question, of course.
- Not directly applicable to primary route to transportation fuel cells--direct hydrogen. But, as a steam reforming process that could be carried out above 5 bar pressure, could be coupled to a hydrogen purification unit for hydrogen production at fueling station.

Question 2: Approach to performing the research and development

This project was rated **2.80** on its approach.

- This approach does not appear it will make start-up time and energy. Don't see how 80 sec combustor heat-up of SR can also heat up WGS at same time.
- Use of available heat exchanger plates may have reduced costs, but probably reduced efficiency and added mass to reformer. If testing for fast-start, should design for fast start and limit any excess thermal mass and should test an integrated system.
- This project is developing a combination of steam reformation, water gas shift, preferential oxidation, and sulfur trapping to achieve efficient reformation of gasoline. The steam reformer prototype design appears to be one of convenience (use existing heat exchanger plate section) rather than function. Experimental details are a bit scant. For example, form of reformation and combustion catalyst not obvious.
- The steam reformer prototype design appears to be one of convenience (use existing heat exchanger plate section) rather than function.

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

This project was rated **2.60** based on accomplishments.

- Precious metals cost is high. Relatively far away from most targets-efficiency, power density, specific power. Low on presented data, is there durability data other than on PROX? WGS reduction good.
- Have demonstrated durability to 800 hrs for PROX. Still a ways to go, but a good accomplishment. Close to 2005 targets. However, WGS due to larger size, should take longer to bring up to temp than steam reformer-temperature control; also more important in WGS and PROX.
- Steam reformer results look quite impressive. Very substantial progress has been made in lowering start-up time to about 80 seconds. Good progress made in reducing the size of the WGS unit, to under 20 L. Significant progress from last year. No PROX reactor developed yet; results limited to catalyst performance data.
- Good progress made in reducing the size of the WGS unit, to under 20 L. Significant progress from last year.

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

This project was rated **2.50** for technology transfer and collaboration.

- No publications/presentations. Lack volume manufacturing system integrator as partner.
- Reasonable number of collaborations with National Laboratories, universities, and private industry.
- In collaborations, Catalytica seems to always be on the receiving end.

Question 5: Approach to and relevance of proposed future research

This project was rated **2.40** for proposed future work.

- Vague on start-up approaches to be pursued.
- Should include test of fully integrated system at end of phase II.
- Future research aimed appropriately at technical targets established by the Hydrogen Program. Startup, transient response analyses needed, including energy costs of startup. Energy costs of startup should be broken down by component (SR, WGS, PROX, HXs, others). Future testing should include repeated start/stop cycles.
- Startup, transient response analyses needed, including energy costs of startup. Energy costs of startup should be broken down by component (SR, WGS, PROX, HXs, others).

Strengths and weaknesses

Strengths

- Start-up of SR in 80 seconds is a significant accomplishment.
- Project has made good progress towards achieving interim startup times to full reformate flow.
- Substantial progress has been made in lowering the required size of the WGS reactor.
- Early work assessing thermal mechanical stress effects. Presumably, generation of kinetic equations for catalysts-this could be fully credited only if the parameters for the equations (at least for same of the catalysts) are shared.

Weaknesses

- PROX still has not made 10 ppm target --most all other developers can do this, at least at one set of operating points.
- Design as fabricated less than ideal flow manifolding for reactants and products is probably not uniform over the plate. Design should be optimized to utilize combustion heat most effectively. H_2S removal is not as easy as authors imply--still a problem if significant sulfur is in the fuel.
- Startup energy costs not yet addressed. Transient response characteristics not yet addressed. Estimations of power density seems to be overly optimistic, given the size of the WGS. Volumes of other subsystems not reported. Fuel processor not tested as an integrated system yet. Components (e.g. PROX) not yet developed.
- Transient response characteristics not yet addressed.

Specific recommendations and additions or deletions to the work scope

- Test design made for this application. Test complete fuel processor system (SR, WGS, PROX).
- Consider repeated startup/shutdown cycles as part of durability testing. Integrated fuel processor testing needed.
- Address energy costs associated with startup; assess transient response characteristics. Integrated fuel processor testing needed.

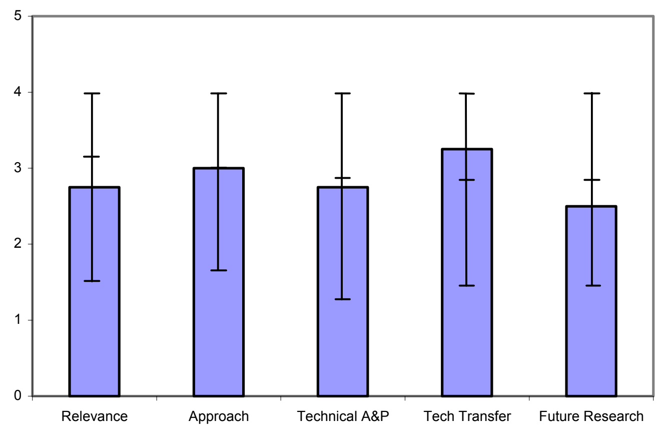
Project # FC-26: Quick Starting Fuel Processors - A Feasibility Study

Ahmed, Shabbir; Argonne National Laboratory

Brief Summary of Project

This Argonne National Laboratory (ANL) project will study the feasibility of fast-starting a fuel processor (FASTER) to meet DOE targets for on-board fuel processing (FP). Objectives are to estimate energy consumed (by FP) during start-up; design, fabricate, and demonstrate the fast-starting capability of a laboratory-scale fuel processor; conduct a collaborative effort with DOE labs and private industry (LANL, ORNL, PNNL, PCI, AM, QG, academia); and model fuel cell system designs to estimate the lifetime (start-up and drive cycle) fuel usage.

Overall Project Score: 2.85



Question 1: Relevance to overall DOE objectives

This project earned a score of **2.75** for its relevance to DOE objectives.

- The project has potential to meet DOE targets for fuel processor, but many hurdles remain.
- Approach is systematic and pedestrian--very straight-forward with standard approach (where is the uniqueness? The innovation?).
- Provides public domain analysis, and should have provided experimental data of relevance to the go/no-go onboard fuel processing decision.

Question 2: Approach to performing the research and development

This project was rated **3.00** on its approach.

- While this project is closer to DOE targets than other reformers, it does not seem practical for meeting the President's Hydrogen Initiative.
- If continued at present pace, the delivered system will not reach start-up time targets.
- Provides additional efficiency challenges over a fuel cell system with on-board storage systems.
- Using vendor parts, ANL has many opportunities to increase system efficiency and decrease integrated component weight. Have outlined current start-up energy sinks and are ready to optimize. Found new heating strategy for catalyst that should significantly speed heating.
- Standard--no clear innovation; but the work/model is solid. Addressed previous reviewers' comments but number of components not really reduced (?).
- Good planning got many National Labs' and suppliers' technology to come together. A bit more analysis prior to commitment to design for experimental work would have helped (20-20 hindsight).

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

This project was rated **2.75** based on accomplishments.

- Start-up time is still not close to requirements.
- Progressive designs have lowered energy consumption, while suffering efficiency.
- Major challenges have been laid out (catalyst heating, start up energy, component weight) and strategies to over come them are in place.
- No PROx reactor developed yet; results limited to catalyst performance data. Power densities/specific power appears to be too high to be consistent with volume of WGS (19L). The SR, PROx, HXs, etc. collectively could not be larger than 11 liters. Did not provide estimates of startup energy, transient response
- Though start-up time has been reduced, it is still not close to meeting requirements. The systems provide additional weight and energy consumption penalties.
- Did not provide estimates of startup energy, transient response.
- Need more information on Δ pressures, flow issues, why the design as configured. Would further design innovations affect results? Multiple air injections -- reasonable for scale-up to practice?
- Very good analysis. Experiments have come along slowly, in part because extreme dedication to efficiency led to a complex, cumbersome design. Heating of downstream components by local air injection and partial oxidation still untested. Good, accurate, honest description of what has actually been accomplished experimentally.

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

This project was rated **3.25** for technology transfer and collaboration.

- There appears to be collaboration between academia and the government but not with OEMs.
- Great collaboration w/National Labs and industry. Project combines components from multiple independent sources into a novel design.
- Very solid group of collaborations in terms of components. But system integration-could it be better optimized (to reduce discrete components?).
- Excellent job of coordinating components and concepts from many sources, albeit a bit of a camel (i.e., a horse designed by a committee).

Question 5: Approach to and relevance of proposed future research

This project was rated **2.50** for proposed future work.

- Future testing should include repeated start/stop cycles.
- Without OEM interest in this technology, the program should reconsider whether or not future research in this area is valuable.
- With future work proposed, ANL seems on target to meet DOE goals with next generations of FPs. Current FP will be used to validate models for future design work.
- Need more specifics: On nozzle (current versus improvement); what else beyond simple reduction in thermal mass; why the current choice of stages?
- Too much hope placed on electrically-heated catalyst support. Alternative means of heating downstream components should be considered.

Strengths and weaknesses

Strengths

- Novel FP design with a high chance for project success. By using components from multiple National Labs and industry, ANL can focus on optimizing FP design while not getting bogged down with component research. Integration is vital.

- Work is solid (but pedestrian); data set very useful. Excellent set of collaborators; strong model to be built upon. Good understanding of feed variations which could affect subsequent operations.
- Thoughtful design and analysis, good application of data on catalysts for FP1. Design would likely give unusually good efficiency, if it can be repeatedly started without damage. A valiant effort.

Weaknesses

- Estimations of power density seem to be overly optimistic, given the size of the WGS. Volumes of other subsystems not reported.
- More creativity in control points (i.e., broader model) with broader range of catalysts.
- Project had very little time and therefore only one shot to get full system database on quick starts prior to go/no-go decision; didn't make it. Had to learn the hard way some things that might have been realized from industrial contractor's efforts-minimize total number of unit operations and don't try coaxial annular reactors until the system has been proven out as a train of linear reactors.

Specific recommendations and additions or deletions to the work scope

- Address energy costs associated with start-up; assess transient response characteristics.
- Beautiful design, continue this work.
- Change of catalysts (or catalytic rates) could alter optional feed conditions-how do you integrate feedback controls? System architecture defines operational controls; need to develop model for feedback controls. Need more $ support to expand program (good solid start).
- If the project continues, replace ATR with a steam reformer, operate at 5-6 bar, and after the shift go to a PSA unit as a forecourt H_2 production unit.

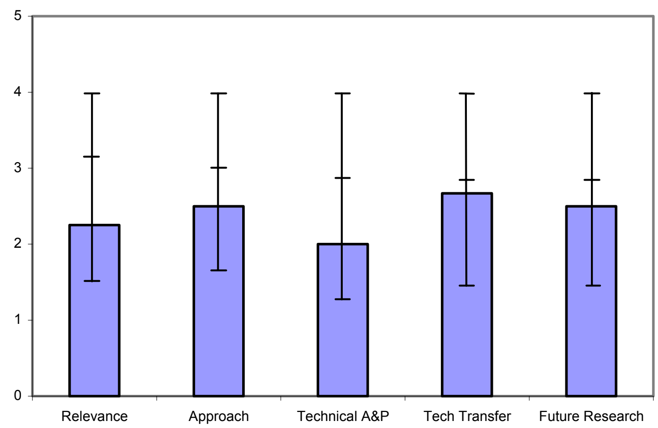
Project # FC-27: Development Status of a Rapid-Cold-Start, On-Board, Microchannel Steam Reformer

Whyatt, Greg; Pacific Northwest National Laboratory

Brief Summary of Project

Pacific Northwest National Laboratory (PNNL) will utilize microchannel steam reformers and vaporizers to demonstrate rapid cold-start of the steam reforming sub-system. Tasks are to develop a prototype microchannel-steam-reforming fuel processor at ~2 kW_e scale that will meet DOE performance targets when scaled up to 50 kW_e; develop reactors, vaporizers, recuperative heat exchangers, and condensers broadly applicable to other fuel processing options; and engage industrial partner(s) to facilitate application of technology to full-scale fuel processing systems.

Overall Project Score: 2.38



Question 1: Relevance to overall DOE objectives

This project earned a score of **2.25** for its relevance to DOE objectives.

- Overall viability of onboard steam reforming of gasoline still questionable.
- This work should be moved to stationary because it is too heavy for automotive needs.
- It is true this work could impart the vision, if successful. However, there is some need to also be contributing novel concepts to reach that goal.

Question 2: Approach to performing the research and development

This project was rated **2.50** on its approach.

- Microchannel processors promise plenty, but fully integrated systems still awaited.
- Interesting approach but needs to scientifically relate back to the DOE targets.
- Data is qualitative with key data sets missing. Gas composition of featured hardware not given. New data (or improved hardware) not available. This makes things impossible to evaluate.

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

This project was rated **2.00** based on accomplishments.

- Fast start reformate flow at 12 seconds encouraging. However, cost and durability not yet addressed effectively. Sulfur remains a problem.
- The start-up energy in the microchannel design shows no advantage compared to ANL, for example.

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

This project was rated **2.67** for technology transfer and collaboration.

- Valuable partnering has been achieved.
- Supplying hardware is ok, but engineering design, catalytic design etc. should also be done as part of the tech transfer process.

Question 5: Approach to and relevance of proposed future research

This project was rated **2.50** for proposed future work.

- Next steps well identified. Be careful about higher temperature operation vs. Inconel cost trade-off.
- Need to address the issue of density and how can it contribute to the DOE goals.

Strengths and weaknesses

Strengths
- Prospects for achieving <60 s start-up time are good.

Weaknesses
- Computer modeling could usefully complement empirical approach to systems integration.
- The careful combination of good modeling with carefully conducted experiments is sorely missing.

Specific recommendations and additions or deletions to the work scope

- Durability testing under repeated start-up/shutdown cycling would be very valuable.
- Future work needs to compare dynamic models (reactive CFD) with well-done, quality test data. PNNL can do much more to advance microchannel technology.

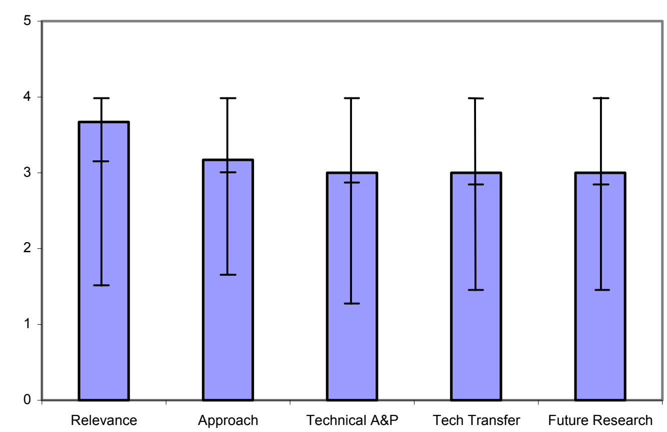
Project # FC-28: Catalysts for Autothermal Reforming

Krause, Theodore; Argonne National Laboratory

Brief Summary of Project

Argonne National Laboratory (ANL) plans to develop advanced fuel processing catalysts which will, when compared to Ni-based steam reforming catalysts, be able to process complex fuel mixtures such as gasoline; process these fuels at higher rates; be more resistant to coking and sulfur poisoning; improve our understanding of reforming reaction mechanisms, catalyst deactivation, and sulfur poisoning; and define operating parameters (e.g., air:fuel and steam:fuel ratios, temperature, gas hourly space velocities (GHSV), catalyst geometry) to optimize catalyst performance and lifetime.

Overall Project Score: 3.17



Question 1: Relevance to overall DOE objectives

This project earned a score of **3.67** for its relevance to DOE objectives.

- Development of new reforming catalysts critical to H_2 production.
- Sulfur tolerance promising. Fairly high Rh loadings/difficult to adhere cost targets. Why perovskites?
- An advanced understanding and development of catalyst for more compact efficient reformers to produce H_2 is necessary.

Question 2: Approach to performing the research and development

This project was rated **3.17** on its approach.

- Approach is excellent. Key is to eliminate or reduce PM content without sacrificing activity. On good path to doing this using mechanistic studies and catalyst characterization.
- Selection of CeO_x supports follows previous work/now moving back to aluminas (modified?). Question need for some characterization (e.g., use of neutron spectroscopy vs. XRD). Well integrated with other research on Ce oxide supported SR catalysts.
- Although the project is building on past experience in catalysts, it does not appear that this is actually being practiced. Why perovskites? Why do 600, 900, 1200 cpi honeycomb monoliths need to be investigated again and how can one set of conditions be used for aging process?

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

This project was rated **3.00** based on accomplishments.

- Excellent progress on developing new WGS catalysts. Pt-Re & $PtCeO_2$-Re & Pd-Base metal.

- Started in '95; seems have achieved good progress but over long time. Should compare to other catalysts that are being developed (not just those available from commercial partner).
- Because sulfur content of fuels is dropping and sulfur can be removed from liquids, why continue to emphasize sulfur tolerant catalysts?

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

This project was rated **3.00** for technology transfer and collaboration.

- Not real clear on how much is really being done. Results of Toyota, Nissan and Süd-Chemie evaluations? Papers/patents as a result of work?
- Patent in 2000. Tech transfer to Süd-Chemie. Mentioned problem with patented catalyst.
- Fundamental catalyst research and a demonstration project w/GE and U of MN don't correlate well. More interaction with industry would be good.

Question 5: Approach to and relevance of proposed future research

This project was rated **3.00** for proposed future work.

- Keep up high level of catalyst characterization to understand deactivation mechanisms.
- Will use characterization studies to improve durability/need to improve activity. Seems heavy on fundamental vs. applied research/consider partnering.
- Understanding fundamental catalyst mechanisms, and hearing this information openly will be the greatest progress in achieving commercially viable catalysts.

Strengths and weaknesses

Strengths

- Excellent approach. Combination of mechanistic studies and modeling with catalyst characterization proving excellent insight on how to proceed with WGS development. Monolith vs. foam comparisons used w/all catalysts.
- Demonstrated a good formulation. Not clear that it meets DOE target.
- Test capabilities.

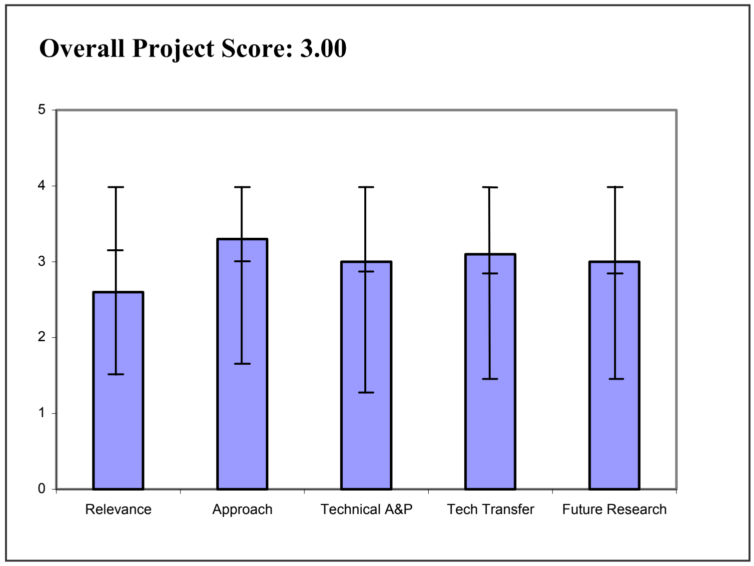
Weaknesses

- Durability and ability to reduce methanization and keep CO levels <1% still critical drivers. More of these aspects in next review.
- Heavy on characterization; should more closely tie this part of effort to improvements in performance.
- Test protocol does not seem to adequately address advancing the catalyst mechanism. Past experience should have predetermined a higher temperature at exit of 1st monolith, etc.

Specific recommendations and additions or deletions to the work scope

- Keep up high level of catalyst characterization to understand deactivation mechanisms.
- Seems a bit heavy on characterization and some question about use of methods.
- Examine catalyst properties required for different reaction zones in reactor. Work with other catalyst suppliers/manufacturers to broaden experience.

Project # FC-29: Water Gas Shift Catalysis
Krause, Theodore; Argonne National Laboratory



Brief Summary of Project

This Argonne National Laboratory (ANL) project will develop water-gas shift (WGS) catalysts which, when compared to Cu-Zn and Fe-Cr WGS catalysts, will be more active (higher turnover rates); less prone to deactivation due to temperature excursions; more structurally stable (able to withstand frequent cycles of vaporizing and condensing water); and more resistant to sulfur poisoning. This project is intended to improve the understanding of reaction mechanisms, catalyst deactivation, and sulfur poisoning, as well as define operating parameters (e.g. steam:carbon ratios, temperature, gas hourly space velocities (GHSV), catalyst geometry) to optimize catalyst performance and lifetime.

Question 1: Relevance to overall DOE objectives

This project earned a score of **2.60** for its relevance to DOE objectives.

- Enhancing WGS catalytical activity (decreasing the volume of catalyst). Reducing cost of catalyst and having long durability of catalyst (>5000 hours) is critical for commercialization of on-board fuel processors.
- Water-gas-shift will be required for decades to make H_2.
- ANL is doing vital research into chemistry and characteristics of WGS catalysts. Testing lower cost materials that can approach DOE targets for performance/durability.
- Catalyst cost & durability still remain as major drawbacks to onboard fuel processing. This project verifies that!

Question 2: Approach to performing the research and development

This project was rated **3.30** on its approach.

- Good mix of catalyst formulation optimization and catalyst characterization by TPR, EXAFS & sulfur effect. Kinetic rate equations are useful for reactor designs.
- Uses advanced techniques appropriately and effectively.
- Excellent approach combining modeling and experimentation to determine best performing catalysts. Combined with ANL FP catalyst research, knowledge can be leveraged from lessons learned.
- All objectives were appropriate to task--particularly need for structural stability--key to durability.

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

This project was rated **3.00** based on accomplishments.

- Gradual progress has been made chronologically from 10/97 to present. Good effort towards improved catalyst activity by changing catalyst formulation. Very good approaches to characterize the catalysts.
- This is a long-term program--could not really evaluate what are current results vs. those done previously.
- Has met all DOE performance/durability targets. Only cost remains to be met. 30,000 h^{-1} space velocity @ 1% Cu with Pt-Re catalysts.
- Progress made in understanding challenges to developing base metal catalysts, but still a long way to go to show viability.
- Coming along at a good rate.

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

This project was rated **3.10** for technology transfer and collaboration.

- Very good interactions with academia (University of Alabama) and industrial partners including Catalytica Energy Systems, Toyota, Nissan & Süd-Chemie Inc.
- A few samples to a couple companies is sufficient.
- Testing and catalyst characterization at university. NDA with Catalytica to evaluate new catalysts. Work given out to Toyota, Nissan, Süd-Chemie.
- Limited interaction with North American industry--why?
- Good collaboration.

Question 5: Approach to and relevance of proposed future research

This project was rated **3.00** for proposed future work.

- It is appropriate to continue the effect of optimizations for both bimetallic PM-BM & BM catalysts. Once the optimization is finished the next effect should be focused on long-term durability testing. Catalyst deactivation mechanism studies are also very important. Address the "quick start" of the developed catalyst.
- Appropriate but should be tied to and funded by industrial partner to help focus efforts.
- Future work focus on lowering cost. Base metal work shows some promise but significant barriers still remain. Work in understanding deactivation methods of WGS catalysts essential to meeting targets.
- Proposed work is appropriate but cost challenge is formidable.
- Sounds reasonable so far.

Strengths and weaknesses

Strengths
- Reasonable progress toward better catalyst activity. Catalyst characterization & kinetic equations.
- Applying knowledge from one field (SOFC) to catalysis issues in another (WGS). Knowledge of appropriate ceramics & metals & their catalytic activities. Ability to easily leverage unique ANL facilities (e.g., synchrotron source) to technical issues of problems at hand.
- ANL is the appropriate location for WGS catalyst work. Can leverage other PM catalyst knowledge to streamline approach/reduce redundant tests.
- Project is well-focused on the right objectives, but could be facing a "Mission Impossible."

Weaknesses

- No durability data; cost issue.
- Tech transfer collaboration with industry. PI should team with someone to get materials out into the world.
- Demonstrating achievement of DOE durability targets--do sufficient candidate catalysts, project resources and time remain?

Specific recommendations and additions or deletions to the work scope

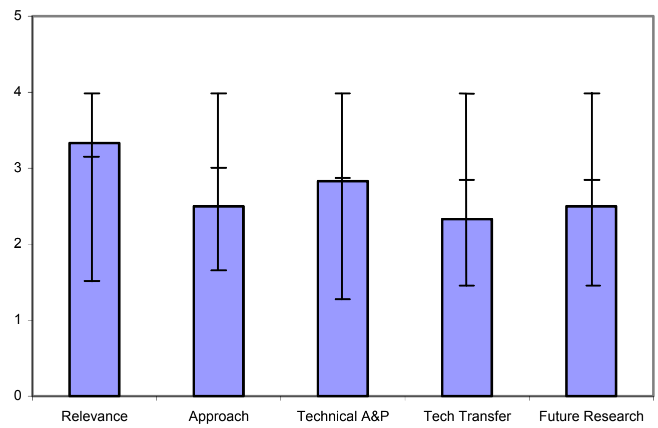
- Once the catalyst formulation is optimized, long-term durability tests should be started ASAP. At the same time, the catalyst deactivation mechanism studies should be carried out. Quick "start-up" strategies should be set up for the optimized catalyst.
- PI is a good scientist doing good work. It's time to move some of these materials out of the lab into practice, if possible to Engelhard, JM and others to transfer technology if it is really worth it. It's time for support of this work to move from DOE gov't to industry.
- Emphasize effort on base metal catalysts, for a finite duration (~ 6 months). Then Review for go/no-go decision.
- What will happen to this project after the go/no-go decision?

Project # FC-30: Selective Catalytic Oxidation of Hydrogen Sulfide
Schwartz, Viviane; Oak Ridge National Laboratory

Brief Summary of Project

The goal of this project is to develop and optimize an oxidative process to reduce sulfur levels to the parts per billion level in reformate using low-cost, carbon-based catalysts. In FY04 Oak Ridge National Laboratory (ORNL) will develop different activation protocols to tailor the carbon-based catalysts, define reactivity tests to determine operational parameters for the selective oxidation reaction, demonstrate continuous removal of sulfur to 'ppbv' levels, and carry out preliminary thermodynamic analysis to verify reaction constraints.

Overall Project Score: 2.70



Question 1: Relevance to overall DOE objectives

This project earned a score of **3.33** for its relevance to DOE objectives.

- Project is aimed at one of the principal barriers to hydrocarbon fuel reformation for fuel cells-sulfur management. This is an interesting alternative to high temperature traps. Similar approach being followed by Berry et al. (NETL), with whom authors are collaborating.
- Performance of downstream components depends on removal of sulfur. H_2S concentrations seem high (explained).
- Removing H_2S is an important goal. 200 ppb may not be good enough. Question -- does this activity contribute to this goal?

Question 2: Approach to performing the research and development

This project was rated **2.50** on its approach.

- Selective oxidation of sulfur may be an attractive alternative to high temperature trapping by metal oxides, which have high bleed rates especially in the presence of steam. Project appropriately evaluated commercial carbon materials first. Also modeled system thermodynamics. Measure of sulfur compounds in very low concentrations can be challenging. The authors should utilize GC-based analytical techniques shown to be very sensitive to sulfur, including chemiluminescence and/or pulsed flame photometric detection. The fact that sulfur compounds were not detected may relate to insensitive analytical methods.
- Good progress w/ORNL catalysts. Should be careful stating that if performance is good that high P (H_2S) it will be good at low P (H_2S) (rate low?).
- Most likely adsorption would be a better approach. No need to oxidize sulfur. Will also lead to hydrogen oxidation-- this needs to be considered. This approach is also adsorption, but after oxidation, where is the benefit?

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

This project was rated **2.83** based on accomplishments.

- New carbon materials show high promise. If validated, this could be a significant breakthrough in sulfur management. Results obtained may be too optimistic because of insensitive sulfur detection methods.
- Would have given higher rating if H_2S concentration more representative of reformer.

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

This project was rated **2.33** for technology transfer and collaboration.

- Good collaborations with NETL staff. Discussions beginning with major industrial players. Participating in important carbon conferences.
- Initial discussions but no substantial collaboration.

Question 5: Approach to and relevance of proposed future research

This project was rated **2.50** for proposed future work.

- Analytical chemistry of sulfur in low concentration needs refinement. COS is an equilibrium compound in reformate along with H_2S and CS_2, and may be important in determining the ultimate S concentration that can be achieved. Some high temperature S traps work considerably less well with COS than H_2S.
- Should do measurements at lower P (H_2S), otherwise good.

Strengths and weaknesses

Strengths

- Project is working on a critically important problem. Approach is an alternative to high temperature trapping, which has received more attention. Good collaboration with others in field. Excellent results obtained so far with new carbon materials, assuming analytical chemistry is not skewing results. Good progress made over the past year.
- Interesting new material.

Weaknesses

- Analytical chemistry techniques employed probably insufficiently sensitive to sulfur compounds at low concentrations.
- Reaction conditions not that relevant.

Specific recommendations and additions or deletions to the work scope

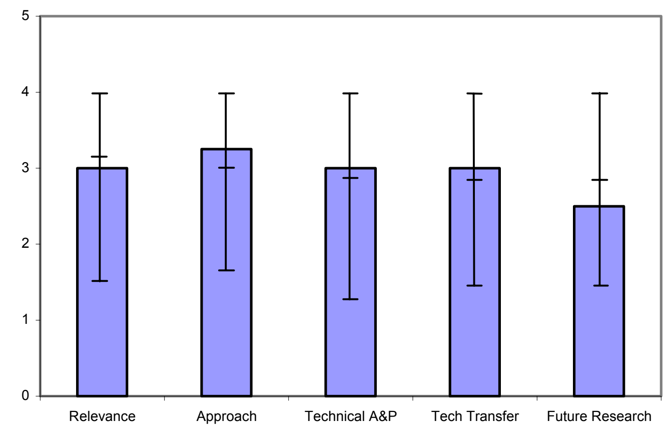
- Utilize chemiluminescence or pulsed flame photometric detection methods with gas chromatography to improve sensitivity to sulfur compounds. Comparison of selective oxidation of COS vs. H_2S could be important.
- Need to consider the implications of adding air into reformate -- excess O_2 needs to be managed- where, how, what impact?

Project # FC-31: Development of a 50kW Fuel Processor for Stationary Fuel Cell Applications Using Revolutionary Materials for Absorption-Enhanced NG Reforming
Stevens, Jim; ChevronTexaco Technology Ventures

Brief Summary of Project

In this project ChevronTexaco Technology Ventures will assist DOE in developing distributed hydrogen production technology with significant cost advantages in reduced reformer + PEMFC system operating costs through improved fuel efficiency, reduced capital costs through reduced system complexity, and reduced reformer + fuel cell system costs. The first six month objectives include samples of low temperature reforming and high temp shift catalysts, CO_2 fixing materials, integrated function materials; process simulation; efficiency analysis; capital cost estimates; and reactor tests.

Overall Project Score: 2.95



Question 1: Relevance to overall DOE objectives

This project earned a score of **3.00** for its relevance to DOE objectives.

- Distributed hydrogen production required for initial implementation of the Hydrogen Economy.
- This technology could provide a solution for stationary fuel cells.
- Project appears to be well-focused on meeting performance targets for converting natural gas to high purity hydrogen.

Question 2: Approach to performing the research and development

This project was rated **3.25** on its approach.

- Reduction in balance of plant, including PSA, noble metals probably best cost reduction strategy.
- Approach of using a carbon absorber with a steam reformer is certainly novel, and may be able to significantly lower the size of a natural gas reformation system. Significant break from traditional approaches to natural gas reformation. Experimental details not very explicit, presumably due to proprietary nature of work. Since a number of commercial reformation catalysts are available from major developers, it is not clear why this project should attempt to develop new formulations. The efficacy of this approach should be demonstrated by using a commercial catalyst for which benchmark data are available.

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

This project was rated **3.00** based on accomplishments.

- Uncertain how CH_4, to CO conversion data relates to hydrogen production efficiency. 1500 hrs or

2000 hrs durability still far away from 40,000 hrs where the current durability was measured using a used N_2 purge stream.
- On targets slide, show performance (status) to those targets.
- Some very promising results shown, with all but 1 or 2% of CO and CO_2 removed from the H_2 stream in prototype reactor.
- Cycleability of absorber materials appears quite impressive.

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

This project was rated **3.00** for technology transfer and collaboration.

- This is hard to evaluate since most data is confidential.
- Appears to be a high level of collaboration and looking toward testing and operation of hardware.
- Collaborations established with CSMP. Other collaborations are proprietary so difficult to assess. Presentations made at national scientific conference.
- Working with Cabot Superior MicroPowders; program just started. Too early to have the universities/laboratories, etc. involved.

Question 5: Approach to and relevance of proposed future research

This project was rated **2.50** for proposed future work.

- Will need to explore use of combustion gas and its effect on the material durability (CaO).
- This project looks fairly close to being beyond research and towards engineering development.
- Research plan consistent with need to meet performance targets established by DOE. Key milestone should be to show advantages of approach by using well characterized steam reformation catalyst.
- No clear plan to expand to large plant; or sequester CO_2.

Strengths and weaknesses

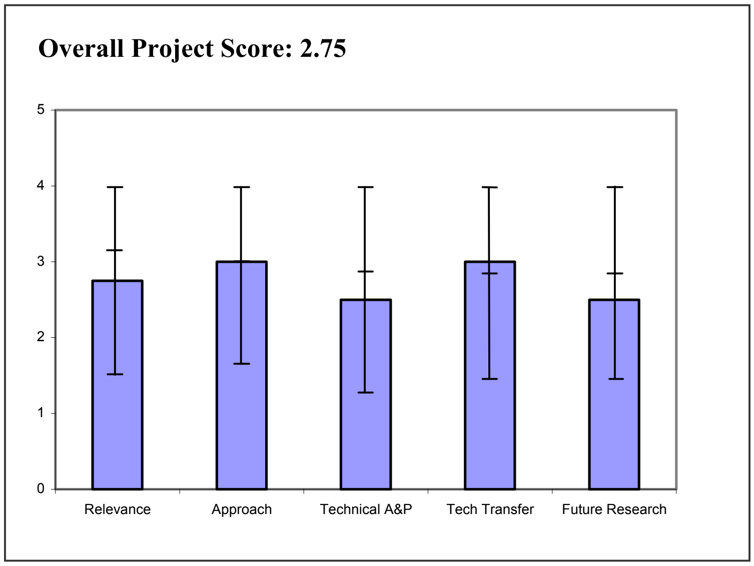
Strengths
- Novel approach to natural gas reformation. Approach could lead to significant simplification of the reformer system, and perhaps lower costs. Initial results look very promising. Absorber materials appear to survive many cycles without degradation.
- Desire to build 50 kW stationary reformer using natural gas is a good plan to produce hydrogen. Good to have major oil company involved.

Weaknesses
- Durability is a key technical challenge, testing needs to be done under "real" conditions, including purge. Sulfur removal technology should be discussed.
- Project is in very early stages, so technical progress is similarly limited. Attempt to develop new reformer catalysts is unnecessary at this stage. Efficacy of approach can be demonstrated using well-characterized commercial catalysts.
- To make significant impact, reactor needs to be bigger than 50 kW.

Specific recommendations and additions or deletions to the work scope

- Focus on performance testing with commercial reformation catalysts to demonstrate efficacy of approach before moving on to novel compositions.

Project # FC-32: Advanced Buildings PEM FC Project
LaVen, Arne; IdaTech



Brief Summary of Project

The objective of the IdaTech project is to demonstrate high electrical and overall efficiency, reduced energy consumption, and reduced emissions for hotel and follow-on applications; overcome technical and cost barriers through the engineering, design and construction of an integrated system with advanced fuel cell, fuel processor, and balance of plant subsystems; validate a 50 kW PEM fuel cell system design through field testing at three separate properties to be co-selected by Marriott International, Sempra Utilities and Puget Sound Energy; and use the information provided from this demonstration to target early market entry opportunities.

Question 1: Relevance to overall DOE objectives

This project earned a score of **2.75** for its relevance to DOE objectives.

- Demos needed to help illustrate the value of and problems associated with fuel cell applications.
- Why is this project going forward when the stocks have high depreciation?
- Trying to reduce cost barriers using 50kW CHP using low temp membrane for hotel, etc. applications is a tough problem.
- This is a good application of PEM FC in a CHP application.

Question 2: Approach to performing the research and development

This project was rated **3.00** on its approach.

- 10/1 scale up when MEA optimization is required has high degree of risk. It is extremely difficult to use 5kW size to model parasitic and heat losses for 50kW system.
- But can they accomplish sulfur handling and catalyst longevity? Use of PSA good but requires high pressure. Can Idatech keep costs in hand?
- Approach of starting w/hotel application seems ideal.

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

This project was rated **2.50** based on accomplishments.

- This is a new project, so results are not extensive yet.
- No real significant progress reported in detail!
- Hard to evaluate; they are only in design stage, early at that. The team has selected development sites.

- Clear statement of progress against DOE technical targets. Decent progress made…could be better, but it appears Idatech is being honest.

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

This project was rated **3.00** for technology transfer and collaboration.

- Should consider an A&E firm to help in beta demo. Scaling PSU seems lightweight?
- Good set of partners.
- Teamed with Hydrogenics using Gore Membrane. Portland State University is a consultant. There are many site selections.
- Good interaction w/suppliers, customers, utility and university.

Question 5: Approach to and relevance of proposed future research

This project was rated **2.50** for proposed future work.

- Very ambitious.
- Details?
- Well planned future on paper; can they accomplish it?
- Future plans could be better flushed out.

Strengths and weaknesses

Strengths
- Well thought out plan to meet technical barriers.

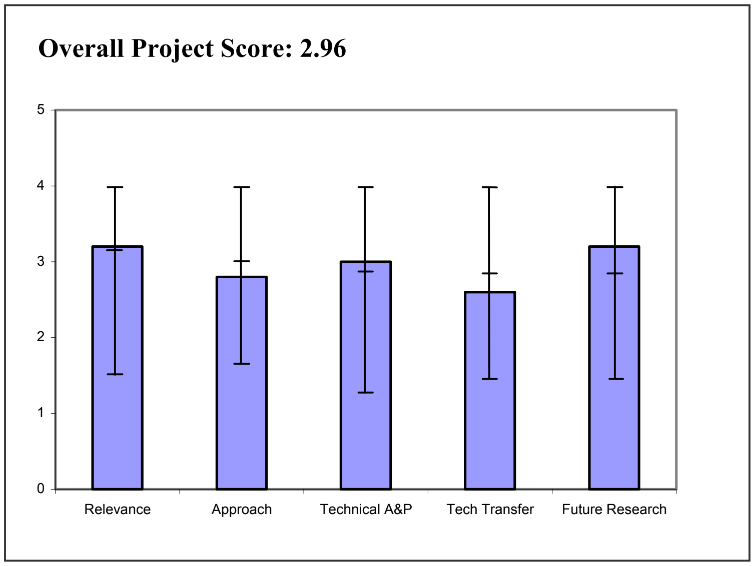
Weaknesses
- Many aspects of technology are either unproven or weak in performance and will be scaled up and operated over some type of duty cycle.
- Details missing in accomplishments and future work. Fuel cell degradation is higher than presented data-what is real case?
- Plan may be difficult to achieve. The fuel cell system needs to be bigger than 50kWe to have significant impact on hydrogen production.

Specific recommendations and additions or deletions to the work scope

- Go/no-go decisions based on demonstrated verification of key elements in plan.
- Share more performance/cost data.

Project # FC-33: 150 kW PEM Fuel Cell Power Plant Verification

Clark, Tom; United Technologies Corp. Fuel Cells



Brief Summary of Project

The UTC Fuel Cells and UTC Power Stationary Power Plant project will resolve critical cell component, cell stack, and power plant reliability issues. Testing will be conducted in 20-cell stacks, and 150 kW power plants.

Question 1: Relevance to overall DOE objectives

This project earned a score of **3.20** for its relevance to DOE objectives.

- Developing FC stationary power system to meet 2010 targets.
- Demonstrating integrated power supply.
- This has nothing to do with automotive but should be useful for stationary applications.
- If successful, clearly adds value.
- Fuel cell development and demonstration necessary.

Question 2: Approach to performing the research and development

This project was rated **2.80** on its approach.

- Working with small 20 cell CSAs to increase durability. Focusing on a novel humidification strategy that goes toward longer cell life. Sealing methods being investigated.
- Fairly straight forward. Could describe component performance. The team seems to have that capability.
- Understands the problems at hand.
- The project objectives seem to repeat UTC's long fuel cell commercialization with PC25 hardware. They need to build on this twenty-year base.
- With all the experience that UTC has in operating fuel cell power plants, why do test plans need to be defined and market analyses, etc. need to be done?

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

This project was rated **3.00** based on accomplishments.

- Not much actual data presented but 117 KNAC FC system is operational & testing. Durability of CSAs is being tested now.
- Delivered 160 cycles & 200 hours @ 139 kW CO from fuel processor. 32 hrs continuous power
- A little slow and conservative but definitely steady!
- UTC is describing a very conventional but adequate plan for getting their hardware operational.
- Tests conducted on a 20 cell short stack are important, but a verified acceleration test protocol is very valuable.

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

This project was rated **2.60** for technology transfer and collaboration.

- Collaborating with local non-profits in Connecticut. Several power authorities are subcontracted.
- There are partners and some collaboration. However, how can this technology be transferred? It looks like it is a private funding for one company's research and development.
- Subcontractors appear to be vendors; may not be technology transfer.
- Although partners have been identified for demos, collaboration assistance in materials improvement, and applicability of information to other fuel cell suppliers and material suppliers is weak.

Question 5: Approach to and relevance of proposed future research

This project was rated **3.20** for proposed future work.

- Planning on getting systems in use at three test locations. Continuing work in cell durability and 20 CSAs.
- Plan for seals seem straight-forward. Will continue testing.
- Sounds reasonable so far.
- The modeling activities are excellent.
- While the plan for demos appears sound and should be based on extensive experience, the overlap between what is learned in the short stack work and the demos is not clear.

Strengths and weaknesses

Strengths
- High power beta test system running, giving good data for optimization of system components. Bottom-up stack design for durability approach shows promise.
- Interesting work in humidification.
- Testing program appears to be on track to achieve requirements (other than perhaps power).
- Looks like a good transition for UTC with PEM as a stationary market.
- Systems demonstration Seal material improvement work with cycling tests.

Weaknesses
- Looks like this will only benefit UTC in the power generation products.
- Not enough information that describes shortcomings and limitations found in demo/beta/power plant tests.

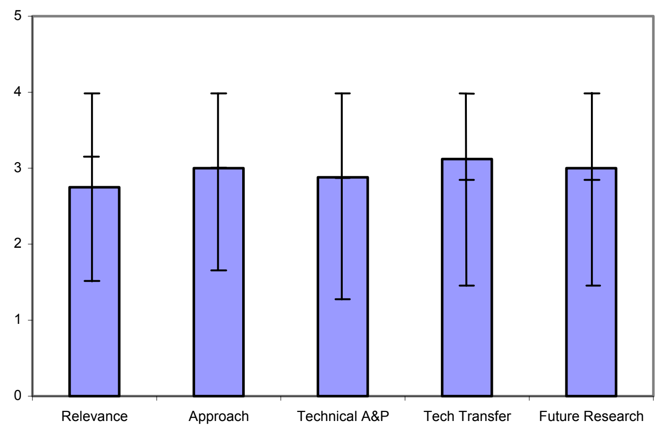
Specific recommendations and additions or deletions to the work scope

- Would like to see more collaboration with National Labs, new membrane work. Might aid durability work.
- What is really developed from this funding that contributes/transfers to the commercialization of stationary PEM fuel cells?
- Need to identify the split in resources and effort between materials and demonstration. Need to show relationship between advances in material results and demonstration operations. Isn't there enough information on market analyses?

Project # FC-34: Back-up/Peak-Shaving Fuel Cells
Vogel, John; Plug Power

Brief Summary of Project

Overall Project Score: 2.95



The objective of the Plug Power project is to advance the state of the art of fuel cell technology with the development of a new generation of commercially viable, stationary, back-up/peak- shaving fuel cell systems. Project objectives are to develop, build and test three identical fuel cell back-up systems and field test them at three sites including an industry host site to identify technical barriers and objectives to develop a cost-reduced, polymer electrolyte membrane (PEM) fuel cell stack tailored to hydrogen fuel use to develop a modular, scalable power conditioning system tailored to market requirements to design a scaled-down, cost-reduced balance of plant (BOP); and to certify design to Network Equipment Building Standards (NEBS) and Underwriters Laboratories (UL).

Question 1: Relevance to overall DOE objectives

This project earned a score of **2.75** for its relevance to DOE objectives.

- Focus on product development rather than advancing fundamental science and moving fuel cell performance to new level.
- Demos are a necessary part of maturing fuel cell technology.
- Good plan to produce power for back-up/peak-shaving fuel cell.
- Lots of challenges to meet telecom requirements.
- This project will bring hydrogen into the commercial market place. This could be an excellent place to work through hydrogen consumer acceptance issues.

Question 2: Approach to performing the research and development

This project was rated **3.00** on its approach.

- Good product development approach and have set up necessary partners to evaluate product in the field.
- Looks good but has several variables that must come together.
- Using industrial grade hydrogen powered fuel cell stack-5kW, but various voltage outputs required-48V and up.
- PlugPower proposes a rather conventional and sound program of product development.

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

This project was rated **2.88** based on accomplishments.

- Plug Power has demonstrated 1000 hrs performance in the field with 1000 start/stops. No performance data shown in presentations to show degradation over 1000 hrs.
- Durability and dependability still have to be demonstrated to some confidence level.
- Made excellent power controller. Initially use batteries for fast start-up, looking at ultra capacitors.
- Early in program, looking at 3 generations; on first one now but have made excellent accomplishments in reducing number of cells, weight and volume by future design.
- 44 V DC backup – worked when telecom source went down.
- The planning is sound. Progress in permitting described. Electric power conditioning appears to be a major advance. It could be very important for distributed generation.

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

This project was rated **3.12** for technology transfer and collaboration.

- For the target market, Plug Power has selected a good team to demonstrate the technology.
- The team seems appropriate for the tasks.
- Working with Bell South, Airgas and Telecordia Labs as NEBS testing agency.
- Market agreement with fuel supplies and customers is important.

Question 5: Approach to and relevance of proposed future research

This project was rated **3.00** for proposed future work.

- Will advance the product design. Introduces electrolysis to generate on-site hydrogen and reduce O&M costs.
- May need to consider back-up in the event the dry cathode stack operation runs into difficulty.
- Continue to develop GenSys stacks, freeze/thaw tolerance evaluation, and dry carbide stack operation. Possible electrolysis made when GenSys not required.

Strengths and weaknesses

Strengths
- Leveraging their extensive field test experience.
- Good team.
- Runs on industrial hydrogen-provides back-up/peak power, when Telecom or other type systems fail. Indications seem to indicate that processes work so far.
- Good technical team. Excellent progress in market development provides story base.

Weaknesses
- Not clear that development of product for niche market with low duty-cycle operation advances the state-of-the-art toward long-term goals. Fuel cell community will not benefit from the learning.
- Several unknowns that should have some back-up or alternative plan associated with them.
- Need to select best GenSys. Have a lot of work to do. Some of their future work may not be feasible.

Specific recommendations and additions or deletions to the work scope

- Establish definite evaluation points for either go/no-go or back-up plan to be implemented.

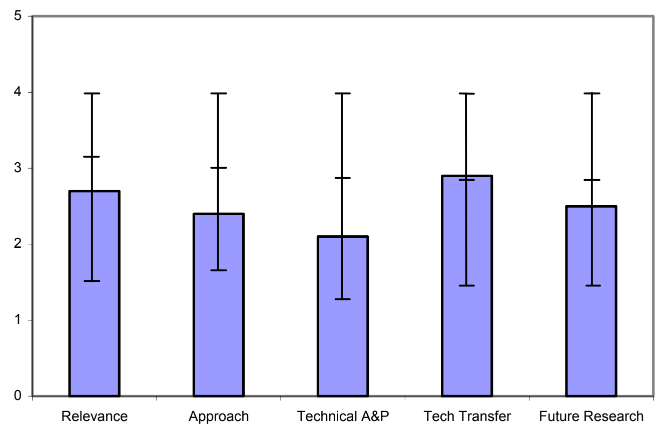
Project # FC-35: Economic Analysis of Stationary PEM Fuel Cell Systems

Stone, Harry; Battelle Memorial Institute

Brief Summary of Project

Battelle Memorial Institute and its team will develop an understanding of the economic, technology, and marketplace drivers needed for commercialization of stationary PEM fuel cell systems out to the year 2015. Their objectives are to evaluate potential stationary PEMFC applications; to identify critical success factors required for commercialization; to develop a technical targets table for each application (cost, reliability, size, response, emissions, electric load versus time, etc.); and to educate stakeholders and raise awareness of National programs.

Overall Project Score: 2.52



Question 1: Relevance to overall DOE objectives

This project earned a score of **2.70** for its relevance to DOE objectives.

- I believe that commercial entities are best at directing the search for market opportunities. If technologies are available, endorsers will seek the best available products.
- Difficult analysis to undertake in a highly competitive emerging technology, but it is essential to try.
- Should have been done before DOE committed scarce resources to stationary electric generation (which involves technology development [low pressure reformers and reformate stacks]) that may not be useful for the main, transportation, goal. But it is better too late than never.

Question 2: Approach to performing the research and development

This project was rated **2.40** on its approach.

- "Expert" focus groups are one approach, but they tend to be opinion driven versus more quantitative assessments of market value & attractiveness. Focus groups can be used to evaluate quantitative analysis of technology benefits against market needs.
- All the objectives are on target and laudable. It is imperative to establish key factors that will create "market pull."
- Too soon to really tell. Project appears totally dependent on quality of input from stakeholders. Does the group actually doing the study have the fuel cell knowledge and experience to judge the quality of stakeholder input? (Though experience in the methodology of such studies [and general wisdom] may be more important than direct technical experience.) Project leaders bring in important experience in economic and technology development.

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

This project was rated **2.10** based on accomplishments.

- Project just started, do not expect much progress. However, 1st expert group appears industry/ university/government weighted rather than end user. Did not show logic used to select back-up power.
- Anyone can do focus groups. Keep in mind that there are many different kinds of stationary power -- and each has its own market (back-up, portable, etc.). An internet sales site will pay significant premiums for 99.999% reliability.
- Early days yet, but baseline information (compelling technologies & benchmarking) will be extremely useful.
- Too soon to really tell. Choice of first panel appeared to ignore the presence of intelligence outside the State of Ohio, probably due to zeal to get started fast.

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

This project was rated **2.90** for technology transfer and collaboration.

- Have lined up large number of participants.
- Well coordinated plan for stakeholder input is clearly in place.
- Nature of project makes it totally dependent on high-quality participation by many collaborators. Might want to draw Battelle's own fuel cell technologists into this process more formally.

Question 5: Approach to and relevance of proposed future research

This project was rated **2.50** for proposed future work.

- This program focused on market analysis and does not advance fuel cell technology toward targets.
- Let it happen.
- Plans look good provided that the transition is quickly made from designing process to addressing critical questions.

Strengths and weaknesses

Strengths
- Does provide framework for large number of inputs.
- Recognition that cost & reliability are the top two factors is reassuring.
- Project members have diverse experience in running such studies and in development of technologies into business.

Weaknesses
- Advances in fuel cell technology will be the most helpful in advancing commercialization. Commercial entities (developers) are most effective at leading or directing search for markets. Market analysis is based on "expert" opinion rather than quantitative analysis of technology/market fit.
- Results should be more obvious to the reviewer in terms of presentation.
- None evident.

Specific recommendations and additions or deletions to the work scope

- Project may have to evolve from an apparent passive collection of input from stakeholders to an active exercise of the judgment of those running the study. Only if that educated judgment is actively and wisely applied will this paper study be worth $3 million plus.

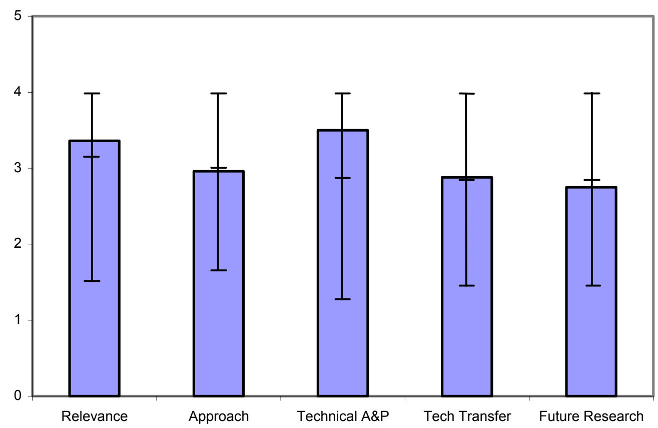
Project # FC-36: Fuel Cell Systems Analysis

Ahluwalia, Rajesh; Argonne National Laboratory

Brief Summary of Project

For this project, Argonne National Laboratory (ANL) will develop a validated system model and use it to assess design-point, part-load and dynamic performance of automotive fuel cell systems. This effort is aimed at supporting DOE in setting R&D goals and research directions and establishing metrics for gauging progress of R&D activities. Objectives are to develop, document, and make available versatile system design and analysis tools, and to apply the models to issues of current interest.

Overall Project Score: 3.09



Question 1: Relevance to overall DOE objectives

This project earned a score of **3.36** for its relevance to DOE objectives.

- The modeling capability of ANL provides DOE the capability to assess critical issues, evaluate/choose development paths, and assess performance of products versus theoretical performance.
- Solid work! May suffer on wrong solution of chosen simulated technology in terms of realizability.
- Good relevance overall, but portions (residential systems) not applicable to FreedomCAR.
- Extremely valuable modeling capability has emerged.
- This effort remains a keystone (after all, this is PA) of the FreedomCAR fuel cell program, providing guidance for many other projects.

Question 2: Approach to performing the research and development

This project was rated **2.96** on its approach.

- Integrates component to vehicle models in drive cycle analysis. Validation of models with data from industry or labs. Works with industry to aid in development and target setting.
- Selection of processes that have been simulated should be seen more critical and competitive. Some not promising technologies included from my point of view (e.g., enthalpy wheel).
- Seems too broad. Attacking different elements of the FC/H_2 challenge somewhat randomly (FP, automotive, humidity, CHP/home heating).
- The redirection of this systems analysis tool away from fuel processing focus to other aspects of FCVs will be most helpful & beneficial.
- Thoughtful evaluation of individual cases, and comparisons between them, provides useful guides to experimental programs. Make sure critical assumptions are clearly stated e.g., in slide of costs of CHP, what were $\$1kW_e$ and life of fuel cell?

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

This project was rated **3.50** based on accomplishments.

- Thermal & water management & high temp membranes are critical areas. Models help set development approaches and identify key parameters.
- Has quantitative results & characterizes benefits. Draws conclusions.
- Profitable application of ANL's analysis tools to diverse alternative FC system options was well demonstrated.
- Gave solid quantitative estimates on a number of important questions. "What If" analysis applied in productive directions.

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

This project was rated **2.88** for technology transfer and collaboration.

- Involved with Tech Teams & individual development teams.
- Not much -- need to develop tech transfer mechanisms.
- Excellent support being given to other significant FC developers, etc.
- Useful communications with many DOE contractors. Would be good to take advantage of increased systems expertise on FC tech team to improve 2-way flow of information, targets, and assumptions between ANL and tech team.

Question 5: Approach to and relevance of proposed future research

This project was rated **2.75** for proposed future work.

- Important topics selected.
- Consider separating into a couple of distinct projects. Lacks central focus.
- Future work well identified and appropriate. Effects of sub-zero ºC start-up and operation would be informative.
- Individual planned activities seem good. Activities still seem reactive and/or spur-of-the-moment rather than part of a coherent plan, but it's worked this far.

Strengths and weaknesses

Strengths
- Skills of PI and ANL modeling group. Collective experience and history of ANL activity in all aspects of fuel cells & system analysis.
- Solid and reasonable!
- CHP for home consideration very interesting.
- Good understanding of systems engineering trade-off is a big asset. Will pay off in terms of systems optimization.
- Good choice of problems to consider. Good analysis of those problems.

Weaknesses
- Chosen processes/techniques are not all state-of-the-art.
- Seems more about application of models rather than model development. If really about application, then need to work on #4 Tech Transfer/Collaborations.

Specific recommendations and additions or deletions to the work scope

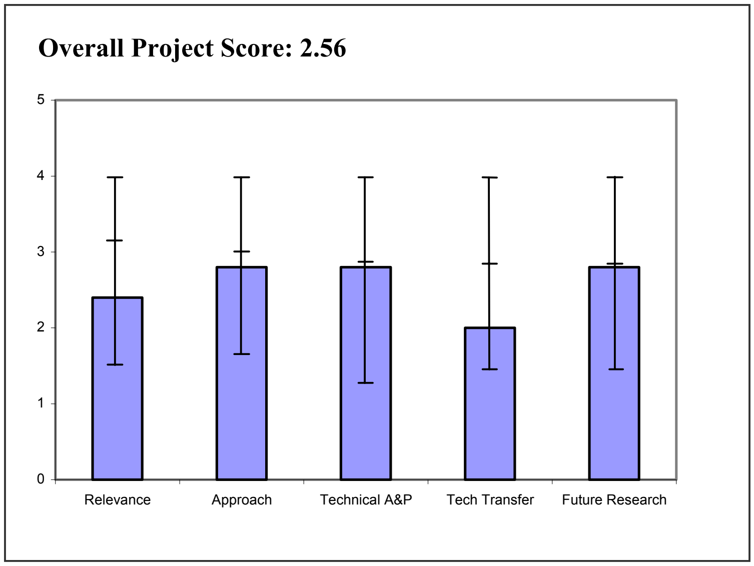
- To bring down weaknesses, involve system engineering capability as well as monitoring and benchmarking competence!
- Narrow down to single theme.
- Link-up with technology validation program to provide real life validation of models would be valuable.
- Seek out mechanisms to get extant and relevant data from non-DOE development programs.

Project # FC-37: Development of a Thermal and Water Management (TWM) System for PEM Fuel Cells

Liu, Chung; Honeywell

Brief Summary of Project

Honeywell's project is to assist DOE in developing a humidification and cooling system for PEM fuel cells in transportation applications. Objectives of the project are to: focus on cathode humidification for a 50 kW fuel cell power system; study pressurized thermal and water management (TWM) system performance; analyze steady-state automotive operating conditions for comparison of concept schematics; establish TWM system/component specification; and demonstrate the performance of a breadboard TWM system with research hardware.



Question 1: Relevance to overall DOE objectives

This project earned a score of **2.40** for its relevance to DOE objectives.

- Balance of plant is too dependent upon stack design and drive cycle requirements to be developed externally. This work should be done by system integrators.
- Important topic for meeting the President's Initiative, but it is not clear that this project has the appropriate plans to be as effective as possible.
- Premise that such a system can be "outside" and not integrated into a stack system is flawed. However, if such a system is given, the approach is methodical and reasonable.
- Developing novel humidification systems for hydrogen fuel cell stacks.
- This issue is important when space is limited and no combined heat and power options nearby.

Question 2: Approach to performing the research and development

This project was rated **2.80** on its approach.

- Considering the constraints on scope of this project, the approach is good.
- Though plans seem a little vague, with some effort they could be improved.
- Comprehensive and systematic and ranking of development priorities is appropriate. Why "pressurized?" No critique as to why different W.M. systems being considered; some may not be mechanically suitable. So why consider them?
- Look first at SS up to 50 kWe concentrating on cathode humidification use. Going to look at various water management concepts, enthalpy wheel, membrane, porous plate cathode recycle. Emphasizing trying to avoid change of H_2O; also looking at advanced mix.
- The thermal management and water management necessarily are coupled-good approach. Volume is appropriate focus. Considerable experience is out there on membrane humidity and the enthalpy wheel. May not add value.

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

This project was rated **2.80** based on accomplishments.

- Program seems too new to have demonstrated much progress.
- Not clear what performance indicators are being used that also align to DOE goals.
- Appropriate, given the stage (early) of project. No data yet. Development priority-appropriate? (More critical scrubbing is needed.)
- Program in early stages. Have established design criteria for various devices; investigated high & low temperature. Have completed some subscale tests on membrane; probably eliminate cathode recycle.
- Project is just underway. Analysis seems OK.

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

This project was rated **2.00** for technology transfer and collaboration.

- This program needs to be much more closely aligned w/real system integrators (e.g., UTC, Plug, etc.). Otherwise the learnings may not translate into real systems.
- Collaboration with OEMs should be stronger. This could help the project to be stronger and more successful.
- No clear commitments from stack developers (or they are not well identified in presentation).

Question 5: Approach to and relevance of proposed future research

This project was rated **2.80** for proposed future work.

- In the future, you must have real valuation, not use "simulation data."
- Future research somewhat vague, but appears to be directionally correct.
- Research plan is appropriate, if premise that a thermal and water management could be effective "outside" of the stack.
- Down select optimum TWM system from 4 different options. Start full-scale "humidifier" test bench. Start component testing in 2005. Complete component testing & demonstrate bread board TWM system in 2006.
- Not much detail. Seems an obvious approach.

Strengths and weaknesses

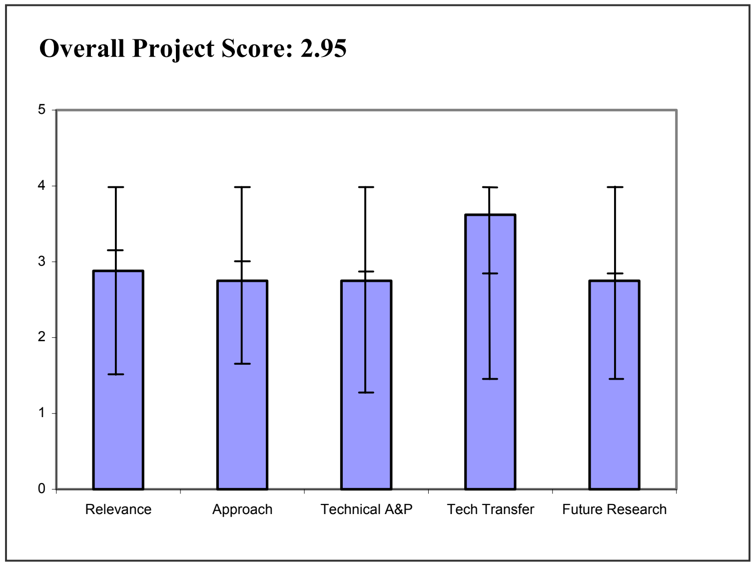
Strengths
- Good breadth in possible system designs.
- Research plan is methodical.
- New humidification systems for hydrogen, fuel cell stacks. Down select best of 4 options.
- Good technical staff.

Weaknesses
- Research too isolated from the real world.
- Premise of a non-integrated thermal/water management system may not be practical. Premature "rejection of cathode recycle option" practical systems may use this approach (in a more integrated fashion).
- Scale-up to large systems and dynamic systems in future.

Specific recommendations and additions or deletions to the work scope

- Adjust scope of collaborations to include state-of-the-art fuel cell system developers.
- Be more specific showing alignment of project performance to DOE targets and goals.
- Be specific about stacks to be needed (which technologies to be coupled with) and source of hydrogen. Project makes sense only when well integrated into entire system. Re-evaluate input criteria (current criteria may be too limiting).
- Work with ANL to establish interface with TWM system and PEM fuel cell stack, particularly absorbent wheel. Honeywell automotive division & advanced "aerospace" H/X i.e., micro channels.

Project # FC-38: Fiber Optic Sensors for Fuel Cell Applications
McIntyre, Tim; Oak Ridge National Laboratory



Brief Summary of Project

The objectives of this Oak Ridge National Laboratory (ORNL) project are to develop small, rugged and inexpensive fiber optic temperature sensors, develop a multi-point measurement capability, demonstrate sensors in an operating fuel cell, meet or exceed all program measurement performance requirements, and establish a path to a cost-competitive commercial sensor (i.e. <$5.00).

Question 1: Relevance to overall DOE objectives

This project earned a score of **2.88** for its relevance to DOE objectives.

- Temperature sensors are important but not crucial.
- Sensors important system components but not critical to core fuel cell technology.
- Absolutely imperative to develop sensors for automobile fuel cell applications given the large variation in temperature and fuel cell will be exposed to, especially on start-up from T<0 ºC.
- Could provide an important research tool to aid the development of fully-capable fuel cell systems.

Question 2: Approach to performing the research and development

This project was rated **2.75** on its approach.

- Presentation does not compare proposed technology relative to industry status. Did not see product specification to guide sensor development. Interactions with (stack) developers to understand how sensor would be used were not evident or discussed.
- Excellent approach. I worry how robust these sensors will be in a fuel cell environment.
- Program seems designed to develop this temperature sensor as a device for mass-production. This technology will likely remain a laboratory instrument. Significant advantage over competing sensors requires implementation of multiplexing schemes - these need to be brought forward and discussed.

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

This project was rated **2.75** based on accomplishments.

- Very thin. Good response time.
- Difficult to judge. Would be informative to benchmark against available technology.
- Initial accomplishments are very good but should accelerate FC tests.
- Nice demonstration of stable, calibratable, fast response for single-point sensors. Still need to demonstrate cases of unique utility.

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

This project was rated **3.62** for technology transfer and collaboration.

- Very extensive.
- Talking to OEMs and have long list of collaborators. Should discuss results or insights gained from collaborations.
- Collaboration with Plug Power is good. Should show timeline on how this interaction will proceed since this work is critical to sensor validation.
- Have a major developer with whom to work closely. Have tried to kick-off significant interactions with other developers.

Question 5: Approach to and relevance of proposed future research

This project was rated **2.75** for proposed future work.

- Logical next steps, including testing in an actual fuel cell.
- Should start testing under fuel cell environment immediately.
- Emphasize multipoint measurements more. Don't spend a lot of time on cost/unit unless a strong pull develops from demonstrated unique utility of prototypes.

Strengths and weaknesses

Strengths

- Good choice of technology to base temperature sensor on. Response time is outstanding.
- Fast sensor not dependent on metal wire leads. Potential for multiposition measurements from a single sensor. Demonstrated (if perhaps misdirected) ability to reduce cost of control electronics.

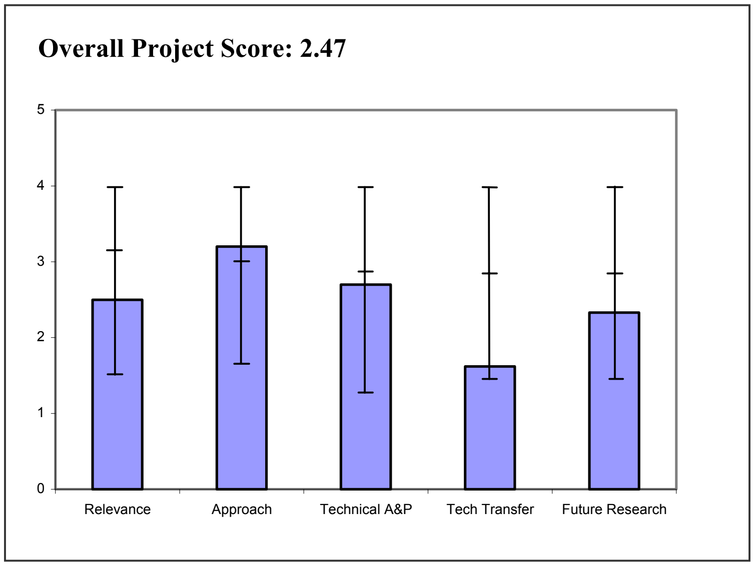
Weaknesses

- Need to discuss how sensor would be used in application, how application needs are driving development.
- Need to consider mechanical strength. How will sensors be incorporated into a cell platform? Will they be put into flow fields or sandwiched between components (e.g., GDL & MEA)?
- Still need to demonstrate cases where this is an enabling technology, allowing critical knowledge to be generated that couldn't be obtained by other means.

Specific recommendations and additions or deletions to the work scope

- Work with someone from automotive sector. These sensors will need to be robust enough to operate in auto fuel cell environment. Accelerate fuel cell testing.
- Emphasize multi-point temperature measurements. Forget about trying to make it cheap enough for use in production vehicles.

Project # FC-39: Atmospheric Fuel Cell Power System for Transportation
Tosca, Mike; United Technologies Corp. Fuel Cells



Brief Summary of Project

United Technologies Corp. (UTC) Fuel Cells will determine the feasibility of an on-board gasoline reforming 50kW fuel cell power plant for commercial transportation applications based on the industry and DOE targets for commercialization. Their Gasoline Fuel Cell Powerplant Phases include FP1: Integrated Gasoline Fuel Processor (FY02 - FY03) and PP1R: Integrated Fuel Cell Power Plant (FY03 - FY04).

Question 1: Relevance to overall DOE objectives

This project earned a score of **2.50** for its relevance to DOE objectives.

- Reference depends on go/no-go decision on on-board reformers. Transition path option to fuel cells in transportation.
- Well aligned with original plan but not sure if reformer technology part of the President's Plan.
- Project started before current hydrogen program was put in place. It ends in September 2004.

Question 2: Approach to performing the research and development

This project was rated **3.20** on its approach.

- Integrates reformer with stack into system.
- Discussed CO level increase with larger output (power) demand. Any possible solutions could be discussed.

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

This project was rated **2.70** based on accomplishments.

- Presenter clearly defined challenges to achieving targets and need for fundamental advances in catalysts & reformer designs to achieve start-up time and volume targets.
- FPS results right on. However, total power plant still appears to take long to come on-line.
- Running out of time! Especially in terms of system integration.
- Delivered integrated gasoline system weight, volume targets not met. Cost-unknown.

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

This project was rated **1.62** for technology transfer and collaboration.

- No partnerships shown in this review presentation.
- No transfer of technology. No collaborations evident.

Question 5: Approach to and relevance of proposed future research

This project was rated **2.33** for proposed future work.

- 5kW APUs find largest application in trucks and work would have to be targeted to diesel fuel.
- End of program -- not really relevant.
- Is the proposed "hereafter focus" a smaller application (APU 5 kW) a consequence of unhandleable complexity?
- None. Project ends in September 2004.

Strengths and weaknesses

Strengths
- Builds on UTC strengths in system integration of reformers and stacks. Leverages UTC stack technology.
- Best safety slides of whole conference.
- Measurement data: Seem to be reliable and reasonable.
- Project demonstrated the difficulty in meeting target with on-board reformers.

Weaknesses
- Program does not advance overall knowledge of the fuel cell/reformer community.
- No "next step" suggestions of how to visualize the solution to 30 second start. No inclusion of cost projections.
- The review presentation does not show whether the goal of feasibility of 50kW Reformer is reachable or not.
- Breakthrough will be required to go forward with on-board processing. Start-up time is too long. Control of CO concentration difficult at higher power transients.

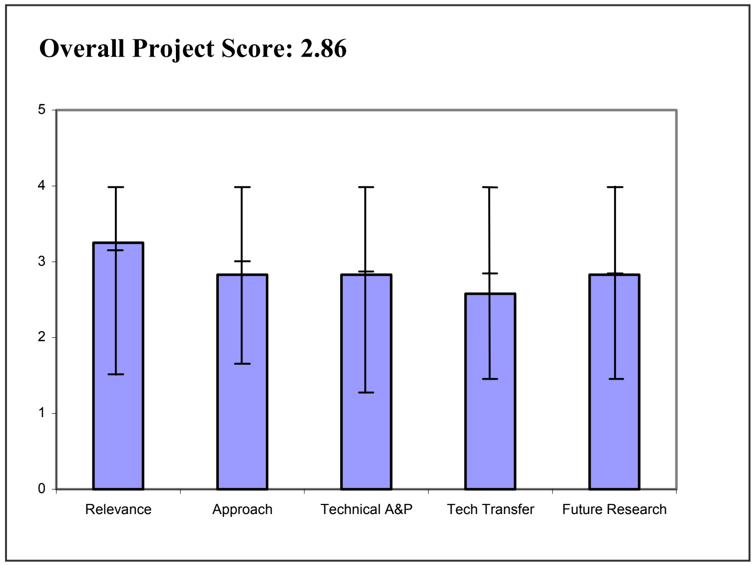
Specific recommendations and additions or deletions to the work scope

- Interesting to note that the best" "state-of-the-art" reformer technology is suggesting completely different approach to reforming problem of 30 second start.

Project # FC-40: Cost and Performance Enhancements for a PEM Fuel Cell Turbocompressor
Gee, Mark; Honeywell

Brief Summary of Project

Honeywell is developing an optimum turbocompressor configuration for integration into a PEMFC that reduces costs while increasing design flexibility. Honeywell is utilizing their expertise in automotive and aerospace turbomachinery technology, variable nozzle turbine inlet geometry, mixed flow type compressors, and contaminant/oil free, zero-maintenance compliant foil air bearings to achieve this objective. The final product will have a modular design, high efficiency, and variable speed motor-controller topology design.



Question 1: Relevance to overall DOE objectives

This project earned a score of **3.25** for its relevance to DOE objectives.

- For transportation systems based on elevated pressure need an efficient compressor/expander.
- For the pressurized fuel cell systems, the air management subsystem is a critical component. Successful completion of this project would greatly help to achieve fuel cell system performance targets.
- Low-cost, durable, lightweight and compact air delivery machines are one of the key enabling balance-of-plant components for successful fuel cell commercialization.
- A new compressor (expander) can assist in many hydrogen technologies, i.e., addition to the target automotive fuel cell.
- This project is vital, as it addresses one of the major balance-of-plant issues for FC systems.

Question 2: Approach to performing the research and development

This project was rated **2.83** on its approach.

- Project started in 1996 still in redesign/build/demonstrate mode. Need to rethink deliverables of this project. Specific hardware or design tool to rapidly tailor compressor/expander for each developer.
- Building on their past experience, they have identified and are addressing the key performance issues, such as variable nozzle geometry for low-flow and low-cost motor and motor controller.
- Need to team with other experts who could provide unique insight to design and power aspects.
- Approach is sound. Likely requires flexibility in allowed operating conditions to apply to FC developer's system.
- Builds off of a quality technical base.
- Approach seems sound.

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

This project was rated **2.83** based on accomplishments.

- Back to the drawing board again with further modified product available for test in near future.
- Based on discussions with fuel cell developers and their own analyses, they are addressing various details, such as liquid cooling, sensor-less control systems, high power density motor, very high transient response, all the while maintaining high compressor-expander performance.
- Unclear from slides: Complete weight (including controller) compared to target. Provide efficiency curves. Show power (mechanical and electrical) over design and turndown operating condition. Cost estimate? Provide data.
- Compressor/turbine seems to have met performance targets. Weight and volume also look hopeful.
- Excellent technical progress to date.

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

This project was rated **2.58** for technology transfer and collaboration.

- Specific interactions with OEM not discussed. OEM inputs are needed to specify product for demonstration.
- Their discussions with automotive OEMs and other developers have led them to focus on issues of cost and durability/reliability.
- Interactions need to be improved.
- Appears adequate. Will C/M/E be supplied to developer using existing program funding? Provide more data.
- What is the content of the interactions with FC Power systems and automotive OEMs?

Question 5: Approach to and relevance of proposed future research

This project was rated **2.83** for proposed future work.

- Work will bring project to conclusion.
- Their proposed activities should bring the project to a logical and successful conclusion, assuming that the hardware tests out as projected.
- Details lacking.
- Good but potentially relies on a FC developer well-matched to the turbocompressor. Either turbocompressor needs to be flexible, or should build test bench to simulate FC. Preferably both.

Strengths and weaknesses

Strengths
- Knowledge of turbo machinery design and manufacture.
- Use of automotive and aerospace expertise in development activities. Scalability is built into the design philosophy.
- Honeywell & Garrett's extensive background in aerospace and automotive air machines. Airfoil bearings promise of clean pure air to fuel cell. High speed leads to compact package.
- This project seems to be on track to be technically very successful.

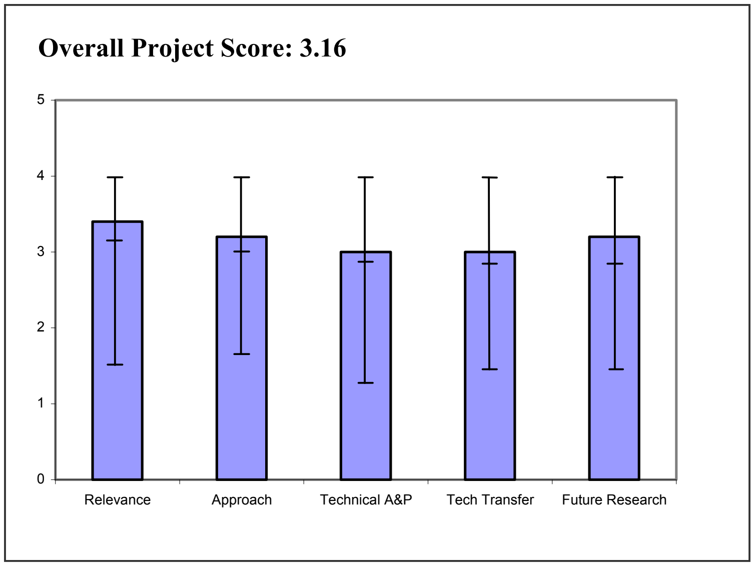
Weaknesses

- Will the cost reductions be adequate for fuel cell developers to use this machine?
- No comparison to current state-of-the-art provided. Why is this approach better?
- Can air bearings achieve automotive stop/start/drive cycle durability requirements?

Specific recommendations and additions or deletions to the work scope

- Other labs have expertise in turbo machinery for air handling. Contact ORNL, SNL.
- Ensure that final design allows for the flexibility of various operating conditions: e.g. different pressures, system pressure drop, expander temperature and water content. Test bench should be capable of evaluating turbocompressor performance without need for actual FC integration.

Project # FC-41: Development and Test of the Toroidal Intersecting Vane Machine (TIVM) Air Management System
Bailey, Sterling; Mechanology, LLC



Brief Summary of Project

Mechanology's overall objective in this program is to develop the innovative TIVM concept into working compressor/expander/motor hardware that satisfies the FreedomCAR guidelines. Objectives include building on the prior demonstration of the basic functionality of the TIVM; developing a detailed design for a prototype compressor/ expander; and beginning fabrication of the prototype compressor/expander with the selected features.

Question 1: Relevance to overall DOE objectives

This project earned a score of **3.40** for its relevance to DOE objectives.

- Better, cheaper, more efficient compressors are critical to increasing power density (and ultimately decreasing system cost) requirements.
- Air management is a key component of successful fuel cell system development. The TIVM approach is a novel one, and, if successful, may well find use in many other applications.
- Blower is often overlooked, while still an integral part of FC system. Fabricating design for brand new blower/compressor.
- Highly recommend to have a TC specific air supply due to its high impact to the overall efficiency.
- Develop TIVM C/E for hydrogen stacks. Designed to meet FreedomCAR objectives. Reduce parasitic losses.

Question 2: Approach to performing the research and development

This project was rated **3.20** on its approach.

- Nice approach: evaluate items critical to quality, fabricate and test on devices optimized through mathematical modeling. Actual working device to be delivered validates program.
- Conceptually, this is a high-efficiency positive displacement machine. The important focus areas are limiting air leakage without increasing friction losses, and improving aerodynamics to decrease entrance and exit losses at the ports.
- Taking concept blower from design phase to reality. Optimizing seals and machining techniques to assemble working prototypes. Very elegant design.
- Theoretically well done. Mathematically approaching and revising since 1985.
- Concentration on 80 kWe hydrogen system. Refining C/E prototype. Positive displacement on flow like turbo compression with turndown.

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

This project was rated **3.00** based on accomplishments.

- Modeling first and then testing is paying great dividends in the progress.
- Significant conceptual design improvement identified. Actual new design hardware is yet to be built and its performance verified.
- Amazing results if the numbers projected hold.
- Demonstrated low friction. Demonstrated can meet required pressure. Demonstrated can do this at low speed. Expander now does both compression and expansion.

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

This project was rated **3.00** for technology transfer and collaboration.

- Are adequate relationships established that will result in a drop-in replacement if program is technically successful?
- While no specific tech transfer contacts have been identified, it was clearly implied that there is considerable industrial interest in their machine.
- Technology has possible broad use implications for several applications. Closely connected with ANL and car OEMs.
- Many "private investors." Collaboration with program.

Question 5: Approach to and relevance of proposed future research

This project was rated **3.20** for proposed future work.

- The proposed work is a logical progression from where they are to where they need to get to verify performance of their new design.
- Optimizing seal selection and final design. Fabricate and test blower. Already obtained a development contract for the technology for other applications.
- Comparison needed to other technologies of air supplying. There must be a reason that this idea just now begins to grow 20 years after its invention.
- Going to develop full machine by end of 2004. This will be proof of pudding.

Strengths and weaknesses

Strengths
- Very good technical progress in a critical area.
- The concept is flexible for a variety of pressure ratios. TIVM is a positive displacement device that has performance similar to rotary machines. Should offer high performance even at high turndowns.
- Elegant design, wonderful possibilities. Further development fund received for other applications.
- Requires only "compliant seals" to eliminate leakage. Expander vane now does both compression & expansion, lowers friction. Have porting device to allow "floating pressure."

Weaknesses
- If mathematical models are wrong, program may not meet goals within established timelines.
- Will cost targets be met? Does it require any motor development? Making pressure ratio flat with flow rate will decrease efficiency?
- Only if machine doesn't work.

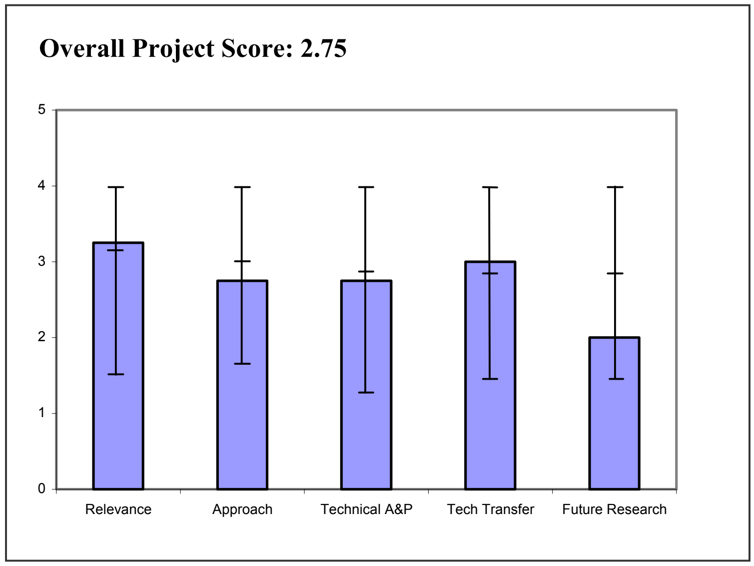
Specific recommendations and additions or deletions to the work scope

- Keep up the good work.
- It is an imperative concept that should be pursued to completion.

Project # FC-42: Development of Sensors for Automotive PEM based Fuel Cells
Knight, Brian; United Technologies Corp. Fuel Cells

Brief Summary of Project

United Technologies Corp. Fuel Cells (UTC) and its team are developing physical and chemical sensors for PEM fuel cell power plants for automotive applications aimed at low cost (<$20 / sensor) at 500k quantity. Work in chemical sensors includes process streams before, in, and after reformer and before and in fuel cell stack; CO, H_2, O_2, H_2S, NH_3 types; and safety (H_2). Physical sensors focus includes temperature, pressure, relative humidity, and flow.



Question 1: Relevance to overall DOE objectives

This project earned a score of **3.25** for its relevance to DOE objectives.

- For widespread deployment of fuel cells in a variety of applications, it will be important to develop reliable, responsive, inexpensive sensors for a variety of chemical and physical parameters.
- Need for reliable, low-cost sensors is definitely relevant for industry to become "real."
- Sensors for diagnostics and controls for fuel cells are very important to meet efficiency goals.

Question 2: Approach to performing the research and development

This project was rated **2.75** on its approach.

- The approach seems to be to evaluate currently available sensors and determine what performance improvements are needed. There was little discussion of how these improvements will be attempted.
- Approach is broad and comprehensive (too broad?). Well coordinated. Need more information on sensor mechanism/chemistry, etc.
- A commercial sensor supplier list including recommendations for the best candidates is lacking. Targets for response times of chemical sensors not indicated.
- Although sensors development for fuel cell system functions is necessary, it is not clear that the requirements or goals are well-defined, and these goals/targets are commensurate with more efficient operations.

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

This project was rated **2.75** based on accomplishments.

- Hydrogen sensor response has been quantified. Some prototype safety-related sensors have been fabricated for testing. Process gas sensor work (for H_2O, CO, H_2S, etc.) is also progressing well.
- Data generated has identified future improvements/steps needed; also addressed previous reviewers' comments.

- Progress is shown, but hard to evaluate comparing figures with test results and project timetable. Results for physical sensor not shown. Sensing lowest level of H_2S (0.05ppm) is absolutely necessary.
- Still difficult to assess technical progress. Test conditions used to show sensor responses aren't correlated to expected "real" conditions and goals.

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

This project was rated **3.00** for technology transfer and collaboration.

- The team itself consists of industrial, research, and academic organizations. Thus, tech transfer should be a seamless process as the sensors reach maturity.
- Strong collaborators with institutions "up" the food chain (materials, suppliers, research institutes); need improved partnerships with end users (beyond UTC).
- A database of the best existing sensing technology is lacking.
- In order to expand the cadre of contributors, and determine whether certain sensors can be improved within their limits, other suppliers could be valuable contributors.

Question 5: Approach to and relevance of proposed future research

This project was rated **2.00** for proposed future work.

- Although little specific detail was offered, it appears the team has a rational work plan for continued development of the sensors.
- Improvements well-stated, but need to flesh out more technical details (more specifics and deliverables and numbers).
- No plans for the future research presented.
- Not clear.

Strengths and weaknesses

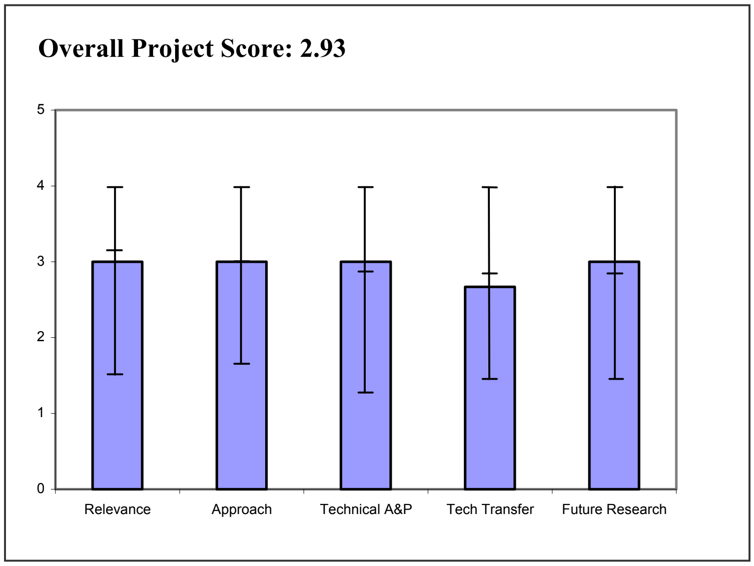
Strengths
- The lead PI is a fuel cell developer so that the developed sensors should be consistent with real-world hardware needs. There is interaction with Honeywell and ORNL who are also developing sensors.
- Shows good progress; strong collaborations.
- Project covers all aspects of sensing for FC systems.
- Addressing need for sensors, both physical and chemical system, capable of testing sensors in a unified way.

Weaknesses
- The step-down response times appear to be long for some of the sensors.
- Need better definition of future programs, more end-users signed up for follow-up; more critical down-selects (where appropriate). Develop more specific recommendations, be more definitive in conclusions.
- Not clear separation between researching and evaluating sensors and sensor development.
- Not clear what goal is-refine targets for sensors? Refine sensor packages? Refine sensor performance?

Specific recommendations and additions or deletions to the work scope

- This work is useful since the developed sensors may find use in other industrial applications.
- Develop more options, if data to-date show need for different technologies. Clarify future challenges; prioritize key challenges (e.g., are cross-sensitivity issues top priority? Or sensitivity? Or response times?).
- Define range of transient test conditions possible in testing. Describe performance with respect to proposed steady-state and transient targets and limits.

Project # FC-43: Sensor Development for PEM Fuel Cell Systems
Magee, Steve; Honeywell



Brief Summary of Project

This project is leading to the creation of physical sensors suitable for monitoring and controlling a polymer electrolyte membrane (PEM) fuel cell system. Key tasks include defining sensor requirements, developing sensors, building and testing prototype sensor, and field testing.

Question 1: Relevance to overall DOE objectives

This project earned a score of **3.00** for its relevance to DOE objectives.

- Sensors all seem directed at internal to systems -- inexpensive external safety sensors should be included in development.
- Have identified technical barriers for fuel cell system sensors.
- Successful development of process and safety sensors is necessary for fuel cell systems to be commercialized.
- PI appears to understand how fuel cells operate and what parameters are important to measure and control.
- This research topic is very important to the automotive industry.
- Project covers the key physical sensing needs in fuel cell systems.

Question 2: Approach to performing the research and development

This project was rated **3.00** on its approach.

- Good approach to define requirements.
- Use of existing technologies should speed development and limit costs. Some durability testing under H_2 environment/fuel cell should be performed to ensure embrittlement doesn't affect pressure sensors.
- This project is primarily addressing physical parameter sensors. The project is exploring how laboratory-type sensors can be modified/adapted as low-cost packages for field use.
- Understands the problems at hand. But the approach seemed uninnovative.
- Results of market survey not presented (in terms of current market products). Clear list of sensor targets.

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

This project was rated **3.00** based on accomplishments.

- Don't show much technical validation data, but indicate good progress. 3-4 s response with resistance temperature detector reasonable.

- Need better response time for temperature sensors, especially for control of fuel processor during startup. Tests in condensing environments and temperature compensation/control at the sensing die are strengths. Flow sensors less advanced than humidity sensors.
- Prototype sensors for humidity and flow have been developed. Same for pressure, pressure drop, and temperature. Response dynamics are yet to be verified.
- Acceptable progress is apparent.
- Progress seems slow for this project.
- Progress consistent with project timeline. Good modeling to support proper design.

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

This project was rated **2.67** for technology transfer and collaboration.

- Should get field testing with UTC or other OEM ASAP.
- The project involves academic, industrial, and fuel cell organizations. The developed sensors should thus find ready transfer to fuel cell systems.
- PI has good set of collaborators especially UTC.
- Should have more than one fuel cell partner for this development. What about the automotive industry collaboration?
- Good collaboration network for addressing various aspects of sensor development.

<u>Question 5: Approach to and relevance of proposed future research</u>

This project was rated **3.00** for proposed future work.

- Looks like plan gets sensors field-tested in appropriate time line.
- Response time for temperature sensors need improvement. If temperature sensors are being used in the fuel processor, the temperature range needs to be expanded to go to at least 850ºC, preferably 1000ºC.
- Future work is consistent with developing the sensors to commercial readiness.
- Plan is good but needs to pick up some speed.
- Not clear when humidity and temperature testing will be carried out. Early testing is key for redesigning and modification.

<u>Strengths and weaknesses</u>

<u>Strengths</u>
- They are factoring in requirements identified by potential customers. Appears to be well executed project.
- Honeywell is a good company and the PI understands the program needs.
- Humidity sensors are the most important. Temperature sensors are not too critical.
- Sensor specifications are clear and cover all requirements.

<u>Weaknesses</u>
- Is there overlap or redundancy with other contracts, such as ORNL or UTC?
- Development rate seemed too slow for what has been delivered.
- Potential problems due to occasional sensor exposure to fuel and air impurities (H_2S, SO_2, NH_3, etc.) has not been addressed.

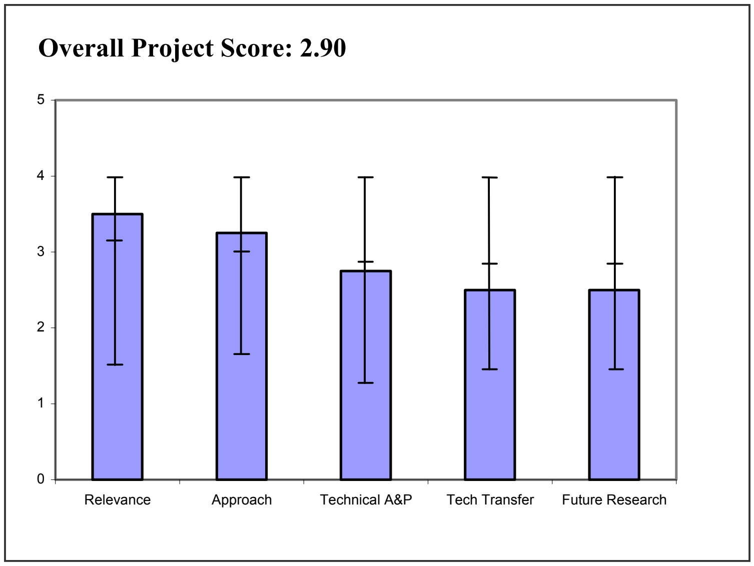
Specific recommendations and additions or deletions to the work scope

- Increase temperature range to include temperatures in high temperature membranes, WGS reactors, PROx reactor and reformer (i.e., increase to 1000C not 100C). Even if there is no reformer, would like T to ~200C if there is a high-temperature membrane.
- Do the target response times suffice for startup requirements (particularly for reformate systems)?

Project # FC-44: Neutron Imaging Study of the Water Transport Mechanism in a Working Fuel Cell

Arif, Muhammad; National Institute of Standards and Technology

Brief Summary of Project



This National Institute of Standards and Technology (NIST) project is intended to develop an effective neutron imaging based non-destructive diagnostics tool to characterize water transport in PEM fuel cells. Objectives include: (1) providing research and testing infrastructure enabling fuel industry to test commercial grade fuel cell flow field designs; (2) providing training to industry enabling them use the imaging facility independently; and (3) transferring data interpretation and analysis algorithms/techniques to industry, enabling them to use research information more effectively and independently.

Question 1: Relevance to overall DOE objectives

This project earned a score of **3.50** for its relevance to DOE objectives.

- Addresses often overlooked aspect of bipolar plate design.
- Since water and its transport are key to PEMFC success, this program is important.
- Dynamic stack diagnostics are essential to advance the technology.

Question 2: Approach to performing the research and development

This project was rated **3.25** on its approach.

- Neutron imaging is uniquely suited for looking at water. Capable of flow field study. Doubtful this can be useful for MEA study.
- Appreciate future goal of imaging entire fuel cell assemblies.
- This is a difficult experimental program to set up.
- Using beam time to assist developers is a good use of Federal resources.

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

This project was rated **2.75** based on accomplishments.

- There is no capability improvement from last year based on the talk. MEA study remains elusive.
- OK-now for imaging of MEA & bipolar plate in real time.
- Progress looks ok but I wonder if it can be extended to understanding stack operation.
- Examples are interesting, but only a few examples were given.

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

This project was rated **2.50** for technology transfer and collaboration.

- Dramatic improvement over last year's collaborations.
- Not enough contact with stack developers who need to know the cell behavior in a stack.

Question 5: Approach to and relevance of proposed future research

This project was rated **2.50** for proposed future work.

- Real time imaging will be a good improvement.
- Needs more interaction with stack developers.
- The emphasis on improving resolution is a good direction.

Strengths and weaknesses

Strengths

- Excellent work on flow-field imaging.
- Outstanding technology providing a rare but vital "glimpse" inside the flow field dynamics.

Weaknesses

- Continued concern over the true practical utility of this technique. Two years have passed and there is no indication there will be any MEA image capability.
- Cost. Unfortunately, the access of this technology for routine development will be prohibited…but still worthwhile.
- More collaboration.

Specific recommendations and additions or deletions to the work scope

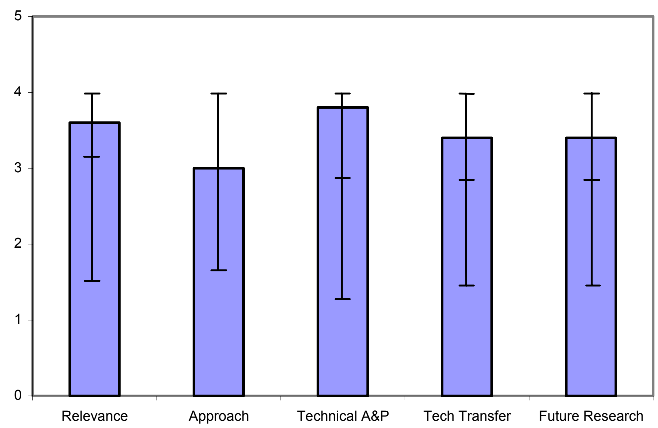
- Show some feasibility study on 10 μ resolution and the path/cost to get there.
- This important tool should also be aligned with modelers as it provides real data feedback to enable refinement of their models.
- The DOE should team NIST with a National Lab and work with a few non-proprietary stacks that allow for open publishing of results, with the purpose of improving diagnostics for the entire fuel cell community.

Project # FC-45: Microstructural Characterization of PEM Fuel Cells
More, Karren; Oak Ridge National Laboratory

Brief Summary of Project

Oak Ridge National Laboratory (ORNL) is working to elucidate MEA degradation mechanisms, including structural and compositional changes as a function of MEA processing, correlation of microstructure with performance, and morphological changes occurring during MEA aging/use. In addition, ORNL will collaborate with PEMFC developers/manufacturers to evaluate MEAs using advanced microstructural characterization techniques and provide feedback for MEA optimization.

Overall Project Score: 3.44



Question 1: Relevance to overall DOE objectives

This project earned a score of **3.60** for its relevance to DOE objectives.

- Good guide on durability issues.
- Effort will help resolve critical mechanical issues. Best technical/analytical advancement of the meeting.
- Analysis of degradation mechanisms very important.
- The program is very important for developers to understand what causes cell decay.

Question 2: Approach to performing the research and development

This project was rated **3.00** on its approach.

- Would have appreciated comparing X-Y direction slices. Is the uniformity in "XY" changing in the "Z" direction?
- Solid techniques developed. First time such analyses have been tied to PEM performance.
- Generally very well planned study.
- ORNL needs to provide better services to developers and encourage dialogue.

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

This project was rated **3.80** based on accomplishments.

- Produced deep understanding of microstructure. Excellent initial durability results.
- Have shown great progress compared to previous year.
- Results critical to the understanding going forward. Excellent work.
- Great progress for the level of funding.
- Much progress made since last year.

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

This project was rated **3.40** for technology transfer and collaboration.

- Great enhancement over prior years.
- Significant expansion of the list of collaborators. Great progress!
- More work needed with stack developers and component suppliers (membranes and electrodes).

Question 5: Approach to and relevance of proposed future research

This project was rated **3.40** for proposed future work.

- Look forward to adding chemical composition capability.
- Endorse future directions on GDL structure studies.
- Must expand effort and scope!
- Need to increase/continue funding for this project. Extremely valuable tool for long term stability/failure mechanisms.
- More focus on analyses of cell components as a function of: temperature, gas feed rates (STOICS), cell potential, cell current density, humidification, flow field configuration, electrode type, GDL type, cell test hours.

Strengths and weaknesses

Strengths
- This team learned from the reviewer's comment last year and is now well connected with stakeholders to make this tool useful. Good job.
- Good study in correlating images with physical performance.
- Solid team, knowledgeable, willing to attack the more difficult issues.

Weaknesses
- Need to pay attention to how the "network" structure changes over aging. It could be important with respect to flooding and H_2 crossover. Nafion degradation needs to be studied.
- Should reach out with other analytical techniques such as, SEM, XRD, etc., to cross-compare TEM images.

Specific recommendations and additions or deletions to the work scope

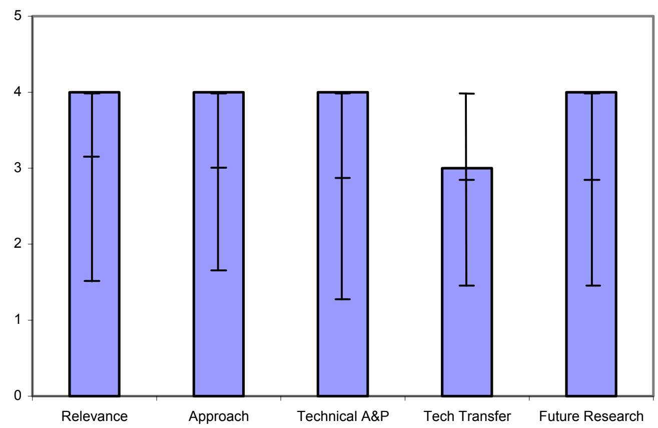
- Analyze X-Y planes to identify "hot spots" for membrane/electrode failure and then perform detailed high resolution images around the failure mode.
- Increase scope to address membrane degradation issues, ionomer degradation issues, lifetime/catalyst screening.

Project # FC-46: Stack Durability on Hydrogen and Reformate
Borup, Rodney; Los Alamos National Laboratory

Brief Summary of Project

In this project, Los Alamos National Laboratory (LANL) will identify and quantify factors that limit PEMFC durability by measuring property changes in fuel cell components during long term testing (membrane-electrode durability, electrocatalyst activity and stability, gas diffusion media hydrophobicity, bipolar plate materials, and corrosion products) and developing and applying methods for accelerated and off-line testing.

Overall Project Score: 3.80



Question 1: Relevance to overall DOE objectives

This project earned a score of **4.00** for its relevance to DOE objectives.

Question 2: Approach to performing the research and development

This project was rated **4.00** on its approach.

- The team seems to have the big picture well understood, which consequently elevated its capability to do this analytical focused project.

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

This project was rated **4.00** based on accomplishments.

-

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

This project was rated **3.00** for technology transfer and collaboration.

-

Question 5: Approach to and relevance of proposed future research

This project was rated **4.00** for proposed future work.

-

Strengths and weaknesses

Strengths
- Important work about durability. Excellent project execution with comprehensive set of tools.

Weaknesses

- Did not show any collaboration outcome even with LANL group.

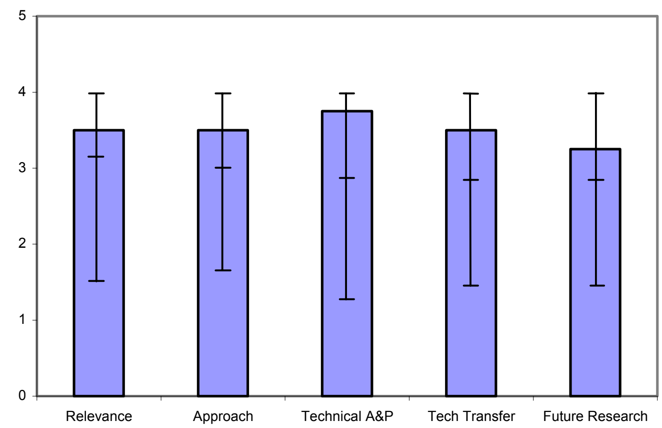
Specific recommendations and additions or deletions to the work scope

Project # FC-47: Direct Methanol Fuel Cells
Zelenay, Piotr; Los Alamos National Laboratory

Brief Summary of Project

This Los Alamos National Laboratory (LANL) project on Direct Methanol Fuel Cells (DMFCs) includes: determining the impact of Ru crossing over the membrane on the oxygen reduction kinetics at the DMFC cathode; developing methods for synthesis; demonstrating new unsupported DMFC cathode catalyst with average particle size reduced by at least 40% and performance superior to the best commercial cathode catalysts; and quantifying losses in the active surface area of the anode and the cathode over at least 200 h of DMFC operation.

Overall Project Score: 3.50



Question 1: Relevance to overall DOE objectives

This project earned a score of **3.50** for its relevance to DOE objectives.

- Appears the overall plan stresses H_2 as a fuel overall. However, military applications may need liquid fuel.
- How can you argue with their advancements in portable power application of DMFC?
- Project has strong relevance if DOE has a sustained focus on portable systems. Project points to nearer-term realities.

Question 2: Approach to performing the research and development

This project was rated **3.50** on its approach.

- Good integration of catalyst membrane MEA work.
- Too product oriented (stack). Focus on technical fundamentals of key components.
- Can't argue with success.
- R&D approach is holistic with focus on relevant areas: electrocatalysts, membranes/MEAs, and stack improvements (integration).

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

This project was rated **3.75** based on accomplishments.

- Continuing this group's tradition of identifying the core problem and providing a solution that achieves milestones.
- Good but not enough depth in the "whys." Why the stack development? Work on electrodes, membranes.
- Excellent technical progress.

- Impressive improvements in stack integration (practical) as well as in fundamental understanding of remaining challenges (basics), e.g., Ru migration issues, durability, membrane structural components.

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

This project was rated **3.50** for technology transfer and collaboration.

- Maintains premier leadership in leading collaboration partners on state-of-the-art DMFC components/systems.
- Good transfer of technology.
- Excellent use of outside collaborators.
- Need to find stronger industrial partners who could capitalize on impressive work at National Lab level.

Question 5: Approach to and relevance of proposed future research

This project was rated **3.25** for proposed future work.

- Disagree with development of new catalysts. LANL appears to have numerous commercial and university collaborators to do that task.
- Focus on fundamentals. Develop stacks for analytical purposes only.
- Many obstacles to DMFC commercialization have been addressed and plan will continue this advancement.
- Key areas of deficiencies well-defined.

Strengths and weaknesses

Strengths
- Continue to be the pioneer in new materials and implementation of these materials in DMFC.
- Group knows the technical issues. Can build on knowledge base with units at Ball Aerospace.
- Excellent understanding of key issues of DMFCs with respect to durability and catalyst and membrane optimization and application of this understanding to build real working stacks.
- Very solid progress on many fronts, including a serious attempt to move towards practical deployment. Balanced, fundamental work along with practical developments. Good work on catalyst dispersion improvement.

Weaknesses
- Should LANL start catalyst preparation/research? Only if industry or universities are lacking in this key area. I believe LANL role should be in defining what is needed in the catalyst and letting others proceed.
- Too prone to hardware development.
- Needs more funding and better industrial partners.

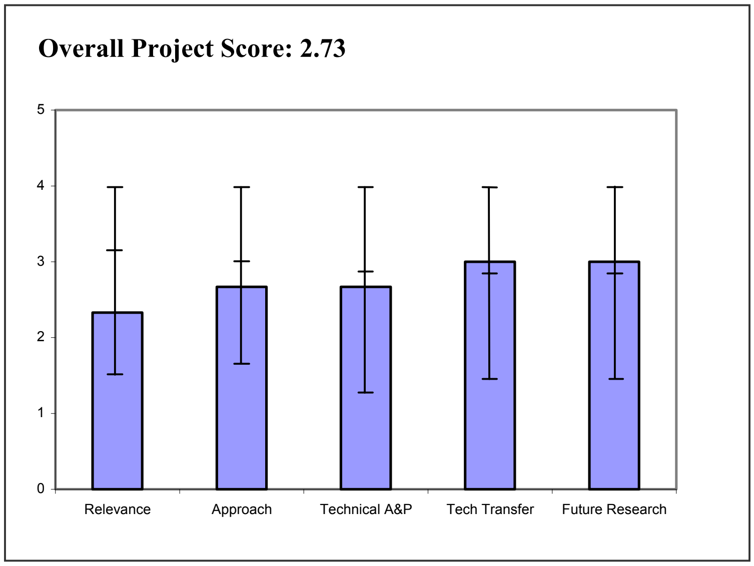
Specific recommendations and additions or deletions to the work scope

- DMFCs are not commercial and are unknown if "further ahead" or "further behind" PEMFCs. Yet portable applications are key. Recommend expansion of funding efforts.
- Perhaps become involved in high temperature membrane effort -- long term, but could be particularly advantageous to increasing anode kinetics. Apply TEM methods to understanding durability issues (as with PEM).

- Ensure that DOE sustains a program that focuses also on portable applications. Continue work to reduce catalyst loadings in DMFC (determine "limits" to how low?). Try to understand the mechanism of Ru "cross-over."

Project # FC-48: Modeling and Control of a Solid Oxide Fuel Cell Auxiliary Power Unit

Khaleel, Mo; Pacific Northwest National Laboratory



Brief Summary of Project

This Pacific Northwest National Laboratory (PNNL) project provides SOFC-based APU development with 1) control algorithms to optimize fuel efficiency and operating life, and 2) models for stack response and structural failure under dynamic loading. Controls work includes developing dynamic system models, determining typical APU usage patterns, collecting electrical usage data from a working truck, and designing control algorithms to optimize fuel efficiency and operating life. Shock and vibration tasks are identifying failure modes under characteristic dynamic loading, determining guidelines for durable SOFC/APU systems, measuring truck excitations, experimentally validating the models, and defining requirements for APU isolation.

Question 1: Relevance to overall DOE objectives

This project earned a score of **2.33** for its relevance to DOE objectives.

- Areas for heavy duty trucks might have merit, but are not part of Hydrogen Fuel Initiative. Developing SOFC might be a component, however.
- Not clear how this project affects the Hydrogen Fuel Initiative directly.

Question 2: Approach to performing the research and development

This project was rated **2.67** on its approach.

- Such model development is critical. Should expand model elements to include entire system.
- If you want to put SOFC APUs into trucks, these activities are important.
- Correlating material stresses from thermal/mechanical conditions of stack with the mechanical stresses of application is reasonable.

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

This project was rated **2.67** based on accomplishments.

- Good start. Lessons learned should lead to more advanced modeling.
- Shock and vibration models on components alone need to be extended to the entire APU if you want useful data.
- Seems to have made good progress in collecting real vibration data and modeling thermal stresses.

Question 4: Technology transfer/collaborations with industry, universities and other laboratories
This project was rated **3.00** for technology transfer and collaboration.

- Have good collaboration.

Question 5: Approach to and relevance of proposed future research

This project was rated **3.00** for proposed future work.

- Not clear why optimization of fuel efficiency equation is necessary.

Strengths and weaknesses

Strengths
- Gaining good understanding of thermal and vibrational shock associated with solid oxide APU.

Weaknesses
- Unclear how this fits in the Hydrogen Program.

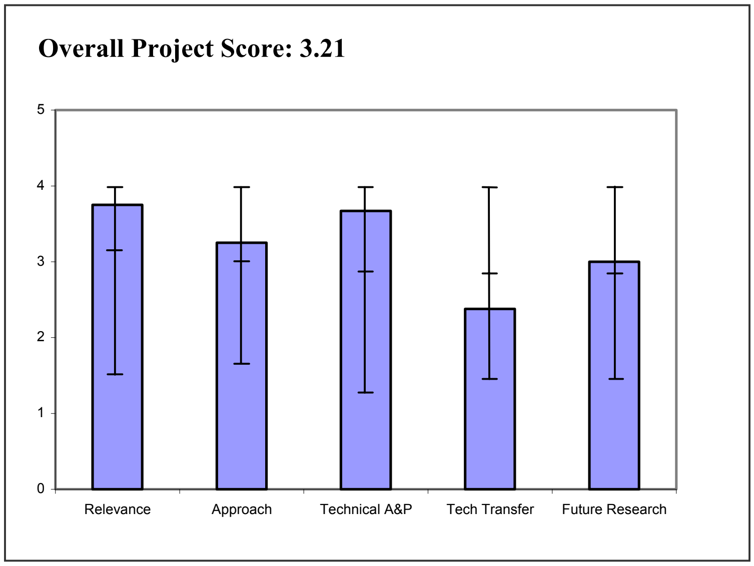
Specific recommendations and additions or deletions to the work scope

- Determining failure modes should be key focus.
- May want to expand into codes and standards that would be available for APU vendors.

Project # FC-49: Bipolar Plate-Supported Solid Oxide Fuel Cell "Tuffcell"
Myers, Deborah; Argonne National Laboratory

Brief Summary of Project

Argonne National Laboratory (ANL) is developing an improved solid oxide fuel cell (SOFC) for auxiliary power units (APUs) and other portable applications, addressing the following SOFC issues: startup time, durability to temperature cycling; vibration and shock resistance; and materials and manufacturing cost.



Question 1: Relevance to overall DOE objectives

This project earned a score of **3.75** for its relevance to DOE objectives.

- This concept could revolutionize SOFC design.
- Addresses many DOE technical barriers and targets. In particular, start-up time & durability are significant challenges here.
- If successful, an enabling approach for highly reliable SOFCs for transportation applications.

Question 2: Approach to performing the research and development

This project was rated **3.25** on its approach.

- PI needs to work with stack developers to better understand stack construction and gas manufacturing.
- Fabrication approach addresses performance and manufacturability.
- Novel fabrication approach. Not convinced that controlled atmosphere sintering is low-cost and/or scalable. Focus on relatively small cell components.

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

This project was rated **3.67** based on accomplishments.

- Progress is very good in relation to the small amount of funding.
- Progress in meeting cost target demonstrated. Addressed a lot of issues for stack development, but test not successful. More issues to address at stack level. Progress in meeting power density goal.
- Making great progress, but not relevant to my automotive interests.
- Power density needs to be stated at 0.7 volts. Usable power densities lower than quoted. Demonstrated toughness. Power density needs to be increased. Disappointing stack test results, but this is extremely challenging.

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

This project was rated **2.38** for technology transfer and collaboration.

- PI needs to talk with SOFC developers and other stack engineers.
- Independent evaluation of samples by Motorola good. Could incorporate more expertise at stack/system level to overcome those problems.
- Good to see interaction with Motorola. However, the durability 5000 hour target implies automotive applications. Is Motorola the best/appropriate partner?
- Collaboration w/organizations interested in supporting cell/stack testing work may help.

Question 5: Approach to and relevance of proposed future research

This project was rated **3.00** for proposed future work.

- PI must move from single cell to 3-5 cell stacks to study gas manifolding and how to apply the needed stack holding (compression force).
- Need to pull in some expertise to help with stack issues, but great on cell development.
- Focus on improving power density. Testing of large area cells, testing under high fuel utilizations.

Strengths and weaknesses

Strengths
- Significant progress made, given relatively small budget.

Weaknesses
- Need successful scale-up/stack test to attract additional non-DOE investment.

Specific recommendations and additions or deletions to the work scope

- Seek advice from stack engineers.
- Reconcile 5000 hr durability target APU with Motorola application.
- Increase cell area-minimum 100 m^2/gram. More detailed cost model to confirm cost advantages would be useful-materials cost by itself is insufficient.

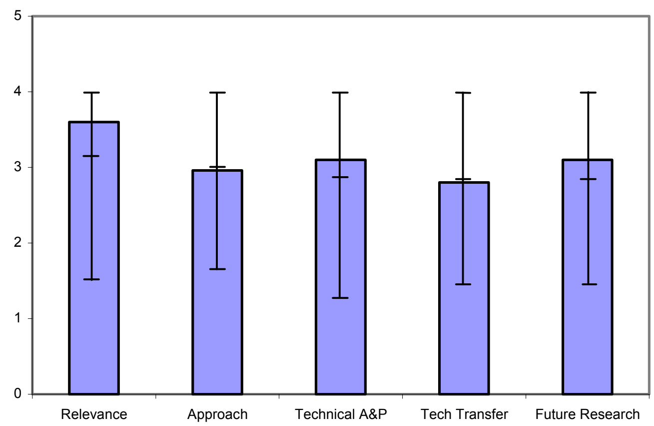
Project # FC-P1: Fuel Cells Vehicle Systems Analysis

Markel, Tony; National Renewable Energy Laboratory

Brief Summary of Project

For this project, the National Renewable Energy Laboratory (NREL) will provide DOE and industry with technical solutions and modeling tools that accelerate the introduction of robust fuel cell technologies, quantify benefits and impacts of Hydrogen Program development efforts at the vehicle level (both current status and future goal evaluation), and highlight potential system level solutions to technical barriers.

Overall Project Score: 3.11



Question 1: Relevance to overall DOE objectives

This project earned a score of **3.60** for its relevance to DOE objectives.

- Need these types of modeling skills and integrated approach to assess development pathways and to select areas for future investment.
- Provides a useful and needed tool to assess the impact of Hydrogen Program technical targets on overall vehicle performance. An excellent tool for public domain access and communication of program impact.
- Need to delete score. Project addresses critical systems issues.

Question 2: Approach to performing the research and development

This project was rated **2.96** on its approach.

- Integrates models at different levels, stack, component, system, vehicle, and drive cycle to assess performance against targets. Modular so individual models can be improved.
- The team seems well aware of the key challenges and has developed a good tool to address these
- Good forward thinking on projecting requirements for "robustness" of the FC operation across multiple ambient conditions.
- Perhaps a bit too much emphasis on making general modeling tools widely available (in the end, the tool developer is best equipped to make good use of it anyway), but also don't want to design specific components for individual customers. Increased depth of analysis of individual questions (not specific components) could improve the impact of this project.

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

This project was rated **3.10** based on accomplishments.

- Focused on critical area of water and thermal management. Calibrated against vehicle data. Evaluation of new concept-O_2 enrichment to improve peak power. Vehicle performance over range of environments important to understand.

- The accomplishments in tool generation are very strong. The applications shown are less clearly so.
- Good work for the budget.
- Useful study of whether DOE targets would lead to available vehicle. Questions for study seem to be those that the model can handle, not necessarily the most technologically-pressing. Supercharged stack analysis did not seem to take into account the difficulties of providing enriched oxygen. Treatment of water in stack will have to become more complete before it can capture experimentally-predominant effects

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

This project was rated **2.80** for technology transfer and collaboration.

- Tools developed clearly relevant to teams but I did not ask the extent or level of interactions that Tony had with industry. Not highlighted in poster.
- Excellent public interaction. Interaction with ANL modeling efforts and the FreedomCAR Systems Engineering & Analysis Tech Team needs further definition.
- Have provided valuable information on automotive drive cycles (and their effects) to a number of projects.

Question 5: Approach to and relevance of proposed future research

This project was rated **3.10** for proposed future work.

- Need to undertake future work in context of interactions with DOE program managers and industrial teams. Design tool for increasingly complex systems (hybrids) and effect of environment. Valuable tool.
- Investigating more extreme environments (altitude, desert environments) is a good next step.
- Thermal/water management could be very useful to FCV. Not sure that oxygen power boost work is applicable.
- Future plans weren't made entirely clear. Plan to look at sensitivity of performance to expected ranges of operating conditions is good.

Strengths and weaknesses

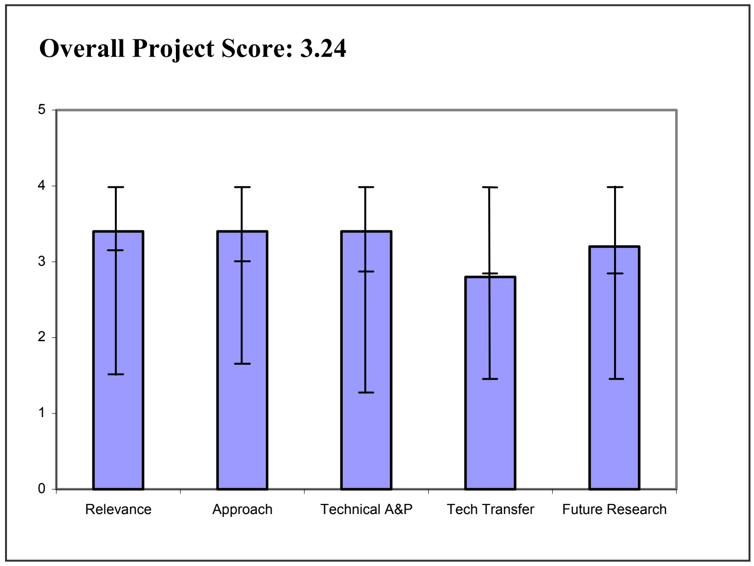
Strengths
- Excellent modeling skills and integration of tools into a useful package targeted to answer critical questions.
- Very strong modeling and analytical skills and tools. Clear desire to work with the FC community.
- Quality of poster/talk in terms of content vs. "flash" has improved greatly this year.
- Connect vehicle drive cycles analytically to a range of important questions.

Weaknesses
- Potential lack of access to vehicle designs and performance data to calibrate model performance.
- Effects that are susceptible to modeling are not always those that exert predominant control.

Specific recommendations and additions or deletions to the work scope

- Increase interactions with industry teams and/or presentation of comparisons of model results and actual data.
- Recommend continued funding. Extend analyses to real-world operation to further guide tech targets and work. Must avoid a design that is too much a "cycle-beater" and instead comprehend real-world acceleration, grade and trailering, warm-up, and extreme environment. Suggest investigation of temperature vs. time after cold start on various drive cycles for various ambient temperatures -- to drive an understanding that high-T membranes must also be robust, efficient at lower temperature
- If supercharged stack (oxygen enrichment) is to be carried forward, check sensitivity of results, to mass transfer resistance of cell and add realistic analysis of what equipment and energy would be required to do the oxygen enrichment.

Project # FC-P2: Cost Analyses of Fuel Cell Stacks/Systems
Carlson, Eric; TIAX LLC



Brief Summary of Project

This TIAX LLC project provides cost and manufacturing analysis. Specific teaks are: to develop an independent cost estimate of PEMFC system costs including a sensitivity analysis (operating parameters, materials of construction, manufacturing processes); identification of opportunities for system cost reduction through breakthroughs in component and manufacturing technology; and annual updates to the cost estimate for the duration of the project. The FY04 focus is on the costing of compressed hydrogen storage.

Question 1: Relevance to overall DOE objectives

This project earned a score of **3.40** for its relevance to DOE objectives.

- Cost modeling can help to identify critically costly components.
- A project of this sort is absolutely necessary for the Hydrogen Program set, to provide an independent assessment of the likely costs associated with PEM fuel cell technologies. The focus on compressed hydrogen storage is particularly appropriate this year.
- Cost estimate for CH_2 tank system consistent with Directed Technologies estimate.
- Knowledge of cost is critical for comparing progress to targets. Would be useful to benchmark current industry status (such as Plug Power's $3K/kW) against your cost projections from a few years ago to check forecasting accuracy.

Question 2: Approach to performing the research and development

This project was rated **3.40** on its approach.

- TIAX is taking a component-by-component (bottom-up) approach for materials and processing.
- The authors considered variations of both 5000 and 10,000 psi composite tank structures, with carbon fiber identified as the most costly item. Tank manufacturing methods from the natural gas industry provided the basis for projecting costs of each step. The authors considered realistic scenarios for an 80 kW_e system, which included coupling with a battery.
- Detailed component/system manufacturing cost estimates/assumptions.
- This project relied pretty heavily on a few key assumptions of tank L/D ratio, carbon fiber choice, etc. Recommend getting industry (auto) feedback on these assumptions and impact.

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

This project was rated **3.40** based on accomplishments.

- Preliminary costing of compressed hydrogen storage systems completed.
- The authors showed quite conclusively that, though sufficient hydrogen could be stored to meet interim targets, the cost would be about double those targets. Meeting long range price and specific energy targets was shown to be much more remote.
- Results are interesting -- indicate that compressed gas approach still has 2-3x cost compared to DOE targets.

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

This project was rated **2.80** for technology transfer and collaboration.

- Tank developers need to be involved -- future work.
- The authors did collaborate with ANL in estimating system requirements, and presumably with composite tank manufacturers before beginning cost assessments. Feedback from compressed hydrogen storage systems developers is planned for the future.
- Interaction with tank developers is planned to vet the cost model assumptions.
- Would like to see significantly more industry involvement (review) of this project.

Question 5: Approach to and relevance of proposed future research

This project was rated **3.20** for proposed future work.

- Compressed hydrogen storage developers will be consulted for refinement of preliminary results. Overall hydrogen fuel cell system cost model will be updated with final hydrogen storage system costs.
- The authors would seek feedback from compressed hydrogen system developers on current work, and would shift their efforts to an update of cost projections related to direct hydrogen production. Project appears to be in final year of five-year contract.
- Update full system cost estimate.

Strengths and weaknesses

Strengths
- Project has provided valuable, independent review of technologies being developed by Hydrogen Program. Demonstrated strong technical basis for cost projections. Showed that compressed hydrogen will have difficulty meeting interim cost targets, let alone ultimate cost and specific energy targets.
- Cost estimate built on referenceable assumptions. No proprietary considerations.
- Despite the uncertainties involved, cost is an important thing to be analyzed.

Weaknesses
- None noted.
- Not clear whether costs include mark-up/profit.
- Results of nearly all cost analyses on fuel cells and their system have never been met. Not even close to ballpark.
- Results may depend too heavily on some of the key assumptions that do not appear to be from industry.

Specific recommendations and additions or deletions to the work scope

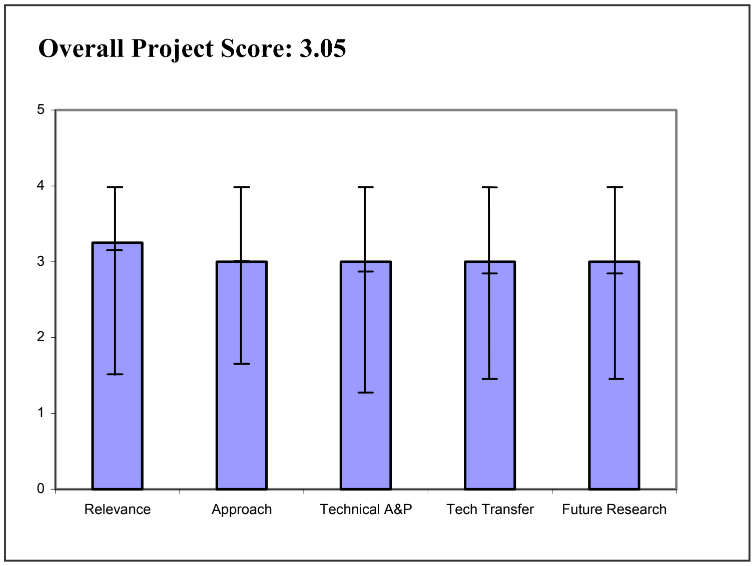
- Analysis of physical and chemical hydrogen storage options would be useful, including carbon nanotubes, sodium alanates, sodium borohydride, aminoborane, others.
- Complete full system cost estimate and change full cell operating conditions to standard 80C, 1.5-2 atm.
- Recommend holding a workshop with key industry stakeholders to discuss assumptions and results.

Project # FC-P3: Development of Novel CO_2-Selective Membrane for H_2 Purification

Ho, Winston; Ohio State University

Brief Summary of Project

This Ohio State University project is producing enhanced H_2 gas stream with <10 ppm CO at high pressure used for reforming, to overcome Fuel-Flexible Fuel Processors Barrier L (H_2 Purification/CO Clean-up) and achieve target <10 ppm CO in the product stream.



Question 1: Relevance to overall DOE objectives

This project earned a score of **3.25** for its relevance to DOE objectives.

- Technique will lead to higher efficiencies in fuel cells - good.
- Important goals are addressed.
- Supports development of cost-effective and volumetrically efficient fuel processors.
- Project not only helps to improve the production and purification practices but assists in CO_2 treatment methods.

Question 2: Approach to performing the research and development

This project was rated **3.00** on its approach.

- Membrane separation science is a good approach. Needs to continue concept development with life and stability to prove out.
- Approach is valid.
- Novel approach with potential to downsize co-reduction components. Dependent on availability of suitable low-temperature WGS catalysts (that do not exist).
- Search for higher temperature materials that exhibit the same CO_2 transfer/H_2 impermeable properties is good.

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

This project was rated **3.00** based on accomplishments.

- Life and stability?
- Project milestones were met, work done on other/impurities such as H_2S; excellent results.
- 10 ppm CO level requires excessively low space velocities or separate methanation step. Capabilities of membrane not matched to WGS catalysts. Not demonstrated for syngas feeds with high CO content.
- Although improvements have been made in operating at higher temperature, rate of progress needs to increase in rate and alternative materials, etc., need to be identified.

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

This project was rated **3.00** for technology transfer and collaboration.

- Time to broaden field of use.
- Various interactions and attempts to license.
- Reasonable for university project. No evidence of collaboration with catalyst suppliers.
- Several companies have been actively involved. More interaction with fuel processor designers could be beneficial.

Question 5: Approach to and relevance of proposed future research

This project was rated **3.00** for proposed future work.

- Should emphasize cost and failure modes.
- Logical extension of work plan for the remainder of the year ok.
- Plans appropriate. Is focus on methanation appropriate? Better to achieve better match between membrane and catalysts? Higher space velocities.
- Focus on polymer performance improvements for operation at higher temperature and not on catalyst effort.

Strengths and weaknesses

Strengths
- Good team approach.
- Novel approach. Membrane development progressing well. Side benefit of reducing H_2S content.
- Understand polymer and CO_2/H_2S transfer mechanism

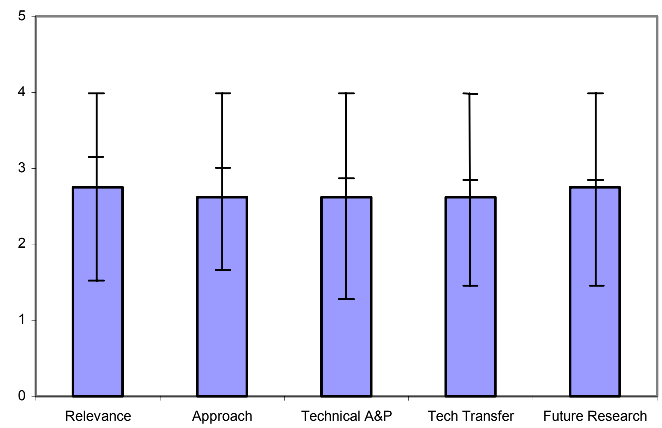
Weaknesses
- Needs better low temperature-WGS catalyst or higher-temperature membrane. Is success dependent on materials breakthrough?
- Apparent limitation of current polymer system in max temperature and CO_2 transfer rate.

Specific recommendations and additions or deletions to the work scope

- Focus on increasing space velocities.
- Membrane temperature of operation and effective flow rates need to be increased.

Project # FC-P4: Microchannel Reformate Cleanup: Water Gas Shift and Preferential Oxidation
TeGrotenhuis, Ward; Pacific Northwest National Laboratory

Overall Project Score: 2.67



Brief Summary of Project

Overall objectives of this Pacific Northwest National Laboratory (PNNL) project are to apply microchannel architectures where appropriate in fuel processing for transportation, stationary, and portable applications to reduce size and weight, improve fuel efficiency, and enhance operation, and to develop a prototype microchannel-steam-reforming fuel processor at 2 kW_e scale that will meet DOE performance targets when scaled up to 50 kW_e. Specific tasks include demonstration of 90% CO conversion in a single-stage WGS reactor that scales to less than 3 liters at full-scale and determination as to whether microchannel architecture provides opportunities for size and weight reduction for PROx reactor.

Question 1: Relevance to overall DOE objectives

This project earned a score of **2.75** for its relevance to DOE objectives.

- If successful, both the size of reactors and cost can be reduced.
- Microchannel reactors could be an important component in the hydrogen economy. This presentation does not present much new that might contribute to that.
- Helps to advance improvements in hydrogen production processes.

Question 2: Approach to performing the research and development

This project was rated **2.62** on its approach.

- Are the catalysts correctly loaded for WGS differential reactor? No CFD modeling information for the WGS & PROx reactors. Not enough data presented especially for differential WGS. How to control temperatures for WGS is not addressed.
- Helping to establish limits of usefulness of microchannel technology.
- Seems to be a review of the microchannel activities. Very little reactor performance information.
- Appropriate for initial proof of concept.

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

This project was rated **2.62** based on accomplishments.

- Encouraging progress, but durability remains an unproven target.

- WGS 2KW$_e$ reactor is very compacted. Kinetic equation for WGS differential reactor is useful. The result of microchannel PROx reactor by combinations of 1st & 2nd end stages is promising (10,000 ppm --> <10 ppm at 93,000/h).
- Creditable progress in last year -- particularly in power density increases.
- Should get thermal profile with respect to flow rates and conversion of CO.

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

This project was rated **2.62** for technology transfer and collaboration.

- More collaboration with fuel cell/fuel processor developers is necessary. A lot of companies like Nuvera have done a lot of work in these areas.
- Little interaction with transportation groups -- credibility issues?

Question 5: Approach to and relevance of proposed future research

This project was rated **2.75** for proposed future work.

- Durability tests are necessarily needed to establish solid technologies of CO cleanup for real fuel processors. Scale-up from 2 kW$_e$ to 50 kW$_e$. Integration with other components as key parts of real fuel processors.
- Durability of complete integrated system under repeated shut-down/restart still yet to be demonstrated.
- Not much vision or direction apparent.
- Need more information on activity and performance during startup conditions with varied H_2O, temperature and flows.

Strengths and weaknesses

Strengths
- Good approaches to reduce the size and cost of the CO cleanup reactors. Potentially, "quick start-up" for on-board fuel processor probably will benefit from these kinds of technologies if successful.
- Promise of achieving power density targets appears good -- but still only based on projections!
- The graphics for this poster were done very well. Mr. TeGrotenhuis presented his work professionally.
- Excellent capabilities for microchannel fabrication and testing in hardware development.

Weaknesses
- Durability is still missing. More data are needed for convincing that these are solid technologies.
- Need to progress beyond initial performance testing of microchannel testing and demonstrate both reliability and durability of operation -- otherwise credibility still in doubt.
- Catalyst emplacement. Range of operating conditions.

Specific recommendations and additions or deletions to the work scope

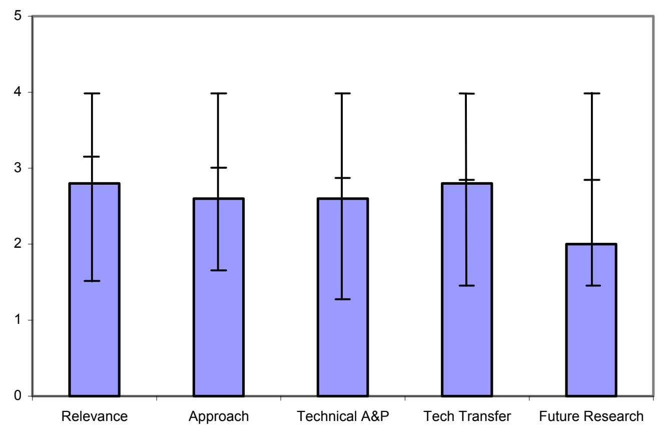
- More collaboration with fuel cells/fuel processor developer. Durability tests. Make a better approach to correlate theory and tests by different tools such as CFD modeling.
- Combine all microchannel projects into one focused effort, then validate or terminate!
- Expand operating tests to include startup conditions and various transients before coupling with primary reformer, i.e., off-design conditions. Improve catalyst life -- examine thermal profile relationship to catalyst activity (both performance and destruction).

Project # FC-P5: Effects of Fuel Composition on Fuel Processing
Kopasz, John; Argonne National Laboratory

__Brief Summary of Project__

For this project, Argonne National Laboratory (ANL) will determine how fuel composition affects reformer performance. ANL will determine how changes/variations in composition affect performance and how tailoring the composition can increase performance, find additives that can increase performance, determine how molecular size affects reforming, and study reforming of two renewable fuels.

Overall Project Score: 2.56



__Question 1: Relevance to overall DOE objectives__

This project earned a score of **2.80** for its relevance to DOE objectives.

- Since no H_2 infrastructure exists, reformed H_2 is needed to enable FC industry.
- Important to understand effects of fuel complexity on reforming.
- Important project but by no means critical.
- "Focus on new enhancers," there should be focus as well on enhancers are serious candidates as fuel additive in terms of costs, availability, complexity of production process, and mass production.

__Question 2: Approach to performing the research and development__

This project was rated **2.60** on its approach.

- Problems clearly outlined and approach well thought-out. Nice job in addressing last year's reviewers' comments.
- While approach is to look at complex fuels, little data shown. Not doing a through job of evaluating matrix. Must have a systematic approach.
- Solid. Improve mechanistic study -- start with simple ones like "what are the reaction steps and rates?"
- Systematic from research point of view, but missing availability aspects.

__Question 3: Technical accomplishments and progress toward project and DOE goals__

This project was rated **2.60** based on accomplishments.

- Very good progress to date.
- Very few tangible results in 3-4 years (started '00).
- No real understanding of how fuel complexity affects reforming…just a few empirical observations.
- No indication of attempt to look at "synthetic" mixtures with controlled molecular weights.

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

This project was rated **2.80** for technology transfer and collaboration.

- Assembled strong team.
- Collaboration apparent but not defined.

Question 5: Approach to and relevance of proposed future research

This project was rated **2.00** for proposed future work.

- Does it make sense to continue producing hydrogen from hydrocarbons? Industry should move towards renewable H_2 production strategies.
- Why ethanol as an additive when ethylene is a problem. Unclear that work focuses on understanding results…just moves to a new system.

Strengths and weaknesses

Strengths
- Good progress. Well-planned research.
- Important project to reach real fuel reforming!

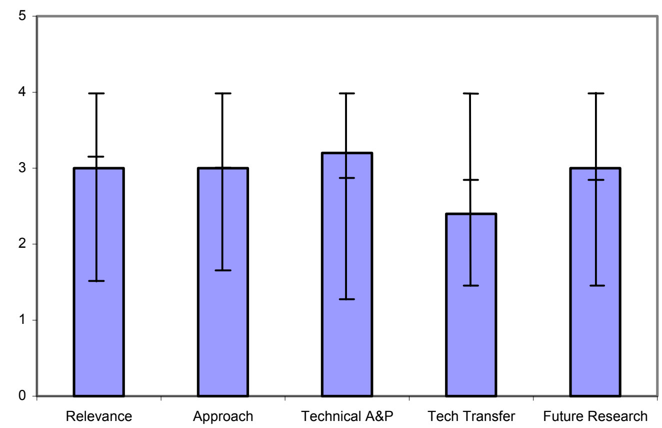
Weaknesses
- Hydrocarbon fuels still required. Still have substantial cost and performance hurdles to overcome.
- No systematic approach to understanding effects of complex fuels on reforming.
- Need to conduct experiment/modeling work to gain mechanistic understanding.

Specific recommendations and additions or deletions to the work scope

- Due to complexity of fuel processing, perhaps $$ should be directed to H_2 storage and not localized generation.
- DOE should focus H_2 production money on renewable sources of H_2.
- Must develop detailed testing matrix to follow through with matrix. Tedious, but critical. Add modeling to this. Contact ONR to discuss their MURI program looking at hydrocarbon oxidation and reforming.
- Computer modeling. Are there any new classes of gasoline additives that improve reforming? A scouting effort built on the learnings so far would give the project new life and importance.

Project # FC-P6: Development of Advanced Catalysts for Direct Methanol Fuel Cells
Narayanan, S.; Jet Propulsion Laboratory

Overall Project Score: 2.92



Brief Summary of Project

The objective of this Jet Propulsion Laboratory (JPL) project is to develop catalysts for direct methanol fuel cells with substantially reduced amounts of noble metal loading. Specifically, JPL will try to reduce noble metal loading below 0.5 mg/cm2 and develop non-noble metal anode catalysts.

Question 1: Relevance to overall DOE objectives

This project earned a score of **3.00** for its relevance to DOE objectives.

- Aligned well with a basic need in DMFC -- more catalyst understanding.
- Technique could develop faster catalyst development.
- I believe that JPL and Narayanan have the correct approach to develop a more active PEMFC anode catalyst.
- If DOE maintains focus on portable systems, this project has solid relevance because DMFC systems are appropriate for portable applications.
- DMFC is only moderately relevant.

Question 2: Approach to performing the research and development

This project was rated **3.00** on its approach.

- PI intentionally left out MEA data -- but I think inclusion of this data would help.
- Good advancement of the technique. Time to focus on new catalyst systems.
- Adequate results have been generated to provide more support for this work.
- Search for reduced precious metals content is needed. Combinatorial efforts are used extensively. Caution: states produced by such methods may be metastable.
- Combinatorial style approach is very intriguing.

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

This project was rated **3.20** based on accomplishments.

- Great progress in precious metal reduction.
- Add criteria for catalyst screening. Begin specific screening studies.
- I believe the progress made far exceeds the small funding ($100K). Please increase this if possible.
- Standard characterizations must be supplemented by tests in fuel cells. Need to quickly down select compositions and determine stability.
- With modest resources, it seems that the technique has been developed to a mature point. Ready to be adapted to solve important problems.

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

This project was rated **2.40** for technology transfer and collaboration.

- Very few listed. May be worthwhile to contact a "DMFC" company.
- Now is the time to start working with DMFC MEA developers.
- OK for such a small funded program.
- Given limited budget, the program is handicapped in its ability to collaborate more widely. Creativity/innovations needed.
- Seeks to work with outside entities.

Question 5: Approach to and relevance of proposed future research

This project was rated **3.00** for proposed future work.

- Include translation to high surface area catalysts -- maybe some of the underlying theory will change.
- Program plans are sound.
- Intentions, programs are appropriate. Need scale-up and actual fuel cell tests to determine whether heat of reaction could alter catalyst phase.
- This project should be given more resources.

Strengths and weaknesses

Strengths
- Great approach to adding more fundamental understanding to DMFC anode catalysts.
- Good technique development and follow-through.
- Methanol fuel cells use an easily transported H_2 media. DOE has too much focus on H_2 storage and is ignoring a great medium for H_2 storage and transport -- CH_3OH.
- Solid, sustainable approach using combinatories (but must determine whether compositions are lowest-energy state -- are these metastable?).
- Approach, good PI.

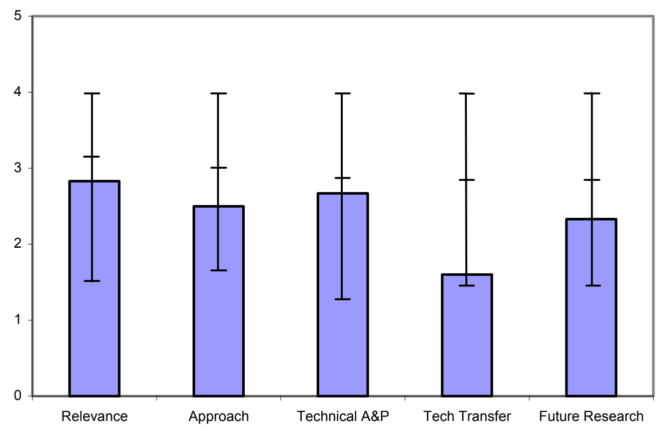
Weaknesses
- Would have preferred to see actual MEA comparisons to link "theoretical" findings to actual results -- not only analytical results.
- Would appropriate, down-selected, compositions be scale-uppable? Need fuel cell test data to compare with fundamental characterizations.
- Level of effort.

Specific recommendations and additions or deletions to the work scope

- Increase funding support in this area --> catalysts for DMFC.
- Funding level must be improved, if DOE intends to support portable applications.
- Expand program to allow collaboration/integration into larger catalysis-oriented efforts.

Project # FC-P7: Non-Precious Metal Cathode Electrocatalysts (new project)
Myers, Debbie; Argonne National Laboratory

Overall Project Score: 2.39



Brief Summary of Project

This Argonne National Laboratory (ANL) project will develop a non-precious metal cathode electrocatalyst for polymer electrolyte fuel cells, promoting the direct four-electron transfer with high electrocatalytic activity (comparable to that of Pt). The four-electron process is desirable due to its higher efficiency and non-corrosive product. Goals are to be chemically compatible with the acidic polymer electrolyte and low cost.

Question 1: Relevance to overall DOE objectives

This project earned a score of **2.83** for its relevance to DOE objectives.

- Low-cost catalysis options are required to enable FC industry; this program addresses these issues.
- Fair, because narrow focus on one critical barrier and limited budget.
- Very relevant towards the non-Pt/low-Pt/low-cost targets.
- Reduction of Pt metal costs is a worthwhile objective.

Question 2: Approach to performing the research and development

This project was rated **2.50** on its approach.

- As candidates fail performance validation, you remove them from the scope of project -- this allows focus on something that may work. Good scientific approach.
- Why are iron oxides being revisited yet again? Wide range of materials classes -- will anything besides electrochemical characterization be done? Metal centers attached to polymer backbone an interesting approach.
- Challenge of acid stability of spinels/perovskites. 3 very diverse approaches; might be better to focus on approach most likely to succeed.
- Duplicate work performed at other National Labs -- focus on carbides and nitrides probably more useful than on complex oxides.
- Choice of starting candidates and basis for them not well-defined thus making interpretation and value of results not clear.
- The approach does not appear original. Several researchers have attempted to identify ORR catalyst over last 20 years and it was not clear from presentation what was original in this work.

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

This project was rated **2.67** based on accomplishments.

- Switch to RDE measurements in perchloric acid not sulfuric acid. Good scientific fundamentals are basis of this project, so success can be easily defined and verified.
- New project, but validated electrochemical characterization methods. Initial results not very promising, but just getting started.
- Project just started. Work on technique development (RDE).
- Good baseline work and development of testing methods.
- The right tests for validation of equipment are being done, but seems to be slow. Priority of candidate catalysts for testing is not clear.
- Baseline reaction kinetics for Pt catalyst were well defined.

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

This project was rated **1.60** for technology transfer and collaboration.

- If you achieve success, how do you envision implementation in commercial systems?
- No collaboration.
- None indicated.
- Seems like project just started -- too early to have such, might benefit from interactions with LANL group.
- Need more collaboration with people experienced in electrocatalyst development.
- Did not see cooperative efforts with universities.

Question 5: Approach to and relevance of proposed future research

This project was rated **2.33** for proposed future work.

- Not much to build on yet -- addition of a modeling effort good.
- Better to focus limited resources on highest approach with highest probability of success.
- Focus on carbides and nitrides. Unlikely to be easy or achievable to stabilize metal oxides in acidic media, results to date discouraging. Fabrication of MEAs -- better to collaborate with someone with more experience.
- Prioritization of catalysts to be tested is needed to bracket the area/type of catalyst for focused effort.
- Not clear if original contributions are considered.

Strengths and weaknesses

Strengths
- Very good science-based program.
- Good history of materials research.

Weaknesses
- RDE measurements could be confounded by use of H_2SO_4. No scale-up contingencies have been proposed.
- Too diverse approach.
- Screening of catalysts for focusing and directing exploratory vs. detailed investigation has not been done.
- Well-traveled research area. No unique approaches identified. Need to team with universities.

Specific recommendations and additions or deletions to the work scope

- Fund this program at increased level to enable rapid evaluation of these new types of catalysts so industry can begin scaling up any new developed catalysts ASAP.
- Too soon to see if this project is on track.
- Select most promising approach and drop others. Leverage research by university interactions.
- Define a prioritization plan for screening and evaluating the different catalyst types.
- Not sure if funds are well spent: the transition metal catalyst approach is the topic of several R&D programs. Does DOE need so many programs? Consolidate efforts if possible. Form team to look at original approaches.

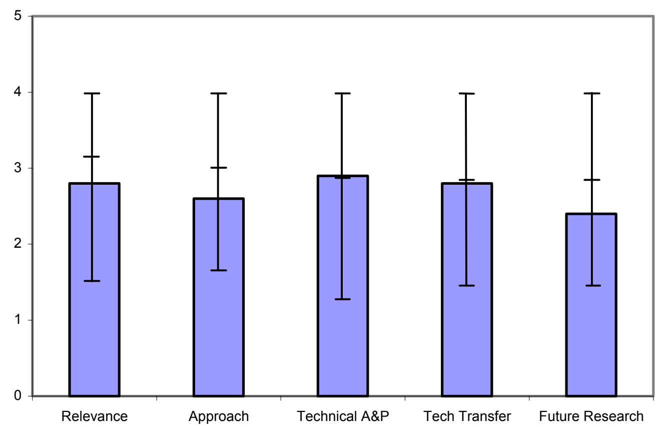
Project # FC-P8: Low-Friction Coatings and Materials for Fuel Cell Air Compressors

Ajayi, Oyelayo; Argonne National Laboratory

Brief Summary of Project

Argonne National Laboratory's (ANL) objective is to develop and evaluate low-friction and wear-resistant coatings and/or materials for critical components of air compressor/expanders being developed for fuel cells by DOE contractors. Efficiency, reliability and durability of such system are dependent on effective lubrication of critical components such as bearings and seals. Such components cannot be oil lubricated, since oil will contaminate fuel cell stacks.

Overall Project Score: 2.70



Question 1: Relevance to overall DOE objectives

This project earned a score of **2.80** for its relevance to DOE objectives.

- Very important niche often overlooked.
- Relevance is based on assumption that air compressors are needed (blowers, too, included in presentation).
- The program appears to support a small, minor issue for fuel cells.

Question 2: Approach to performing the research and development

This project was rated **2.60** on its approach.

- Based on written presentation, appears program is providing an analytical service -- not clear if expanding understanding of the needs of tribologically challenging materials.
- Good criteria for material selection.
- Approach does not question need for compressors; what if low-flow fans are needed for air feeds? Need to understand the melting points of the coatings (caused by surface roughness of substrates).
- Why wouldn't industry do this program for all compressor operations?

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

This project was rated **2.90** based on accomplishments.

- As a past reviewer, I note real progress towards achieving overall goals.
- Progress remains at property-level; needs to be integrated into device consequences. OK for a property evaluation program (but understand polymer degradation issues and gas-phase contaminants).
- Continue to show progress and meet objectives.

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

This project was rated **2.80** for technology transfer and collaboration.

- Real improvement over last year. Providing key information to partners.
- Extend discussion to other developers of air-feed systems beyond compressor companies. No blower companies mentioned.
- Making contacts with industry. Results were not on slides and should be. Is industry not included in this material?

Question 5: Approach to and relevance of proposed future research

This project was rated **2.40** for proposed future work.

- Would have liked an explanation of "direct hydrogen systems" for future work.
- Remains more a basic materials program. Must raise the bar into a device-in-system program. Must understand polymer chemistry.
- This program is at least 3 years old and should be transferred to industry for industry to use

.

Strengths and weaknesses

Strengths
- Developed outstanding methodology to guide selection process. Working with good partners -- making good efforts in technology transfer .
- Coating material characterization.
- Solid materials program.

Weaknesses
- Currently appears to be more empirical -- "try and see."
- Need to expand program to device level and how air composition may affect stacks. Expand base of collaborators -- name the blower companies.

Specific recommendations and additions or deletions to the work scope

- Has done a great job developing the method -- would it be within the scope of this program to develop the understanding behind why some coatings are more resistant to wear and low friction?
- Closer relationship with air compressor developer to transfer this technology.
- Work on chemistry beyond mechanicals (i.e., polymer rheology, polymer degradation at elevated temperatures).
- Terminate effort since program is 3 years old and should be transferred to industry.

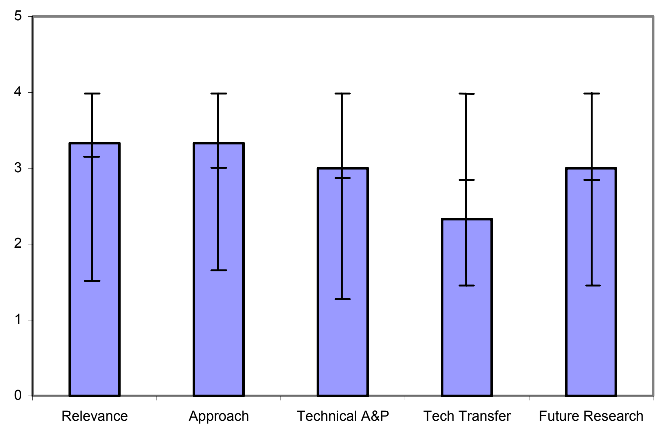
Project # FC-P9: Montana PEM Membrane Degradation Study

Spangler, Lee; Montana State University

Brief Summary of Project

Montana State University's overall objective is to determine membrane degradation mechanisms and how to prevent or mitigate them. Specific goals are to determine changes in membrane material properties as degradation occurs, determine if any electrical properties can act as a signature of developing degradation, and investigate the potential of advanced control systems to prevent degradation problems.

Overall Project Score: 3.00



Question 1: Relevance to overall DOE objectives

This project earned a score of **3.33** for its relevance to DOE objectives.

- Understanding the mechanism for MEA failure is critical for improving reliability of PEMFC.
- Success in mitigating membrane degradation will greatly increase durability target. So far, not too much success shown in preventing degradation or why degradation occurs.
- Durability is a major barrier to fuel cell commercialization.

Question 2: Approach to performing the research and development

This project was rated **3.33** on its approach.

- Use of NMR imaging to measure water diffusivity through MEA as tool for evaluating degradation is good idea. Would be beneficial if this project could investigate chemical degradation of MEA.
- Started with one cell to refine methods, currently measuring 80 cell stack. High number of data points providing excellent information to analyze -- gives a clear picture of 2 years of data to determine which, if any, events cause degradation.
- The concept could use some more focus. One should consider external effects and if there will be any combinatory effects of impurities along with normal usage thermal and water effects.

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

This project was rated **3.00** based on accomplishments.

- Appears that most of equipment is in place and are ready to begin collecting data.
- Have noticed degradation in cell performance, but have not clearly shown why it is occurring. Suggests reduced H_2 through membrane, yet does not say why this occurs. More work to be done with identifying and controlling degradation.

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

This project was rated **2.33** for technology transfer and collaboration.

- It is unfortunate that a MEA manufacturer/stack manufacturer could not be convinced to participate in this project
- Little work with outside entities; however many papers have been published documenting work. NAMS has been contacted.

Question 5: Approach to and relevance of proposed future research

This project was rated **3.00** for proposed future work.

- Expand scope (if possible) to investigate causes of chemical degradation of MEA
- The right steps have been outlined to reach goals, yet few clues are provided towards their success.
- Need to consider external effects such as start/stop, sub-zero temperature effects, and impurities from external environment and how that will effect the durability.

Strengths and weaknesses

Strengths
- Addressing issues such as transition metal poisoning which have not been previously addressed. (Would be beneficial if the source/cause of the transition metal could be identified?)
- Right approach to problem, great data collecting and documenting. Look to be working toward the right goals with their future research. Spatial resolution of NMR novel, giving good data
- Very important R&D.

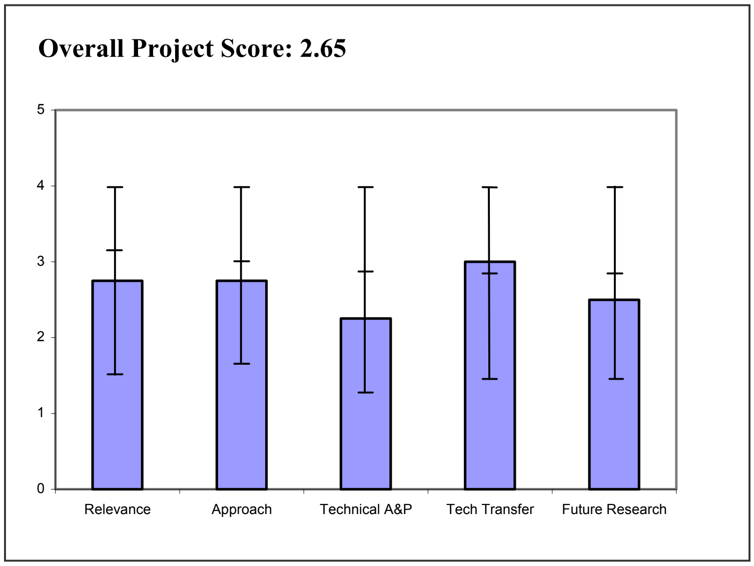
Weaknesses
- Without interest/involvement from MEA and stack manufacturers, not sure of the overall project benefit-basically who will listen? -- Will they accept your approach/results? How sensitive is the water diffusivity to degradation -- could you see substantial degradation without significant changes in H_2O diffusivity?
- Long way with lots of analysis to accomplish before their goals are achieved; not much information given as to why phenomenon occurs (still to come in future work).

Specific recommendations and additions or deletions to the work scope

- Expand scope to characterize chemical degradation.
- Should conduct more parallel work to speed up year 1.
- Align your work more in parallel to move even faster.
- Need to collaborate with fuel cell manufacturers to make sure work is of value. It may be useful to have collaboration with NIST to see if the experimental work can be cross-correlated.

Project # FC-P10: High Temperature MEA for PEMFC Device Based on SPEEK Blends
Bellows, Richard; Oxford Perferature Materials, Inc.

Brief Summary of Project



For this project Oxford Performance Materials, Inc. has an overall goal to develop MEAs to operate PEMFCs at 120C. During the first six months, they will examine materials and processing by developing novel polymer blends for 120C and low relative humidity (RH), establishing their laboratory capability, and fabricating blends into membranes and catalyst layers. During the final 18 months, MEA feasibility at 120C and low RH will be the focus, through characterization of membrane resistance and strength; fabrication of MEAs from blends; and demonstrating feasibility, optimization of MEA performance, Pt loading, and MEA durability (100 hours).

Question 1: Relevance to overall DOE objectives

This project earned a score of **2.75** for its relevance to DOE objectives.

- New project too early to evaluate.
- Higher temperature operation is desirable from CO tolerance and heat rejection considerations.
- High temp MEA significant for autos.
- Development of new MEAs is definitely critical and supports the RD&D plan objectives. However, it is not at all clear how this program will achieve this. The presentation gives no information at all about gas transport, surely an important aspect for an MEA. Similarly, how will the ion channels be formed in the presence of the electrode materials?

Question 2: Approach to performing the research and development

This project was rated **2.75** on its approach.

- Similar materials, such as PEEK, have been reported in the literature. The probability of having some success is high, although it is not clear why these materials or hybrids of these materials would be superior to other similar materials
- Interesting concept but needs more thought to overcome barriers.
- Conductivity is one goal but gas transport is another and it is not mentioned. A major issue in MEA design and construction appears to be ignored. How will the connectivity channels be maintained in the presence of the electrode nanoparticles? The project is dependent on FC-P12 where the separator part is developed. The MEA system seems to be much more difficult to understand. There is not much detail given on this

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

This project was rated **2.25** based on accomplishments.

- This is a relatively new project. They have spent much of the time thus far setting up the laboratory facilities and conducting some preliminary tests.

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

This project was rated **3.00** for technology transfer and collaboration.

- This is rated "good" in spite of it being a relatively new project because the prime contractor is a manufacturer of specialty polymers, and the team is a good mix of academics and consultants.
- Strong collaboration with UCONN to develop polymer blends.
- Modest program.

Question 5: Approach to and relevance of proposed future research

This project was rated **2.50** for proposed future work.

- The proposed future work is primarily to characterize material performance. Discussions with the poster presenter did not identify alternative paths if any, that they would follow if the tested materials do not pan out.
- Confirm feasibility of approach in fuel cell tests.
- Approaches like this are needed to attack problem.

Strengths and weaknesses

Strengths
- The project team has a good mix of industrial, academic, and consultant people. Membrane formation under an electric field is an interesting concept. If it is successful here (as it appears to be, based on slide 9), it may also be applicable to composite membranes being developed by other researchers.
- Good concept. Experienced PI.
- UCONN subcontract looks good -- pursues an interesting if risky concept. However, this is separately funded
- Collaboration with UCONN is excellent and the work there is pursing an interesting, if risky concept.

Weaknesses
- The only MEA performance data plot shown was obtained at fairly high humidities (75% RH at 800C, Slide 11). It would have been useful to report such data at 25% and low humidity, and at higher temperatures but still with low humidities. There is no discussion in either past or future work of dimensional stability of these materials.
- Not clear that approach covers all needs for high T membranes, e.g., system start-up.
- Lack of attention to gas transport. Effect of electrode particles on morphology of polymers needs to be specifically included in plans. Future plans are very vague.
- It looks as if methods used are for Nafion which indicates that this developer may not be that clear of what he is doing and is dependent on the UCONN subcontract.

- The progress appears to be all at UCONN which receives different funding from this program. What has the contractor actually done?
- There is no provision for what to do if the blended polymers do not work in the presence of the electrode particles. There is no provision on what to do if the gas transport is inadequate. Not enough detail given to evaluate future plans. Impression given that there is not a lot of fundamental understanding.
- There is no collaboration planned on the electrode part which is the focus of this work. Seems to this reviewer that the contractor would benefit from help in MEA understanding, particularly in the area of gas transport.

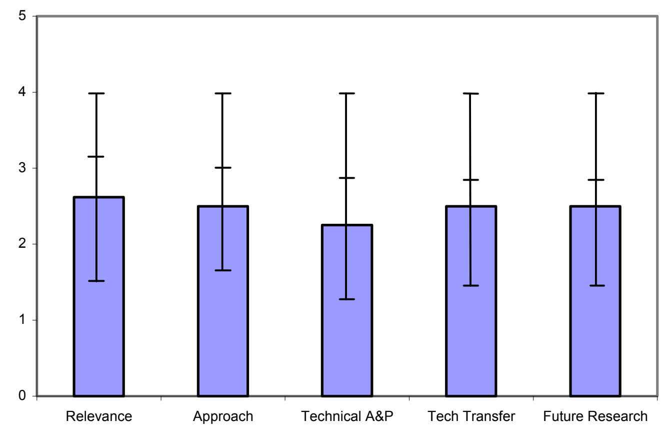
Specific recommendations and additions or deletions to the work scope

- It is not clear why reducing the loading of Pt and Ru should be part of this project, at least at this stage or in the near future (i.e., in FY 2005). Is feasibility really demonstrated at 3 ohm cm^2 area specific resistance? The program target is 0.1 ohm cm^2.
- Determine how well MEAs perform at ambient condition and low RH. Durability testing needs to extend beyond 100 hrs under cycling operating conditions.
- Gas transport and surface effects on morphology need to be specifically include in plans.
- Even though the title is high-temperature membrane, the major focus should be on low-humidity operation. 30% RH @ 120C may still be too humid -- even lower humidity is desirable.

Project # FC-P12: Polymer Blend Proton Exchange Membranes

Weiss, Robert; University of Connecticut

Overall Project Score: 2.47



Brief Summary of Project

This University of Connecticut (UCONN) project is intended to develop new membranes based on polymer blends for operation at temperatures of 120C or higher.

Question 1: Relevance to overall DOE objectives

This project earned a score of **2.62** for its relevance to DOE objectives.

- This work is specifically focused on high temperature membrane development which is a "bottleneck" point for high temperature PEM fuel cells at low RH for both transportation and power system applications.
- Narrow focus on one aspect of one barrier. Fairly small budget.
- Higher temperature membrane is benefit for PEM. Data reported was at 80C or less, not high temperature.

Question 2: Approach to performing the research and development

This project was rated **2.50** on its approach.

- As far as funding ($95,000) for FY04 is concerned, the team's progress is good. SPEKK as a high temperature membrane material is not new but the SPEKK/PEI-blend PEMs are quite interesting which will provide a hope for DOE's high temperature, low RH PEM fuel cells for transportation purposes.
- Acid-base blend is a good idea, but which base polymer? At what concentration? These need to be studied first.
- Very interesting approach. Important to study process/film forming methods on film morphology
- Approach did not include electrochemical testing of membrane at elevated temperature. Why not?

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

This project was rated **2.25** based on accomplishments.

- SPEKK/PEI-blend PEMs are promising. Good progress made on proton conductivity, methanol cross-over. If it is true that percolated path present before water is added, it is very meaningful for high temperature PEM fuel cell program for transportation applications.
- Good progress synthesizing and characterized condition. But, what is evidence for oxidative stability?
- Work reported at low temp. Direct methanol work reported -- how is this part of program?

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

This project was rated **2.50** for technology transfer and collaboration.

- It is still in the early stage (first half -- 10/02 to present). This program's collaboration with other organizations is very small and limited. The collaborations with external fuel cell developers are very important for the success of this project.

Question 5: Approach to and relevance of proposed future research

This project was rated **2.50** for proposed future work.

- Once the optimization of membrane development is done, the enhanced fuel cell performance tests at high temperature and low RH should be pursued in order to prove if the membrane material is suitable or not. Durability tests and crossover of H_2 should be addressed.
- Need to do concrete analytical work to understand the H-bond nature and impact on conductivity.
- Good focus on process conditions to control properties. Electric field orientations could be useful.

Strengths and weaknesses

Strengths

- SPEKK/PEI blend membrane has time properties of a relative high ionic conductivity, less cross-over of methanol, and less water for proton transport.
- Acid-base blend polymer is worthy of funding, but I doubt this team has the right skill sets to be successful.
- Platform understanding of these materials.

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Weaknesses

- More SPEKK/other materials blend membranes should be pursued in order to have an optimized configuration. More PEM fuel cell performance tests under high temperature (>120C) and low RH. Durability tests. Collaborations with other organizations.
- PEI reduces SPEKK conductivity. The team lacks any strategy to either understand or mitigate this problem. Missing knowledge/insights on the basics of ion mobility and acid-base interaction principles.
- Carbon hydrogen bond is proposed weakness of this type of material. Researchers did not address this issue. Why not? Do they not know of this weakness?

Specific recommendations and additions or deletions to the work scope

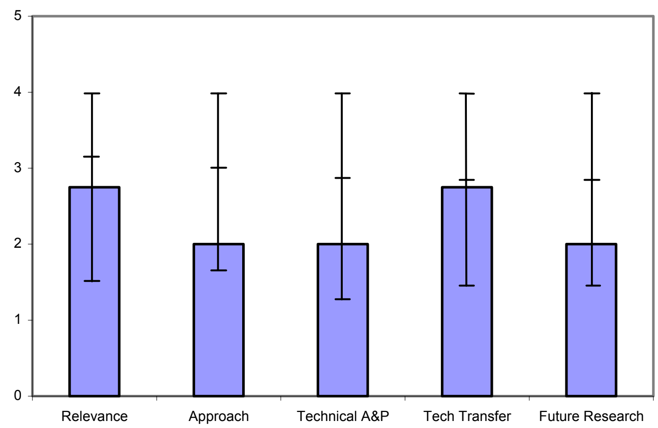
- This project is not going anywhere. Need significant revamp, maybe interact with physical chemists/analytical chemists who are working on membranes.
- Stay focused on high temperature properties of membranes and dry operation -- do not confuse with direct MeOH membrane properties. Consider non-aqueous electrolytes in combination with SPEKK/PEI blends.
- Characterize at high temperature.

Project # FC-P13: High Temperature, Low Relative Humidity PEM Fuel Cell Membranes
Nair, Bindu; Foster Miller

Brief Summary of Project

The objectives of this project are to develop a high temperature capable (150C) PEM fuel cell membranes that can operate at variable relative humidity, to develop PBO/acid membranes that might compare to PBI/acid membranes, the only viable high temperature membrane currently available, and to use polymeric acids instead of small molecule acids to improve the stability of the PEM to thermal/humidity cycling.

Overall Project Score: 2.30



Question 1: Relevance to overall DOE objectives

This project earned a score of **2.75** for its relevance to DOE objectives.

- Not clear how PBO/PBI systems will enable fuel cell market faster than PFSA systems. Not clear how PBO may be better than PBI.
- The development of polymer electrolyte materials that can operate at a variety of temperatures and humidities would offer much greater flexibility in fuel cell system designs and their applications.
- Not entirely clear on the benefits of PBO vs. PBI. If PBI works, what are the advantages of PBO that make it better? Looking at non-leachable systems is definitely worthwhile but this is not made clear. We do not know if the non-leaching sample is PBO or PBI.

Question 2: Approach to performing the research and development

This project was rated **2.00** on its approach.

- Still scouting conductivity of sample membranes; the industry needs membranes now that can be scaled up at competitive prices. This project seems to seek improvement of some F.M.-proprietary technology solely to enable F.M.-proprietary membranes at the expense of developing the right membrane.
- It is not clear that PBO offers a uniquely different substrate from PBI -- why does it enable the use of stronger acids or polymeric acids any more than would PBI? The researchers need to be concerned about the chemical stability of their materials under fuel cell conditions.
- Difficult to evaluate this as the non-leachable sample is not described. A guess would be PBO plus Nafion which would be reasonable given the conductivities of the other polymeric acid. No information is given on how the conductivity will be further improved so it is impossible to judge the soundness of the approach. Furthermore only conductivity in the bulk membrane considered. What about gas transport (permeability) and how materials will behave in the presence of electrode material? The presentation gives no indication that this is considered and yet building an MEA is planned. Surely some thought should be given to this.

Question 3: Technical accomplishments and progress toward project and DOE goals
This project was rated **2.00** based on accomplishments.

- Showed no baseline data…how does PBO compare to PBI/PA at low temperature/low RH and high temperature/Low RH? This makes it hard to evaluate technical progress. Durability?
- Unimpressive results after 13 months of funding.
- The PIs have measured reasonable (but not yet adequately high) conductivities with phosphoric and sulfuric acids. The PIs have shown that membrane preparation methods can affect the conductivity substantially -- hopefully, they can exploit this to further advantage.
- The materials discussed are commercially available except for non-leachable sample which may also be. The conductivity of latter sample is not exactly stellar and no information is provided about gas transport, mechanical properties, or behavior with electrodes materials. Progress is slow for $150k in year 1.

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

This project was rated **2.75** for technology transfer and collaboration.

- Good to be working with CWRU, inventors of PBI/PA.
- They have several academic collaborations. They are working with other potential sponsors (Air Force), which, if successful would leverage this work for other uses.
- The collaborations are good although the presentation does not explain what the participants are doing in enough detail. Fortunately, this reviewer is familiar with these participants and their capabilities. Otherwise the collaborations and other interaction are inadequately explained.

Question 5: Approach to and relevance of proposed future research

This project was rated **2.00** for proposed future work.

- Future expectations not clearly outlined.
- Since the method of preparation seems to have such a significant effect on conductivity, an investigation of the underlying reasons, e.g., morphology at the University of Akron, would be very worthwhile.
- There is no specific approach described to tell us how the conductivity will be improved. There is no approach to tell us how the MEA will be built. What properties of the membrane material will matter. What tests will be run besides building a cell and running it? What morphology tests will be used and how will they be related to structure etc.?

Strengths and weaknesses

Strengths
- They seem to have a membrane that conducts at high temperature/low RH conditions.
- The concept of using larger functionalized molecules, such as acidified polymers is a good one to reduce leach ability. The researchers must keep in mind, however, that such polymer backbones may not be stable under fuel cell operating environments.
- The concept of a non-leachable acid with PBO/PBI seems to be worthwhile and built upon a system that works.

Weaknesses

- No clear work plan. No clear methodology to scale-up (i.e., developmental partners) if membrane becomes successful. No durability data or plan to measure durability data.
- The measured conductivities are still at least 2 orders of magnitude too low. It is doubtful that simply modifying the preparation procedure would provide the needed improvement in conductivity.
- Gas transport is not considered. Nor is the effect of the electrode surfaces. Difficult to be confident this is going the right way when no details of the FMI sample is given.

Specific recommendations and additions or deletions to the work scope

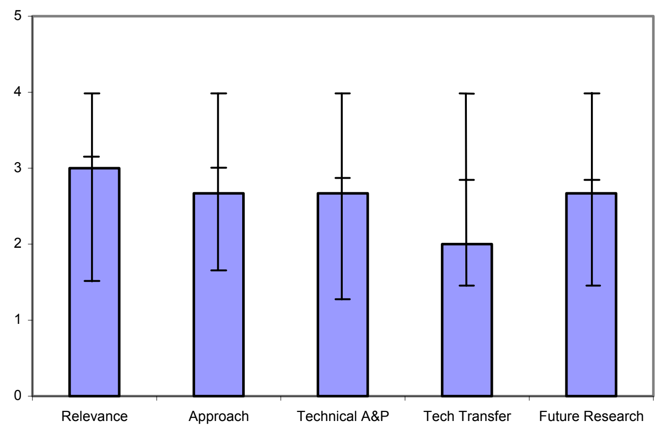
- Focus on durability (not just loss of acid) of these types of systems, or eliminate this program entirely.
- While improving the conductivity is, of course, a desirable objective, the first bullet under "Future Work" does not say what they will do to achieve it. Low temperature conductivities (i.e., at 250C, 500C, etc.) should also be measured and documented, all at low humidities.
- Gas permeability tests need to be run on both membrane and MEAs. More detail on fundamentals of how the morphology studies will be carried out.

Project # FC-P14: High Temperature Polymer Electrolytes Based on Ionic Liquids
Pivovar, Bryan; Los Alamos National Laboratory

Brief Summary of Project

Los Alamos National Laboratory's (LANL) overall objective is to develop high temperature polymer electrolytes for transportation applications. Specific goals are: to increase conductivity at high temperature (~120C) and low relative humidity (<50% RH); improve fundamental understanding of conduction in 'free' proton containing ionic liquids; develop robust polymer systems; and probe the dependence of properties on ion capacity, water content and temperature.

Overall Project Score: 2.60



Question 1: Relevance to overall DOE objectives

This project earned a score of **3.00** for its relevance to DOE objectives.

- High-temperature membrane.
- Development of high temperature PEM will help resolve many complex issues with current PEM technology.

Question 2: Approach to performing the research and development

This project was rated **2.67** on its approach.

- Initial testing at 50% RH and 100C rather than 25% RH and >120C to gain understanding-but-mechanisms are likely to be very different in the 2 regimes.
- Approach is good. Moving to tethered cations and very promising approach. Tethered ion has been studied in Japan before in ionic liquid community…check literature.

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

This project was rated **2.67** based on accomplishments.

- Many electrolytes have been synthesized and tested but results are not very encouraging -- conductivity, stability.
- Making good progress towards identifying candidate system. Good scientific approach.
- Need to keep working on water solubility.

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

This project was rated **2.00** for technology transfer and collaboration.

- No industry collaborations mentioned.

- Not described in poster.
- Some collaborations so far. Need to better address the future plan to working with industry.

Question 5: Approach to and relevance of proposed future research

This project was rated **2.67** for proposed future work.

- Next steps are logical although not certain to improve success.
- Has identified appropriate systems for future study. Proposed work based on good scientific grounds.
- Continue the work but look towards showing its application.

Strengths and weaknesses

Strengths
- Good science with innovative thought. System offers promise as anionic membrane.

Weaknesses
- Need to consider alternative polymer backbones…PI is aware of this and is considering options.

Specific recommendations and additions or deletions to the work scope

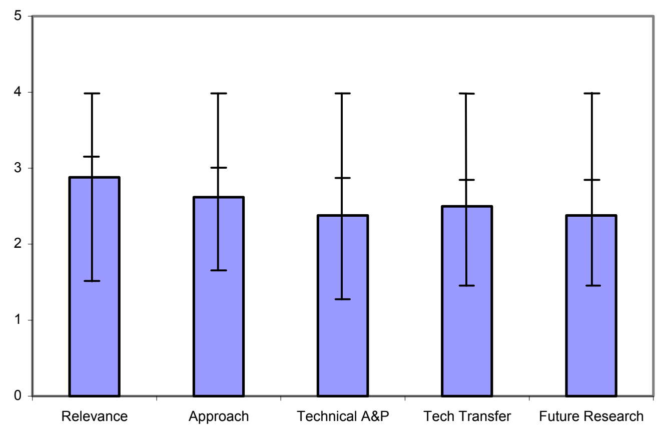
- Needs to expand testing envelope to lower humidity and higher temperature.
- Continue on same path.

Project # FC-P19: New Polymeric Proton Conductors for High Temperature Applications
Kerr, John; Lawrence Berkeley National Laboratory

Brief Summary of Project

Lawrence Berkeley National Laboratory (LBNL) will investigate the feasibility of solid polyelectrolytes for water-free, high temperature operation; measure conductivity; mechanical/thermal properties of Nafion® and polyether polyelectrolytes doped with imidazoles; determine effect of imidazoles on Pt catalysts; and covalently attach imidazoles to appropriate polymer backbones and test for conductivity; mechanical/thermal behavior and gas permeability.

Overall Project Score: 2.55



Question 1: Relevance to overall DOE objectives

This project earned a score of **2.88** for its relevance to DOE objectives.

- It is very important for the success of PEM fuel cells in transportation at the condition of high temperature (>120C) of low RH or no water.
- Narrow focus on one barrier and small funding level.
- Need for HT membranes is understood. Program must be aware of limitations above 120C where corrosion increases.

Question 2: Approach to performing the research and development

This project was rated **2.62** on its approach.

- It is a good approach to replace water-based electrolyte.
- Imidazole-based approaches are not new. In this aspect, the team's approach is ironically unimpressive in contrast to the presenter's self-confidence.
- Main outcome will be better understanding of potential solutions; not actual material solutions -- this is what National Labs should do.
- Approach appears to address basic issues but need to move toward fuel cell work.

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

This project was rated **2.38** based on accomplishments.

- Nafion doped with imidazole or N-methyl imidazole is promising for HT operation without water. However, it is too early to draw any conclusion.
- Need also look at the conductivity and mechanical property in presence of some water/RH. Water exists in FC no matter what.

- Good progress relative to stated program goals, but poor progress toward over-coming the actual barrier. Very useful set of data on doped Nafion -- nice work. Good to measure catalyst ORR effects too.
- Data is confusing if Grotthus mechanism is observed concurrently. Not sure what statement about Schroder's paradox means if Grotthus conclusions observed.

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

This project was rated **2.50** for technology transfer and collaboration.

- Based on the project schedule, the level of collaborations is ok.
- Need to get active collaborations going.

Question 5: Approach to and relevance of proposed future research

This project was rated **2.38** for proposed future work.

- The future plan is fine. Namely (1) water-free separator membrane prepared based on Nafion-imidazoles, (2) MEA fabrication, (3) real fuel cell tests (optimization & conditions), and (4) durability tests.
- The team has enough data to show that this project is almost done; there is no real potential to meet DOE HT membrane goal.
- Concern that efforts to optimize membrane properties will be for naught since they are hydrocarbons not fluorocarbons -- not stable.
- No statements about testing under fuel cell conditions. Expect to see allyl group fail. Polystyrene is well known to fail as a fuel cell membrane support. Not sure why this material is considered.

Strengths and weaknesses

Strengths
- Scientifically, it is a right approach to make water-free polymeric electrolyte for high temperature, no water operation.
- Polymer architecture. Leverage Li-polymer electrolytes work. Future plan is fine logically.
- High level expertise, understanding.

Weaknesses
- It is still at an early stage of these kinds of electrolyte development. No data about real membrane, real MEA package, or real fuel cell set-up. No performance data of real fuel cells.
- The imidazole approach is fundamental to this work. 3 yrs ago, this approach would be interesting.

Specific recommendations and additions or deletions to the work scope

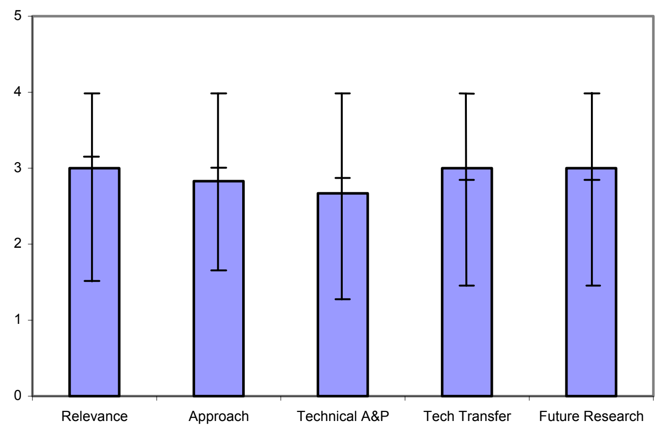
- Follow the future plan to make water-free, high temperature MEA package. Assemble the fuel cells for testing under the expected conditions. Have fuel cell testing results for evaluation. In addition, both of the original electrolyte (Nafion) and doped organic compounds should be extended to wider range to explore.
- From results to date, clearly the tethered polymer would not be nearly conductive enough to meet HT membrane requirement. Re-direct to basic science funding or use the learning and revamp the program with innovative concepts.
- Put more effort into working with materials that will have high temperature stability rather than optimizing ones that won't be stable.
- Recommend add fuel cell stability testing ASAP. Materials will most likely fail at 150C as fuel cell.

Project # FC-P20: Fuel Cell Reformer Emissions
Fable, Scott; TIAX LLC

Brief Summary of Project

The purpose of this TIAX LLC project is to quantify the emissions from fuel cell vehicles with on-board reformers. Data from fuel processors will be used to evaluate potential emissions from vehicles with on-board fuel processors.

Overall Project Score: 2.90



Question 1: Relevance to overall DOE objectives

This project earned a score of **3.00** for its relevance to DOE objectives.

- Verification of claimed very low emissions is important to the transportation fuel cell industry and commercialization.
- Need data on emissions. Need solutions to reduce overall emissions.
- Important that fuel cells and fuel cell systems meet or exceed emissions requirements.
- Emissions from reformate-based fuel cell systems are expected to be very low, but it is important to measure and document them.
- Project started out during period when on-board fuel reforming was emphasized. Not as much relevance under current program.
- Analysis required to confirm low emissions of reformer-based fuel cell vehicles.

Question 2: Approach to performing the research and development

This project was rated **2.83** on its approach.

- Measurements on actual fuel processors although not over an actual drive cycle.
- This project concentrates on measurements only, should also come up with recommendations for reducing emissions.
- Measuring these emissions is not easy, particularly during start-up. These are among the first such reported data. Although further corroboration will be rated, particularly as fuel processors and fuel cell systems evolve, these data provide a useful first estimate.
- Comprehensive analytical techniques for measuring emissions.
- Test data obtained on "real" prototype reformers. Lag between test systems and state-of-the-art (by definition).

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

This project was rated **2.67** based on accomplishments.

- Measurement of 4 different systems nearly complete.
- Need to compare measurements with Tier 2, Bin 5. Question -- why are the NO_x levels measured so high? Suggest trying FTIR to check chemiluminescence technique.

- Some of the results are questionable and need further verification. Total emissions were given as a sum of start-up emissions and steady state emissions whereas the total emissions would be a time-weighted average of these two. After PROx showed NO_x emissions when reactors are filled with catalyst similar to NO_x reduction catalyst, and are under very reducing conditions at which NO_x should not survive -- perhaps they are measuring ammonia or something else.
- They will have made measurements on four different systems by the time the project is completed in the next few months. Their use of the data to model drive-cycle emissions will provide the first view of how clean these fuel cell systems will be.
- Progress slow primarily due to unavailability of suitable reformer systems for testing. Without fuel cell in system, results may be considered "worst" case measurements.
- Data collection and analysis well conducted. Focus of data collection on transients and start-up is sound.

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

This project was rated **3.00** for technology transfer and collaboration.

- Fuel processors were obtained from 2 developers.
- Please be careful in publications not to overstate the emissions, these measurements need to be made carefully.
- Collaborations with fuel processor developers are good.
- It is mentioned that they have discussed this work with technology developers and others outside DOE but no specific interactions were identified.
- Interactions with major fuel processor developers -- few.
- Seems to be communicating with developers.

Question 5: Approach to and relevance of proposed future research

This project was rated **3.00** for proposed future work.

- Project is nearly complete.
- Could also include other fuel effects on the start-up emissions. Concentration on the tail-gas combustor is needed. In a real system, that component is going to define all (or nearly all) emissions. A detailed examination of the reformer/vehicle start-up is needed. Since this is probably not yet defined, need to explore all scenarios
- This is not really applicable as the project is nearing completion in the next few months (early in FY2005).
- Project ends in October-November time frame.
- Perhaps this project should be refocused toward stationary.

Strengths and weaknesses

Strengths
- Collaboration with Nuvera and McDermott.
- They have successfully developed measurement and analysis techniques, even for systems that are not quite complete fuel cell systems. They will use measured data to model emissions over drive cycles.
- Have obtained speciated HC emissions data. Will be useful in determining H_2 fuel quality requirements.
- Organized, well-thought out approach.

Weaknesses

- The lack of an actual fuel cell in the test loop results in overstatement of emissions (although emissions still seem to meet targets). Unfortunately that none of the fuel processors were capable of load following during a simulated drive cycle.
- Calculation of emission example appeared to have a math error.
- Don't appear to have a good knowledge of how the tests were run (conditions, etc.) to be able to provide a correlation of emissions with operating conditions. There are some questions about the analytical techniques used, especially for NO_x measurements. It seems they see NO_x coming out of the PROx, which uses catalysts similar to those used for deNO_x and is operating under reducing conditions. In addition, the start-up procedure wasn't clear what the procedure was and whether the anode gas burner (AGB) was operating, this could have a huge impact on emissions. Start-up emissions will be determined by the AGB since the exhaust should be fed to this to limit pollutants.
- Since the measurements have been made on experimental systems, it is not clear how applicable the results will be to further developments in fuel processors.
- Current scope on-board reforming. Go/no-go decision pending.

Specific recommendations and additions or deletions to the work scope

- Re-examination of NO_x data and possible interferences worth looking at AGB efficiencies.
- The project is nearly finished, but if possible, particulate matter emissions should be determined. As indicated under "Future Work," emissions from direct hydrogen and stationary reformate systems (such as those from Plug Power) should also be measured (perhaps in a separate project since this one is almost concluded).
- Include in the final report, all information regarding different species that were identified.
- Re-focus toward stationary FC systems (or SOFC).

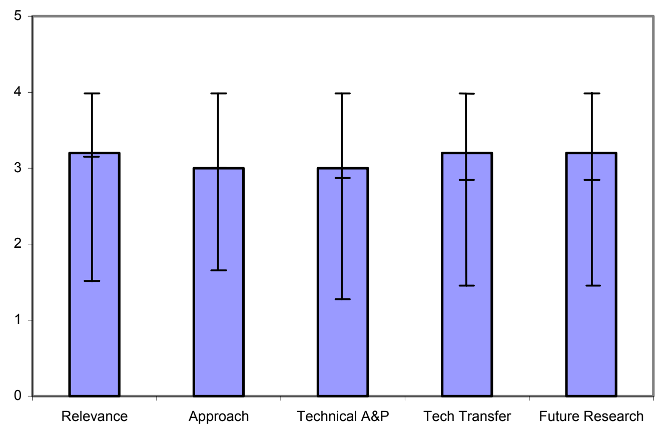
Project # FC-P22: Residential Fuel Cell Demonstration by the Delaware County Electric Cooperative

Schneider, Mark; Delaware County Electric Cooperative, Inc.

Brief Summary of Project

In this project Delaware County Electric Cooperative, Inc. will validate objectives of propane-fueled hydrogen fuel cells for edge-of-grid residences via a field trial demonstration to understand the technical and economic viability of fuel cell alternatives to new line construction. Specifically, they will measure and report technical performance, provide raw cost data and economic viability analysis, document maintenance and operations concept enhancements specific to residential fuel cells, share safety related vulnerability analysis and lessons learned, and promote education of state and local consumers.

Overall Project Score: 3.12



Question 1: Relevance to overall DOE objectives

This project earned a score of **3.20** for its relevance to DOE objectives.

- Project designed to obtain actual field data in residential environment which is necessary for developing residential FC systems.
- Here's a program we'll really learn something from about linking the fuel cell to a typical American home.
- Demonstration projects are extremely important to facilitate technology commercialization.
- Demonstrates one of the key advantages of fuel cells, i.e., off-grid, distributed generation.

Question 2: Approach to performing the research and development

This project was rated **3.00** on its approach.

- Well thought out approach for evaluating fuel cells for residential use in rural areas. Realistic understanding of likelihood of project success and the benefit of the study.
- It is not clear what the essential objectives are in terms of the DOE program.
- It's worth a few thousand dollars to tune the house to the fuel cell environment, e.g., better insulation, thermo pane windows (if not already in place). Let's make the fuel cell look good.
- Well thought out plan. Risk associated with propane, but now may be the time. Cost risk -- are there sufficient funds for fuel cell?

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

This project was rated **3.00** based on accomplishments.

- Difficult to evaluate because funding has not been released. Initial work plan is well developed.

- Making good progress; need to get the contracting process over with. Most details seem well thought out and planned for.
- Good plan established.

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

This project was rated **3.20** for technology transfer and collaboration.

- Good collaboration between regional electric companies and New York State government.
- Interfaces and collaborations look appropriate.
- Collaborations with local and state organizations.

Question 5: Approach to and relevance of proposed future research

This project was rated **3.20** for proposed future work.

- Sound research plan for acquiring data/monitoring site demonstration and for evaluating data. How will the local consumers "be educated?"
- Pure evaluation program.
- This project needs to be funded to completion without any cutting of corners.
- Well thought out plan.

Strengths and weaknesses

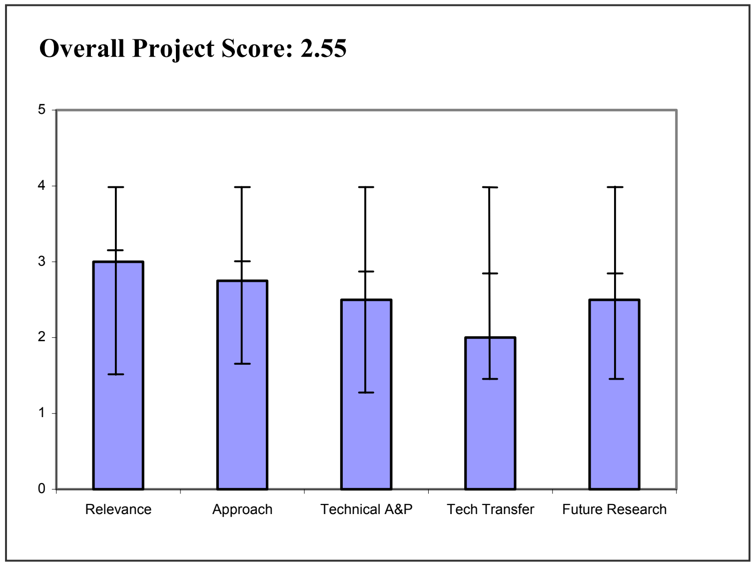
Strengths
- Very realistic in project expectation, objectives and benefits of the project. Like the idea that the fuel cell site demonstration will not be designed around the lifestyle of the test subject to "favor" success of the project but will be designed to obtain data in realistic setting where test subject sets requirements.
- Much needed demo project that could give the EERE fuel cell program "front page" exposure in the information media.
- Good approach/plan

Weaknesses
- Need to ensure project is adequately funded.

Specific recommendations and additions or deletions to the work scope

- Identify plan for "educating the consumer."
- Contract or work with a university program to help with the data gathering and performance monitoring might (1) save money, (2) make for a rewarding educational experience, and (3) bring some fresh ideas to the performance tracking process.

Project # FC-P23: Fuel Cell Operated Smart Home
Alam, Mohammad; University of South Alabama



Brief Summary of Project

The University of South Alabama project will demonstrate that a 5kW fuel cell power plant (FCPP) can satisfy the power demands of an all-electric home and that the FCPP can handle both transient and steady-state conditions.

Question 1: Relevance to overall DOE objectives

This project earned a score of **3.00** for its relevance to DOE objectives.

- Household energy management should help to improve the overall energy efficiency of residential fuel systems.
- Yes, we need hands-on experience of real world applications to ensure the acceptance of hydrogen technology.
- These kinds of projects could put fuel cells in the forefront of consumer thinking about alternative energy options.
- I don't see any value of this project to advancing technical barriers -- perhaps a philosophical difference.

Question 2: Approach to performing the research and development

This project was rated **2.75** on its approach.

- Approach is good -- however, how will the activities in the model home be established to model the general activities in a typical household?
- Phase I is necessary, but compared to Phase II. Phase II: overloaded, nice targets but impossible to fulfill all of them.
- I'm worried about the "managed load" approach. It looks a bit too managed. How well does the model home emulate a real (average) home?
- Extremely expensive approach for what industry eventually will do on their own nickel.

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

This project was rated **2.50** based on accomplishments.

- What is the overall energy efficiency of the SMART house compared to a non-SMART house? Hope to see data from SMART house at next year's review.
- What has been done?
- Looks like this project is moving along at a good pace!
- Appears to be making progress against their goals, despite reservations described above.

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

This project was rated **2.00** for technology transfer and collaboration.

- Tech transfer is not clear -- who is the end user of this project's data?
- What are the contacts made to other FC research groups for? This is more an education program, than an objective of research.
- Teaming could be stronger, but all the bases appear to be covered by the existing team.
- Collaborations not evident.

Question 5: Approach to and relevance of proposed future research

This project was rated **2.50** for proposed future work.

- Question -- how are the ten homes being supplied by a single FCPP? Does not seem to be enough power. Why is hydrogen cogeneration being considered for this project?
- Focus it. Overloaded Phase II with the half funding of Phase 1.
- Phase II looks like a large but credible step beyond Phase I; and it's the kind of test that will teach much about fuel cells.
- Well defined plan, but…

Strengths and weaknesses

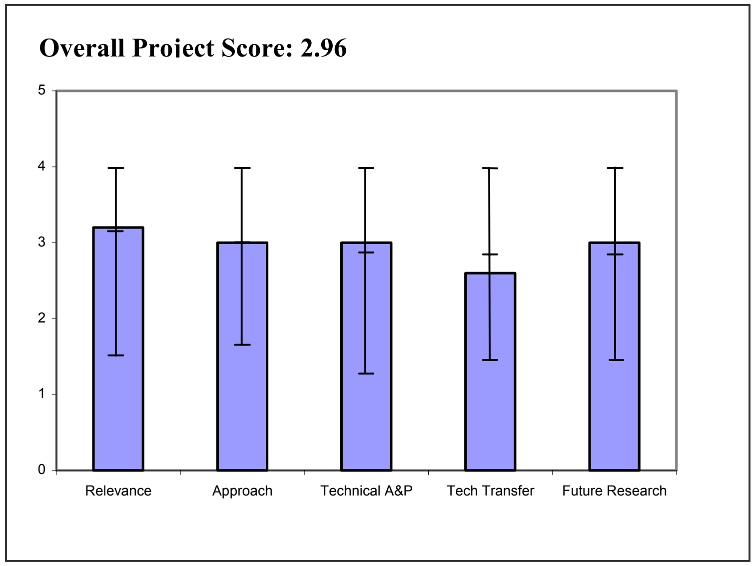
Strengths
- None provided.

Weaknesses
- Not clear if project takes into account thermal/electric management especially in northern climates where thermal and electric demand are not in sync -- summer thermal-low, electricity high; winter thermal high, electricity low. How do you plan to educate the consumer?
- A house built inside a building is not the ideal model but it will probably do for Phase I.

Specific recommendations and additions or deletions to the work scope

- Should interact with residential fuel cell developers such as Plug Power to provide knowledge/lessons learned. Question -- since the model house is built inside a larger building, how do you account for the temperature moderating effect of larger building? Does this affect air conditioning demand? Studies by Argonne National Laboratory have shown that maximum energy efficiency requires a cogeneration system -- a fuel cell plus either natural gas heating or a heat pump -- do you agree?
- How about getting a utility involved?
- This is a ton of $$$ for a project that will not advance the potential for commercialization of fuel cells.

Project # FC-P24: Graphite-based Thermal Management System Components for Fuel Cell Power Systems
Lara-Curzio, Edgar; Oak Ridge National Laboratory



Brief Summary of Project

Oak Ridge National Laboratory (ORNL) will develop compact, low-weight, effective thermal management components for fuel cell power systems using carbon-based materials. The objectives include: the design of thermal management system components based on graphite foam and 3-D woven graphite fiber performs; synthesis of graphite foams with different pore sizes and assessment of the effect of pore size on heat transfer, permeability and mechanical strength; determining the feasibility of weaving high-stiffness graphite fibers into complex 3-D architectures; evaluating the effect of fiber architecture on the heat transfer and permeability of 3-D fiber preforms; and broadening industrial collaborations.

Question 1: Relevance to overall DOE objectives

This project earned a score of **3.20** for its relevance to DOE objectives.

- Project appears to be addressing one of the key concerns of using fuel cells in a vehicle. Make sure in future to show performance to the goals being addressed.

Question 2: Approach to performing the research and development

This project was rated **3.00** on its approach.

- Approach identified looks well thought out.
- Weaving of low-cost carbon fibers could lead to low density, low-cost, high thermal efficiency heat exchangers.

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

This project was rated **3.00** based on accomplishments.

- Though project has not been running for long, it does seem to be making progress.
- Project is in beginning stages and appears to be off to a good start. Real test will be when woven fibers are assembled if there is good thermal contact between fibers.

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

This project was rated **2.60** for technology transfer and collaboration.

- Collaborations between carbon-fiber manufacture and 3D weaving will probably be a key to success of project.
- Need to identify a partner now who will do some real-world validation for performance.

Question 5: Approach to and relevance of proposed future research

This project was rated **3.00** for proposed future work.

- Address durability by testing. May be a good project, but too early to tell. Will need to address cost soon.

Strengths and weaknesses

Strengths
- Collaborations are in place.
- For $129K, I'm supportive of letting ORNL try this and see what develops.

Weaknesses
- Consider an automotive or fuel cell integrator as a partner/collaborator.

Specific recommendations and additions or deletions to the work scope

- Key to the concept will be the thermal conductivity from strand-to-strand in the weave. Work to improve thermal contact between strands or fibers should be added.

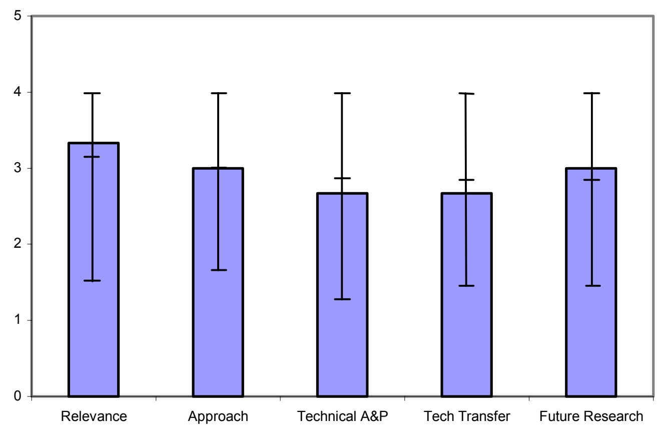
Project # FC-P25: CO Sensors for Fuel Cell Applications

Garzon, Fernando; Los Alamos National Laboratory

Brief Summary of Project

Los Alamos National Laboratory (LANL) will develop CO sensors that can detect carbon monoxide in a hydrogen-containing gas stream, specifically addressing the targets of 1-100 ppm CO at <150C, 100-1000 ppm CO at 250C, and 0.1-2% CO at 250C-800C. These sensors can be used to control the air bleed into the fuel cell anode and could also be used to control the oxygen input of the PROx reactor.

Overall Project Score: 2.93



Question 1: Relevance to overall DOE objectives

This project earned a score of **3.33** for its relevance to DOE objectives.

- This technology can be important in preventing the poisoning of FC stacks, if successful.
- CO in H_2 streams -- a real need in practice (even to support ongoing R&D projects).
- CO monitor is very important to the fuel reforming industry. There is a heavy need for this sensor. Since this has little to do with automotive systems, should be transferred to stationary systems.

Question 2: Approach to performing the research and development

This project was rated **3.00** on its approach.

- Novel approach with consideration of all key factors.
- Accomplishments show that sensitivity and response time are still challenges to be addressed.
- Tough challenge; presenter was excellent. Need to clearly identify which sensors can work as "continuous" versus those that provide "cumulative" info. Good discussion on clean-up.
- Not really innovative.

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

This project was rated **2.67** based on accomplishments.

- Not clear there was lots of progress over last year.
- As response time and sensitivity are so critical, this is still a barrier to be addressed, though response time (post PROx) is good.
- Good data on known gas compositions on model/compositions. But how does system respond with "real-life" feeds? Examples: SO_2, H_2S, NO_x contaminants.
- Progress is good but is this the best technology to pursue?

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

This project was rated **2.67** for technology transfer and collaboration.

- Need collaborations with end-users also (current collaborators are "up" the food chain -- materials companies).
- Need to collaborate with fuel cell manufacturers to make sure work is of value.

Question 5: Approach to and relevance of proposed future research

This project was rated **3.00** for proposed future work.

- Work on durability and stability as well as response time and stability.
- Need to extend into work with live feeds (where other contaminants exist).
- Need to focus on one development to accelerate the technologies. So far, none of the targets are met with any reasonable pathways to meet it.

Strengths and weaknesses

Strengths
- Well-developed basic program where need of such systems (of improved accuracy) is real. Presenter has solid understanding of current systems (including alternatives).
- Needed development for stationary approach.

Weaknesses
- Need to explore larger compositional space to observe multi-gas interactions.
- No longer applies to automotive and also too slow for automotive needs.

Specific recommendations and additions or deletions to the work scope

- Involve more end-use partners. Articulate challenges to such developments more definitively.