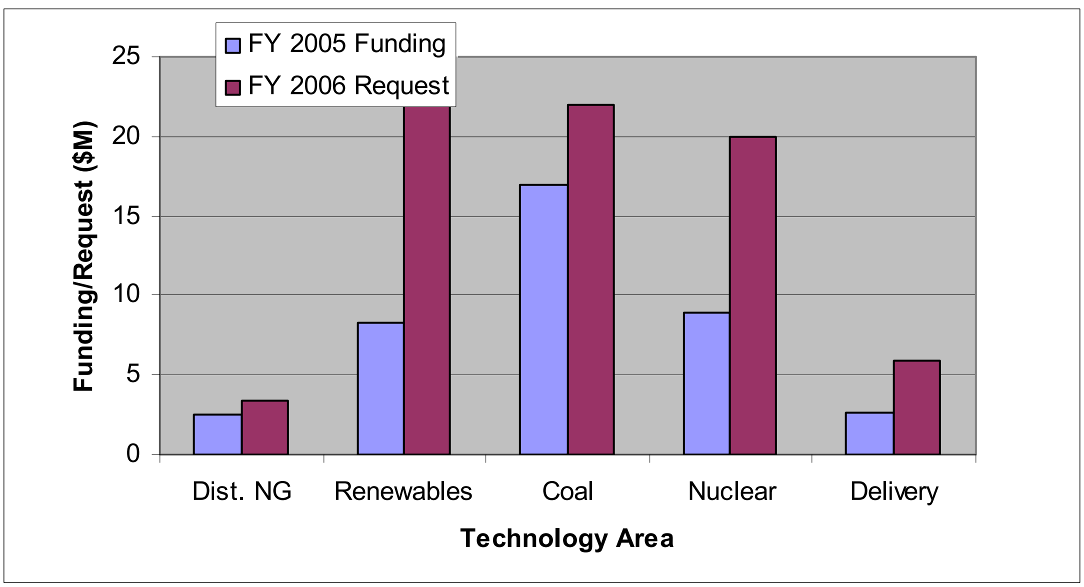
Hydrogen Production and Delivery
Summary of Annual Merit Review Hydrogen Production and Delivery Subprogram

Summary of Reviewer Comments on Hydrogen Production and Delivery Subprogram:

For the first time, this review session combined hydrogen production and delivery research from all DOE programs working on the President's Hydrogen Fuel Initiative including: the Offices of Science; Fossil Energy; Nuclear Energy, Science & Technology; and Energy Efficiency and Renewable Energy. Reviewers commented that production and delivery technology plans are comprehensive and clearly stated in terms of the Hydrogen Program mission and the President's Hydrogen Fuel Initiative. The production and delivery projects are considered to be appropriately diverse in terms of energy sources and related process technologies. Reviewers commented that the program's production and delivery plans described include concise goals and technical barriers, plans to overcome barriers, and timely milestones to overcome the barriers and meet targets. Another general review comment was that the recently developed hydrogen production analysis tool, i.e. the H2A Model, is making a major contribution by allowing research projects and technologies to be evaluated using common assumptions and parameters.

The major concerns identified in some areas by reviewers were: 1) collaboration roles with some industry partners and other research organizations need to be expanded and clarified; 2) some projects need to better define objectives to align with the Program's technical targets; 3) more project test data is needed to assess progress; and, 4) specific go/no-go decision points are needed on some projects.

Hydrogen Production and Delivery Funding by Technology:



Majority of Reviewer Comments and Recommendations:

In general, the reviewer scores for the production and delivery projects were high to average, with scores of 3.71, 3.04 and 1.92 for the highest, average and lowest scores, respectively. The scores are indicative of the technical progress that has been made over the past year. Recommendation and major concerns are summarized below.

Distributed Natural Gas Reforming: While the diverse project teams were viewed favorably, cost data presented was determined to be lacking. Also, some reviewers requested that partners broaden cooperative efforts beyond current customer base in light of public monies received for the research. The projects reviewed are thought to be well-aligned with the Program goals.

Electrolysis: Projects in electrolysis development were generally scored favorably. Most of the projects were viewed to be in-line with current program goals and objectives. The highest scoring projects included electrolysis development integrated with renewable energy sources and also fundamental electrolysis system development. One project will be discontinued based on reviewer scoring. Several reviews made comments regarding the standardization of analysis and cost modeling used in these projects. DOE is currently proceeding on these goals using both H2A modeling and feedback from industry on assumptions used in these models.

Biomass: This technology area has been re-focused since the 2004 Merit Review. The two projects in this area are new and were reviewed favorably. Both projects are high risk research aimed at potential cost breakthroughs using different approaches. The high risk nature of these efforts was noted by the reviewers. The reviewers' recommendations to focus on the key high risk element of each project with clear go/no-go decisions will be followed. Also, some projects are focused specifically on distributed reforming of bio-derived renewable liquids and are recognized as an important pathway for hydrogen production.

Solar-Driven High Temperature Thermochemical: There was only one project reviewed in this area, and it was reviewed favorably. The reviewers expressed concern that too much effort had been spent on screening potential thermochemical cycles. The screening has now been completed and laboratory research on the most attractive cycles has been initiated. Two new projects in this area will be getting under way shortly and will be reviewed in 2006.

Photoelectrochemical Hydrogen Production: The projects in this area received mostly high ratings from the reviewers. The projects were seen as generally well thought-out and logically organized with good scientific results and collaborations. This technology area should appropriately continue to focus on materials research and development.

Biological Hydrogen Production: The projects in this area received generally high ratings from the reviewers. There have been several significant advancements in the past year that were recognized by the reviewers. The projects that started this year, even with low levels of funding, have made progress. There are collaborations set up that are working well in this technology area.

General Separations: There was only one project reviewed in this area. Reviewers emphasized that the research is fully relevant to RD&D Plan objectives and that lowering the cost of hydrogen separation technologies is critical. Bridging the gap between modeling and real world experimental results with potential commercialization partners is key. Three new projects will be getting underway shortly and will be reviewed in 2006.

Hydrogen from Coal: The reviewers agreed that process intensification, including the combination of water-gas-shift reaction and hydrogen separation in a single membrane reactor would offer the best promise to reduce hydrogen production from coal in the downstream coal gasification step. Good progress was noted in the membrane development area. Recommendations included the use of a system engineering model to incorporate the proposed work with front end coal gasification to provide R&D guidelines. Also recommended was the need to obtain more long-term coal-derived gas separation technology performance data.

Hydrogen Production Using Nuclear Energy: In general, the projects reviews in this area, which included the development of high-temperature electrolysis, thermochemical cycles, and supporting systems, were favorable. Comments were positive on the experimental nature of the research and the progress to date. Most of the project reviews noted an interest in clearer communication of future research plans and milestones. Many also identified research areas (e.g., economic analyses) which are addressed by different parts of the nuclear program. The program will make adjustments in the future to clearly articulate links between projects, the planning documents, and other program activities.

Hydrogen Delivery: This area received generally high scores from the reviewers. The projects were viewed as well-aligned with Program goals with generally good approaches to the research and sound collaborations. Nearly all of these projects are just getting underway. There were concerns raised as to possible duplication of efforts and the need for coordination across the several hydrogen pipeline projects. DOE has just formed a hydrogen pipeline working group consisting of all of these pipeline projects that will meet periodically, will help to coordinate efforts, and will strive to create synergy across these projects.

Project # PD-01: Hydrogen Production & Delivery

Devlin, Pete; U.S. Department of Energy, EERE
Schmetz, Ed; U.S. Department of Energy, FE
Henderson, David; U.S. Department of Energy, NE
Mallock, Tom; U.S. Department of Energy, SC

Brief Summary of Sub-Program

The purpose of this Hydrogen Production and Delivery Sub-program Overview and introduction is to describe sub-program 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 puts into context the R&D and analysis projects which will be presented in this sub-program area during the Annual Merit Review.

Degree to which the Sub-program area was adequately covered and/or summarized

- Very broad range of objectives included in this sub-program. As these span basic biology to materials engineering, it is difficult to get a very good summary in one presentation. Still, major goals and achivements well articulated.
- Excellent summary of program.
- Coverage of the sub-program's technologies was comprehensive.
- Overview would be improved with more discussion of where funds are being spent and why.
- Adequately covered, but the presentation of information could be enhanced by using more comparitive diagrams rather than endless lists.
- Sub-program was well covered and summarized showing clear and concise goals, barriers, approach and plans to overcome barriers, milestones and timelines to overcome the barriers and meet targets.
- A good job in covering the many facets of this sub-program.
- Very articulate summary.
- Good overview of money and trends.
- Clear summary of technical scope.
- Unclear definition of going forward plans -- appears to be studying too many areas with few dollars.

Were important problem/issue areas and challenges identified/discussed, including plans for addressing these items in the future?

- Several "target" numbers and strategies for achieving them were outlined.
- Issues with respect to target volumes were inadequate. Expectations should be set for volumes at various dates from major project areas (hydrogen from fossil, electrolysis by power source, etc.). Cost alone is not particularly useful, and projects should be aware of the overall project goal and address their parts.
- New cost basis of gge's on an FC/ICE efficiency ratio basis needs to also explore a range of fuel cell efficiencies.
- Identified, but not sufficiently discussed.
- Comprehensive presentation in terms of content but correlations between goals/time/readiness and challenges were not clear.
- Yes, important barriers, including cost targets, were identified and plans and timelines to address them were outlined.
- Issues/problems are being addressed in a well planned out manner. The program has decision points in place and has the flexibility built in to eliminate or go around obstacles along the way.
- Clear decision points laid out for near- to mid-term.
- Roadmaps and working groups discussed.
- Funding not clearly discussed.
- DOE Gen IV strategy not specified.

Does the Sub-program area appear to be focused, managed well, and effective in addressing the Hydrogen Program R&D needs?

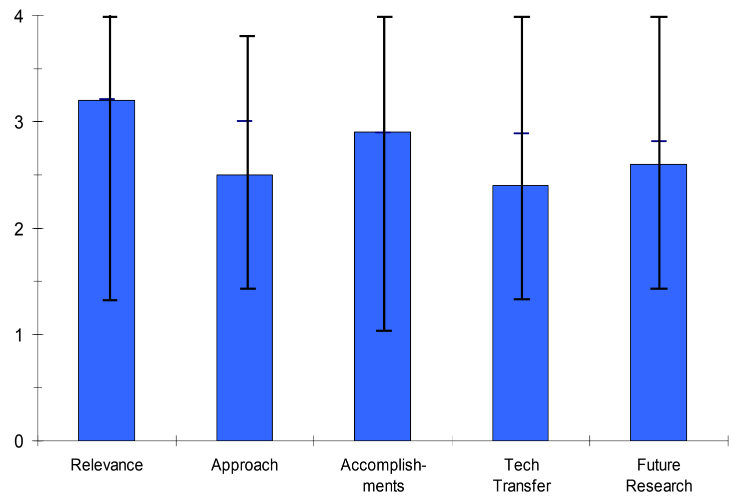
- Yes, it does appear to be focused. The H2A project is making a major contribution to putting projects on an equal footing.
- Updated plans, cost goals, and target guidance are indicators of active, fully engaged, effective management of the sub-program.
- Sub-program area is well focused.
- Course corrections have been made to address the economic needs of the real world deployment for hydrogen fuel cell vehicles in terms of technology required to satisfy them.
- Program appears to be running well.
- Clear hydrogen tecnology path articulated.
- Unclear nuclear roadmap -- key to selected hydrogen technology.
- Program clarity required to tie nuclear to hydrogen programs!

Other comments:

- Gge's are great for transportation. Another unit should be considered for power application, perhaps kW efficiency.
- Coal program should consider picking off easy hydrogen before passing on the remaining carbon and hydrocarbons to the power plant.
- Reviewers task for projects that have not yet started is unclear. These were already subject to solicitation assessments. What is the reviewer supposed to be adding?
- The large number of presentations in follow-on Production/Delivery sessions made discussion hard or impossible. Reduction or grouping (in panels?) might help.
- Having advanced copies of presentation was extremely helpful. Great progress here.
- Too little time allowed to cover the material for a sub-program with so many facets.
- EERE Team Lead briefed the group on the use of genetically modified algae at NREL to achieve higher efficiency without addressing the risks and implications of genetic engineering — this is an area of concern regarding NREL's competence and safety in this area.
- Funding allocations for 2004 and 2005 were shown in pre-charts. Would be nice if target funding ratios (or percentages) were shown on the same charts to show whether the funding targets are being met.
- Logic and structure of EERE Team Lead's efforts should be carried over to NE, which appears to be stuck on a GenIV reactor/ hydrogen roadmap decision.
- Unless quick action is taken, DOE dollars will be wasted if GenIV strategy is not established, communicated and then implemented.
- Most disorganized effort in entire session.
- Complete unwillingness or inability to time-manage the session.

Project # PD-02: A Reversible Planar Solid Oxide Fuel-Fed Electrolysis Cell and Solid Oxide Fuel Cell for Hydrogen and Electricity Production Operating on Natural Gas/Biogas
Tao, Greg; Materials and Systems Research, Inc. (MSRI)

Overall Project Score: 2.8 (6 Reviews Received)



Brief Summary of Project

This industry-academic joint project will develop a planar 1 kW stack for generating clean hydrogen for onsite application and electricity for power-parks, directly from either distributed natural gas or biogas fuel. It is based on the novel concept of composite/hybrid solid oxide fuel-fed electrolysis cell (SOFEC) and solid oxide fuel cell (SOFC) technologies. This project will focus on material research, stack design and fabrication, and experimental verification.

Question 1: Relevance to overall DOE objectives

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

- Good mix – a SOFC- Electrolyzer combination.
- This project is intended to address the need for production of low cost hydrogen.
- This project is well aligned with the DOE R&D plan
- Tightly focused on hydrogen program goal of improving efficiency and flexibility in hydrogen production from natural gas and renewable resources.
- This project provides a relatively near-term transition option — an interesting alternative to the standard water electrolysis.

Question 2: Approach to performing the research and development

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

- Appears feasible for composite Fuel Cell/Electrolyzer. No discussion of barriers and how they will get through them.
- The approach proposes the integration in a single system of Solid Oxide (SO) technology to generate electricity from fossil and renewable fuel to produce hydrogen through electrolysis.
- Integration of the combined functions, power generation and hydrogen production, in a single SO stack has, in similar projects, resulted in poor performance of both functions.
- Good technical approach, but need to develop targets for system/component cost and performance and then report progress against those.
- It is not clear that replacing electricity from the grid with electricity from an SOFC will lead to a more efficient process. An analysis to support that claim was not presented.
- It is not clear that reforming some natural gas to produce hydrogen to make electricity to electrolyze water to produce hydrogen is more efficient than the proposed method.
- Approach of using fuel-driven electrolysis has great potential to reduce voltage needed to electrolyze water to hydrogen.
- As an adjunct to this program it would be very helpful to see and overall system analysis and optimization study to see how the use of fuel to drive electrolysis compares with the use of the same fuel to make hydrogen via steam reforming. In other words, if hydrogen is the desired product, would it make more sense to make it from gas via reforming, instead of the scheme proposed here?

- The approach, as presented would use no precious metals and use no external electricity; however it was unclear specifically how the technology would be applied.

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

This project was rated **2.9** based on accomplishments.

- 25% complete. Good scale up from button cell to 4 cell stack to 5 cell stack. Talked about future but did not show future slides.
- Good progress in button and short stack testing but performance is rather poor.
- Substantial effort will be required to improve performance to an attractive level.
- Improvement in fuel use efficiency must be realized for approach to be commercially viable.
- Good progress on SOFC materials in less than a year.
- Substantial progress made in relatively short period of time: button cells prepared and tested, temperature effects on I/V curves measured; cells tested in SOFC and SOFEC mode; proof of concept demonstrated for reducing voltage needed for electrolysis by putting fuel on cathode side of fuel cell; and a number of cathode materials developed and tested.

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

This project was rated **2.4** for technology transfer and collaboration.

- Did not discuss.
- Good team of university and industrial partners.
- Two companies and a university are involved. Project is relatively new and outreach should be encouraged.
- Don't know. Cannot recall the presenter delineating the roles and contributions of collaborators at the University of Missouri and Aker Industries.
- Both industry and University collaboration.

Question 5: Approach to and relevance of proposed future research

This project was rated **2.6** for proposed future work.

- Did not show timeline to accomplish future work.
- Future plans should be focused on improving integrated performance of fuel cell and electrolysis cell in the combined configuration. Performance should exceed that of dual (separated SOFC and SOFEC) units.
- Good emphasis on durability testing and performance optimization.
- Could perform some cost analysis sooner rather than later to help set performance and cost targets.
- The system configuration and operating plan/duty cycle is not well defined. How much electricity will be available for export? Or will most of it be consumed internally because of high ASR?
- This program is clearly now in data generation mode, collecting data on new materials performance under a complex set of experimental variables. Plans are solid and well thought through. As noted above, plans should include an analysis of the trade-offs in using the fuel component for direct generation of hydrogen, instead of reducing voltage required for electrolysis.

Strengths and weaknesses

Strengths
- Good idea but needs work and more information/detail on slide presentation.
- Good team making strong progress toward achieving the project objectives.

Weaknesses

- No time scale on graphs.
- The project would benefit from defining a target-driven path for achieving cost competitive hydrogen/electricity production and then benchmark against those targets.
- The process is not well defined. The amount of hydrogen production relative to electricity generation and the thermal efficiency of the overall process are apparently not known or were not presented. The approach to lowering the ASR of the cathode material was not discussed other than to say that it would be improved. This is very important to system efficiency.

Specific recommendations and additions or deletions to the work scope

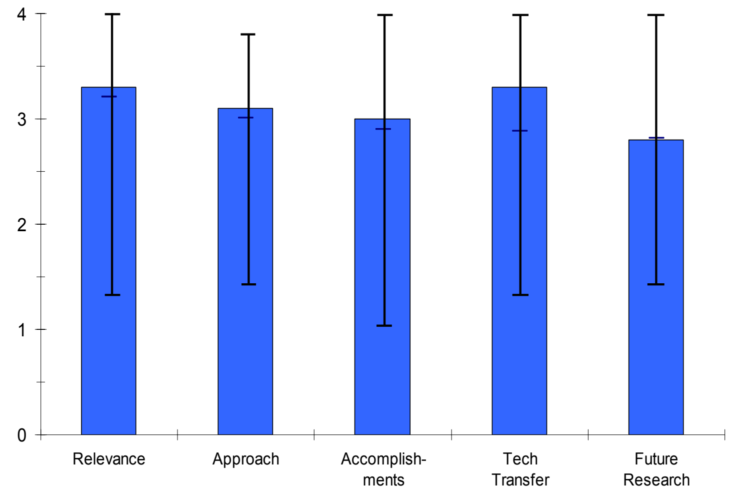
- Presentation needs work. Not enough detail to this project to justify. Need to see results against time.
- Focus on performance improvements.
- A process analysis and well-to-electricity/hydrogen analysis is definitely needed. The thermal efficiency of the process needs to be determined. DOE's system integration experts may be able to help in this regard. This analysis should be a high priority for the next year.
- Possibly explore deployment scenarios (in addition to balance of plant cost analysis).

Project # PD-03: Autothermal Cyclic Reforming Based Hydrogen Generating & Dispensing System
Kumar, Ravi; General Electric Global Research (GEGR)

Brief Summary of Project

GEGR designed fabricated and is demonstrating a hydrogen generating system designed for vehicle refueling. The system, based on novel autothermal cyclic reforming technology, can produce 40 kg/day of hydrogen, sufficient for the refueling of at least 1 bus or 8 cars daily. GEGR partner Praxair completed tests using simulated reformate at greater than 120 psig demonstrating that 99.99% pure hydrogen stream can be produced with greater than 75% recovery.

Overall Project Score: 3.1 (4 Reviews Received)



Question 1: Relevance to overall DOE objectives

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

- States they can come close to DOE target.
- The project addresses distributed production with a novel natural gas reformer process.
- Directly relevant to the DOE program objectives
- Project approach addresses a simplified lower potential cost of hydrogen production.

Question 2: Approach to performing the research and development

This project was rated **3.1** on its approach.

- Good slide, sufficient detail and information. Good explanation of ATR process. Good slides on targets and on safety.
- PI should describe the innovation involved with the PSA and compression and dispensing and which barriers they address.
- Need to comment on how barriers B, C and E are being addressed.
- Should provide more information on how the capital costs are being reduced.
- The approach is to develop an autothermal methane reformer that does not require the use of precious metal catalysts. Nickel catalysts are reduced to the metal state by recycling the PSA tailgas through the reformer, an interesting approach.
- GE should analyze where the thermal efficiency losses occur in their process and compare the analysis with a similar analysis for conventional SMR.
- GE should determine the impact on the process (cost and efficiency) of meeting the proposed higher quality hydrogen requirements that are in-line with the consensus quality requirements from the FreedomCAR Fuel Cell Tech Team and the North American consensus requirements that are being advanced to the ISO.
- Brought together an integrated team.
- Used the expertise of the partners well.

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

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

- Good task schedule slide. Catalyst change out 4 times per year seems like a lot.
- Need to describe the safety approach addressing the reformer cycling between fuel rich (reforming) and air rich (regeneration) steps without creating an unsafe mixture of fuel and air within the reformer.
- GE has made significant progress over the past year in bringing this project close to the demonstration phase. They appear to be on track with regard to permitting the facility and beginning operation this year.
- The project has made great progress on demonstrating the concept works.
- No data is presented on cost relative to the $3/gge. Clear that not all the information is available, but indications could be shared.

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

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

- Good slide from Praxair.
- Collaboration with Praxair on PSA and with UC-Irvine on-site leverages the partnership capabilities.
- Good collaboration between GE, Praxair, and UC.
- Well designed team.

Question 5: Approach to and relevance of proposed future research

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

- Future work seems to be on target. This project is off to a great start, and should contribute well to DOE program goals.
- Appears that the PSA and compression/dispensing add little new knowledge in light of other DOE funded projects.
- No mention of considered contingencies, optional paths, or off ramps.
- Project will end this calendar year. Operating data should determine whether GE met the DOE performance targets and cost target.
- Durability is modeled at this point, but the next phase needs to get real data.

Strengths and weaknesses

Strengths
- Good slide responses to previous year's comments.
- High pressure reformer saves parasitic load, i.e. no reformate compressor.
- Designed for a high number of starts and stops.
- Safety approach is inclusive of ASME, NFPA, and local fire marshal.
- Excellent project team. The project looks like it will result in a functional system and provide data which can be compared with the DOE cost and performance targets.
- Appears to be a path that drives out cost through simplification.
- Great to see the prototype using real world codes.

Weaknesses
- Catalyst life needs to be extended to reduce operation and maintenance cost.
- Efficiency appears to be low due to: 1) Methane conversion is low (~70% as inferred from slide 7); 2) PSA recovery of ~75%; and 3) Parasitic power required for air blower/compressor.
- There is little evidence of development in PSA and compression/dispenser.
- Catalyst lifetime is relatively short which could have an impact on the overall economics.

- Primary goal is to address the DOE cost goal for hydrogen production, but no data is presented. That seems to be a significant omission. How can we tell if we are on the right path? i.e. the program needs down-select measures if possible.

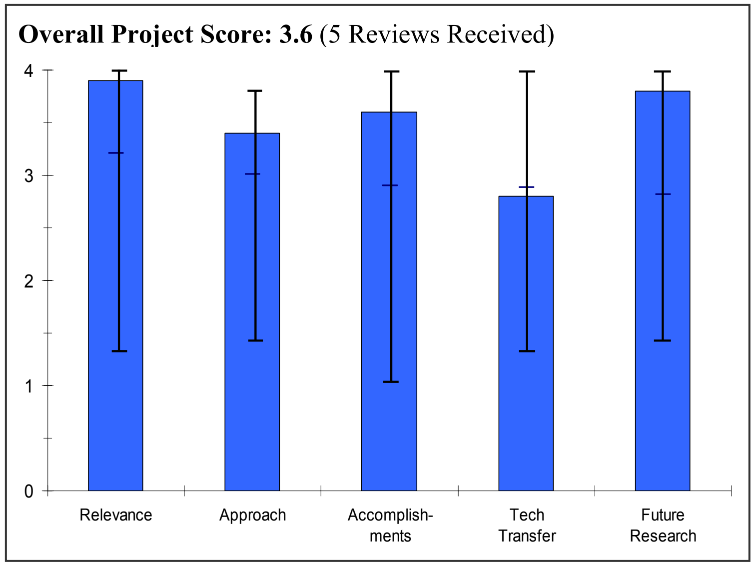
Specific recommendations and additions or deletions to the work scope

- Address how to overcome barriers.
- Develop and report the system efficiency and compare to the DOE target. Document progress against all DOE targets as the project proceeds.
- Test high pressure reformer and optimize methane conversion.
- Hydrogen quality is a moving target. GE should determine the impact of changes (both greater and less) in quality hydrogen requirements on the process and system design.
- Need to consider more robust catalyst system. Three month life is not a commercial life cycle. Not addressed is the cost; if the catalyst is very low cost, this might be ok. Can't evaluate further since that information is not presented.

Project # PD-04: Development of a Turnkey Hydrogen Fueling Station
Guro, David; Air Products and Chemicals, Inc.

Brief Summary of Project

Air Products and Chemicals, Inc. is working on a project to demonstrate the economic and technical viability of a stand-alone, fully integrated hydrogen fueling station based on the reforming of natural gas. Building on the lessons learned from the Las Vegas Hydrogen Fueling Energy Station program, the project seeks to optimize the system, advance the technology, and lower the cost of hydrogen. The demonstration will be done through the operation of a fueling station at Penn State University with the purpose of obtaining adequate operational data to provide the basis for future commercial fueling stations. The top priority of the fueling station is maintaining safety standards in its design and operation.



Question 1: Relevance to overall DOE objectives

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

- Good budget slide. Good level of detail on slides.
- Hydrogen distribution infrastructure is one of the key points to bridge the gap to a hydrogen economy. This project supports the President's Hydrogen Fuel Initiative to accelerate the introduction of hydrogen as the primary energy carrier in the USA. It is also in agreement with the recent DOE on-board fuel processing no go decision.
- Clear relevance to near-term objectives.
- Working on the right issues.
- Important to validate current distributed reforming delivered cost of $3.00/gge and an overall efficiency of 65%.

Question 2: Approach to performing the research and development

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

- Good target slide. Good breakout/discussion on components.
- The project is very well designed.
- All the technical barriers of the hydrogen refueling system were addressed.
- Very structured, methodical approach to addressing technical issues.
- Not clear how the change between Las Vegas and Penn State is happening; they are projections, it appears. It might help to illustrate this in future presentations.
- Decision to use SMR over POX, AATR, and CPOX is a critical one and more information should be given about that decision.

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

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

- Good slide on timeline. Good "forward looking" concepts. Good interfacing with NIST to write regulations.
- Hydrogen production and PSA system efficiencies as well as hydrogen cost meet the DOE 2005 targets.
- System approach very effective.
- Would rate a 4 if the cost data was presented along with quantifying what amount was driven by which technology enhancement (simply showed a list).
- Packaging (conceptual) very compact.
- The results of the project need to be more data driven. No real data given in the presentation. It is important to prove that the system works well and quantify reliability by showing line charts, statistics, and assumptions used for determining economics and efficiency numbers. Perhaps this is not the venue for so much detail disclosure, but it should be reported in other publications.
- The PSA results and efficiencies and cost reduction numbers are significant for distributed reforming.

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

This project was rated **2.8** for technology transfer and collaboration.

- Good discussion regarding Penn State and their activities.
- Collaboration with the university or other laboratories is not clear. The project was basically developed by the industry.
- Nice interface with the University community.
- Learned from Las Vegas project regarding vehicles.
- Would rate 4 if the role of the University was more clear; is it beyond just being the site host?
- To have AP develop this system and commercialize it is a significant advancement for the Hydrogen program. Testing of fuel cell vehicles would show that in fact the purity is as stated.

Question 5: Approach to and relevance of proposed future research

This project was rated **3.8** for proposed future work.

- Good characterization of future work.
- The future work is focused on the integration of hydrogen generation step with purification/compression/ dispenser.
- Good plan.
- Great to see balance of plant items being aggressively addressed.
- Reformer based system needs to begin as soon as possible. LH_2 demo is of minimal value. CNG blends in vehicles are less desirable then FCV use since latter would demonstrate purity is being met.

Strengths and weaknesses

Strengths

- Good enough to lead to another proposal/ project on compression and CNG blend. Good description of future work.
- The project is very well designed, and it addressed all the key technical barriers of the hydrogen refueling station.
- Progress in packaging.
- APCI is a critical participant in this phase of the program and station is important for the distributed reforming work. Cost and efficiency numbers for the PSA and the overall process are significant findings.

<u>Weaknesses</u>

- Don't use white type on light background and black type on a blue background. Too hard to read.
- The time scheduled to integrate the hydrogen production sub-system and to operate and test the complete system is too short.
- Cost transparency.
- Results should be quantitative and data used to show how goals are being met. There is no way to validate that the quoted cost of $2.72/gge is accurate.

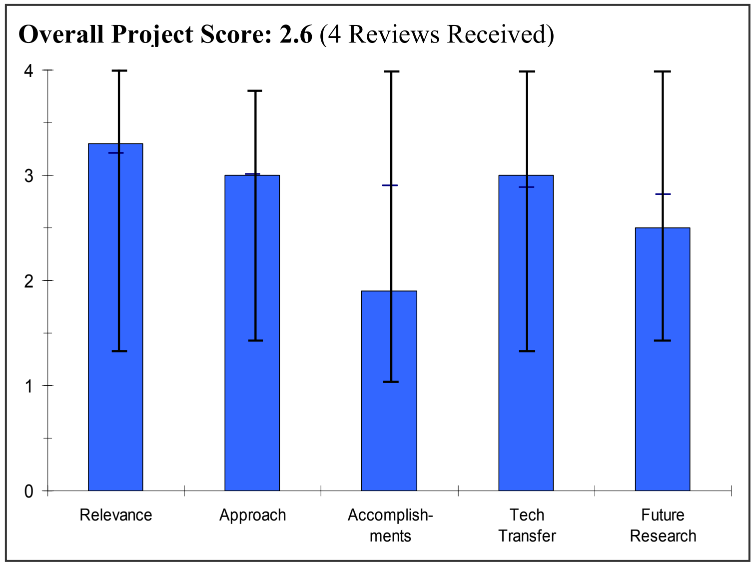
<u>Specific recommendations and additions or deletions to the work scope</u>

- There will not be available time to collect enough data of reforming sub-system coupled to overall system.
- System optimization is claimed in the presentation, but no details provided of process used to optimize and the specific results. Understandably, there is some rationale for a company to develop and protect future market advantages, but this will also limit dissemination of learning from this cost-shared project. If another entity wants to compare SMR over other process options and then optimize that system, then they should have access to the precompetitive fraction of the results from this project

Project # PD-05: Development of a Natural Gas-to-Hydrogen Fueling System
Liss, Bill; Gas Technology Institute

Brief Summary of Project

GTI is designing a competitive, fast-fill natural gas-to-hydrogen fueling system with 40-60 kg/day delivery capacity that strives to meet the DOE hydrogen cost goal of $2.50/kg or less. GTI will undertake system design and analysis to identify potential pathways, conduct development and lab testing to confirm subsystem operation, integrate the system and incorporate controls, and conduct lab and field testing to validate performance and reliability.



Question 1: Relevance to overall DOE objectives

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

- Difficult to determine which of the many accomplishments presented are relevant to the original scope of work.
- Project addresses most of the issues regarding on-site reforming. Some issues not addressed are hydrogen quality and reliability.

Question 2: Approach to performing the research and development

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

- Appears good approach.
- The project addressed all the technical barriers of the hydrogen refueling station based on reforming of natural gas.
- Why were Proton electrolyzers evaluated?
- How is it relevant to the natural gas hydrogen target?
- Extremely broad array of technologies tested. As a consequence, the project is too diffuse.
- Unclear what GTI did to optimize unit performance
- Highly diverse team.

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

This project was rated **1.9** based on accomplishments.

- Good description of various generations, too much detail on accomplishments.
- Hydrogen production cost and overall efficiency still need to be improved.
- The performance of the purification process has to be improved.
- Accomplishments are unclear.
- Unclear if any of the units' performance was improved versus what is available from these unit producers.
- Unclear how the project contributed to cost reduction.
- No data presented on cost progress which is the primary goal.

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

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

- Good mention of partners.
- The project evaluates technologies for purification, compression, storage and dispensing of different companies.
- The plan for technology transfer is not described.
- Project appeared to rely on other companies as simple suppliers.
- Looks like the project is set up for success.

Question 5: Approach to and relevance of proposed future research

This project was rated **2.5** for proposed future work.

- Appears good, but needs to be focused.
- The future work consists of the construction of the complete system of hydrogen generation, and testing the integrated system.
- Focus has to be sharpened.
- Future work seems to be completing the laundry list of tests without conclusive improvements expected.
- Not clear that meeting the cost objective is driving the work. May be a presentation issue, but comes across as a list instead of cause and effect relative to the major program objectives.

Strengths and weaknesses

Strengths
- The approach of project address all the steps involved on the hydrogen delivery. The project also evaluated different technologies of several suppliers.
- Very diverse partners.

Weaknesses
- Are any of the accomplishments "milestones"?
- The integration and demonstration of the complete hydrogen refueling station still are not defined.
- Project budget and timeline not presented.
- Accomplishments in many fields (production, purification) not made clear. Statements about feasibility not backed up by any specifics.
- Not clear if any of the reformers actually produced on-spec hydrogen.
- Project seems to be very diffuse lacking clarity and focus.
- Unclear contribution of this project beyond the simple measurement of performance of existing technology
- Unclear deliverables.
- Short on data concerning costs.

Specific recommendations and additions or deletions to the work scope

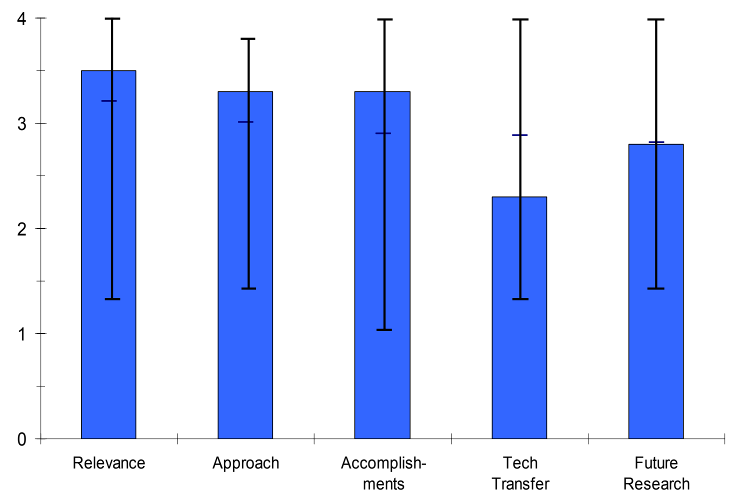
- There were a lot of elements to this presentation -- modeling, storage, economics, etc. Needs better organization of the actual accomplishments under this program.
- Eliminate electrolyzer from scope.
- Add measurement of hydrogen quality.

Project # PD-06: Production of Hydrogen by Biomass Reforming
King, David; Pacific Northwest National Laboratory

Brief Summary of Project

Pacific Northwest National Laboratory (PNNL) will develop cost-effective reforming technology for the distributed conversion of biomass feedstocks to hydrogen using the following potential feedstocks: ethanol, glycerol; sugars, sugar alcohols (xylitol, sorbitol, glucose); and less refined starting materials such as cellulose or hemicellulose. In addition, PNNL will provide technical and economic comparisons with alternate biomass conversion approaches.

Overall Project Score: 3.1 (4 Reviews Received)



Question 1: Relevance to overall DOE objectives

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

- Directly supports 2015 objective of reducing cost of distributed H_2 production from biomass-derived renewable liquids to $2.50/gge (delivered, untaxed) at the pump.
- Addresses distributed reforming of renewable liquids. Addresses cost issues, efficiencies, feedstock variety. As long as this project stays focused on reforming to hydrogen from "realistic" feedstocks, it is relevant.
- The project is fully relevant to the long-term goal of producing hydrogen from renewable feedstocks.
- A novel pathway!

Question 2: Approach to performing the research and development

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

- Project addresses feedstock impurities issue by exploring glucose and hemicellulose in the upcoming fiscal year.
- Safety issues with respect to lab-scale experiments are addressed.
- No information presented on reactor or process capital costs.
- The R&D approach is adequate.
- Use of combinatorial screening of catalysts was appropriate. Remaining approach addresses barriers. Would have liked to hear mote about the role of microchannel reactors in this project; are they a focus?
- There appears to be significant overlap with the Virent Aqueous Phase Reforming project (which was initiated in late 2005), but the collaboration activities are not specifically discussed.
- Well designed, but many years ahead before the pathway is commercial. Not clear how this might fit in from time scale.

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

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

- Project has made great progress towards the completion of each task to date.
- Catalyst performance is measured against the specificity/productivity/lifetime targets established by project.
- Sorbitol APR: what is the difference between the productivities on slide 13 (91.3 L/Lcat/hr) and slide 14 (~57 L/Lcat/hr)--what are the process conditions for these runs of different C3 feedstocks?

- No comparison of results for different feedstocks.
- Project is on track.
- At basic science level 4.0. At a cost trend for production cost, not much data yet.

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

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

- Collaboration with Virent project and ethanol producers was mentioned.
- Details of the collaborations are lacking.
- Are there synergies with traditional reforming or lessons to learn from other reforming projects?
- Coordination with Virent was not defined -- there should be ongoing information exchange and coordination between the two projects to ensure efforts are leveraged and are not duplicated.
- No collaboration has been established with an ethanol producer for the ethanol steam reforming work.
- Expand further.

Question 5: Approach to and relevance of proposed future research

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

- Future work is investigating feasibility of using less pure renewable feedstocks--this is key to economic viability of technology since feedstock costs account for a significant fraction of the production cost.
- Ethanol reforming work focuses on meeting thermal efficiency and production cost targets.
- Are catalyst lifetime studies of 100 hours sufficient? (1,000-10,000 hours is often used by catalyst development companies).
- Economic analysis will be most important. Go/no-go decision points are appropriate and are scheduled for next year.
- Improved collaboration efforts are needed to focus future work.
- Better articulate the work planned and the results expected, instead of just a task list.

Strengths and weaknesses

Strengths
- The technologies being investigated have the potential to achieve DOE goal of economic, renewable-based hydrogen.
- Very novel pathway.

Weaknesses
- No indication of what the catalyst productivity/specificity and other technology targets correspond to relative to the cost of hydrogen.
- Need more feedstock comparisons.
- Provide more cause and effect data.

Specific recommendations and additions or deletions to the work scope

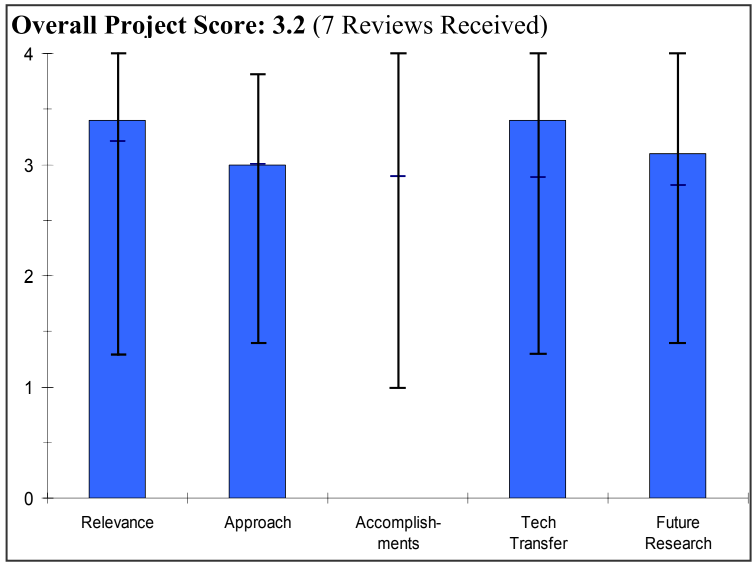
- Expand outreach to industry beyond what is currently in place.

Project # PD-07: Hydrogen Generation from Biomass-Derived Carbohydrates via the Aqueous-Phase Reforming (APR) Process

Cortright, Randy; Virent Energy Sys.

Brief Summary of Project

This project will combine the expertise of Virent Energy Systems (Virent), Universal Oil Products LLC (UOP), Archer Daniels Midland Company (ADM), and the University of Wisconsin to demonstrate the feasibility of generating high yields of hydrogen from corn. This proposed concept takes advantage of the fact that corn contains large amounts of starch which can be extracted and converted to glucose and sorbitol. Sugar based feedstock can also be produced from other biomass sources. The resulting aqueous solutions can be fed to the Virent's novel aqueous-phase reforming (APR) process that generates hydrogen in a single reactor. The effluent gas from the APR process can then be efficiently purified to produce high purity hydrogen utilizing a pressure swing adsorption.



Question 1: Relevance to overall DOE objectives

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

- Project directly supports the objective of generating H_2 from renewable bioliquids by 2015 at $2.50/gge.
- Technology is innovative and offers a pathway for renewable resource-based hydrogen.
- Clearly addresses technical objective: "By 2015, reduce the cost of hydrogen produced from biomass...by developing reforming technologies..."
- Also well-focused on goal of attaining "distributed hydrogen production technologies": an intermediate step toward long-term hydrogen production goals.
- Rather than focusing on natural gas or liquid fuels (the "low hanging fruit") attempts to access renewable carbon sources as hydrogen feedstock directly.
- Ultimately how much hydrogen could be expected from agriculture biomass in the U.S., without impacting food and industrial uses?
- Catalyst work is important to success of hydrogen from renewable liquids.
- Project is fully relevant to supporting the objective of developing low-cost methods for converting biomass to hydrogen.
- The project is aware of DOE hydrogen program objectives and the need to meet targets
- The project does support the hydrogen RD&D plan.

Question 2: Approach to performing the research and development

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

- The R&D approach makes sense.
- Project only looking at glucose and sorbitol as feedstocks--what about less clean feeds such as hydrolyzed lignocellulosics?
- The rationale behind APR of oxygenated hydrocarbons, as opposed to alkanes, is well articulated and reasonable.
- APR avoids high temperatures and pressures while, at the same time, using biologically derived feedstocks rather than petroleum products -- APR approach is therefore particularly mission-relevant.

- Little discussion of reactor design or scale-up possibilities.
- Project is a combination of integration and component R&D.
- Early focus on glucose and catalysts is appropriate. Go/no-go decisions points appear to be appropriate, but it is not clear if work will continue with a different feedstock if glucose is a no-go.
- Little detail presented on the actual project approach (too much detail presented on reaction pathways, etc.).
- Project timelines provide a reasonable sequence of events.
- Good to see that the thermal efficiency and economics of the baseline APR will be calculated in the first year, prior to the first go/no-go decision.
- The proposed plan seems reasonable.
- The PI should assess whether low system efficiency due to high water content is a concern.
- How likely is project to meet DOE cost targets?
- The approach appears to be sound for a new project.
- Increased emphasis should be placed on catalyst development, testing and evaluation early on in the project. This will impact the overall cost and efficiency of the project.

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

This project has not started and therefore was not scored on accomplishments.

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

This project was rated **3.4** for technology transfer and collaboration.

- Project team appears qualified for performing the work proposed.
- Team includes a player in the biomass feedstock industry.
- Collaborating with PNNL project for reactor configuration work.
- Well integrated-university, national lab, and industry collaboration.
- Overlap with PNNL is apparent; the separate roles of PNNL and Virent (and University of Wisconsin) are not well defined.
- Facilities, staff, and project infrastructure is very impressive.
- Partners are appropriate. PNNL work in this area should be coordinated to eliminate duplication and improve chances of success.
- Unclear what the specific role of UOP will be.
- Good mention of similarity with PD-6 presentation.
- This program appears to have a good diverse team.

Question 5: Approach to and relevance of proposed future research

This project was rated **3.1** for proposed future work.

- Project recognizes the impact of feedstock cost on hydrogen production cost, but is centered on use of glucose.
- PIs may need to consider lignocellulosic feeds in order to meet DOE cost targets.
- A good plan is articulated.
- "Identify candidate sugar streams" is listed as a first year goal, but only glucose is discussed as a target for reactor design. Is there a plan for considering other sugars or sugar alcohols?
- Choice and optimization of catalyst is discussed. Reactor design and potential pitfalls therein are not discussed.
- Slides 3 and 4 not same as Future Work Gantt chart on pages 18 and 19. Off ramp step-up after catalyst development in Gantt is much better.
- Project has not yet started, but decision points are good and work plan seems reasonable.
- Project timelines provide a reasonable sequence of events.
- It is considered that the timeline is optimistic.
- The plans go beyond go/no-go decision point, which makes sense as this can help to indicate a future path on meeting the goals at the decision point and give confidence for the future achievement of results.
- This project appears to have a good overall plan.

Strengths and weaknesses

Strengths

- Technology addresses the production of renewable resource-based hydrogen.
- Technology is novel.
- An excellent first step toward practical reforming of renewable carbon sources to produce hydrogen.
- Involvement of ADM integrates agricultural production industry into an ongoing university/national lab/industry collaboration.
- Significant potential contribution to hydrogen production.
- Clear understanding of issues. Strong collaboration areas.
- The PI has a good background and experience in this field.
- The project appears to have a very competent and experienced team.
- The initial technical approach appears to be sound.

Weaknesses

- Quantifiable milestones and go/no-go decision points were not presented.
- Technology performance targets were not given.
- Project uses glucose as feedstock rather than lignocellulosic biomass.
- Issues involved in reactor design and fate of waste CO_2 are not addressed, though both are part of the upcoming 3-year project.
- Dependent on success of catalyst development.
- Possible conflict with other uses of agriculture product. Is this in addition to food and other uses? What is the potential for surplus agricultural and or new agriculture?
- Potential duplication with PNNL.
- Project should use H2A economic assumptions in the future for cost analyses.

Specific recommendations and additions or deletions to the work scope

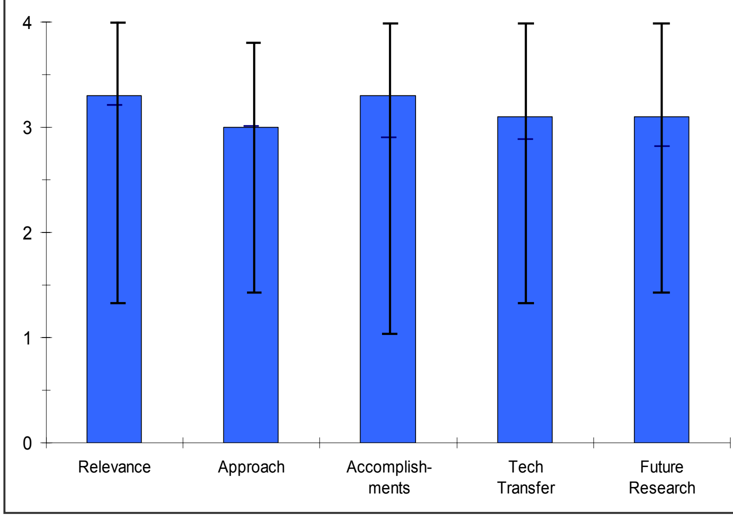
- As acknowledged by the authors, using sorbitol/sugars rather than methane as feedstock will result in a proportionally much larger amount of waste CO_2 per molecule of H_2 produced. (This concern will apply to any plan for converting biomass to hydrogen). The recovery and fate of the waste CO_2 should be accounted for, in reactor design and total hydrogen production costs. However, the CO_2 released is recycled back onto the growth of new biomass so this pathway is a near-zero net GHG emitting pathway.
- Biomass program would benefit from a combined approach to a wider array of biomass.
- Competitive uses for agricultural feeds should be evaluated.
- Program should identify potential contribution to overall U.S. hydrogen production. Project should be asked to relate activity to this ultimate goal.
- Focus on catalysts is the first decision point -- knowledge from catalyst work may be beneficial even beyond this project.
- Combining this project with PD-6 should be considered as there is much similarity and potential overlap.
- Value only comes with scale up -- scalability should be established at an early stage.
- The project should show progression toward reforming of base corn waste, stover, etc., soon, not 'refined' sugar products.
- Emphasize catalyst development and testing early on in the project.

Project # PD-11: Advanced Hydrogen Transport Membranes for Vision 21 Fossil Fuel Plants
Sammells, Anthony; Eltron Research, Inc.

Brief Summary of Project

This project involves the development of an environmentally benign, inexpensive, and efficient method for separating hydrogen from gas mixtures produced during industrial processes, such as coal gasification. Currently, this project is focusing on four basic categories of dense membranes: mixed conducting ceramic/ceramic composites, mixed conducting ceramic/metal (cermet) composites, cermets with hydrogen permeable metals, and layered composites containing hydrogen permeable alloys. Eltron's layered composite hydrogen separation membranes have an order of magnitude higher hydrogen permeability than current palladium based membranes and are 200 times cheaper. In addition, these membranes operate at 320-440^{o}C, which is consistent with water-gas-shift temperatures in gasified coal feed streams.

Overall Project Score: 3.2 (7 Reviews Received)



Question 1: Relevance to overall DOE objectives

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

- Would be good to specifically address this in the presentation.
- What advantages does this technology offer over the conventional technologies?
- Barriers listed in overview were not adequately addressed in presentation.
- This project supports the President's Hydrogen Fuel Initiative to accelerate the introduction of hydrogen as the primary energy carrier in the USA.
- The project shows close bearing to DOE's RD&D Plan. If successfully implemented, it is essential for the realization of the President's Hydrogen Fuel Initiative.
- Relates to a separation of hydrogen.
- Close attention paid to the membrane integration into a coal gasification plant to produce hydrogen.

Question 2: Approach to performing the research and development

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

- The project has a lack of focus on durability testing prior to scale up. The effects of impurities other than CO need evaluated for Fossil Energy application.
- Have any experiments on hydrogen purity been performed? Or conversion of CO? None were shown in the presentation. Permeation and flux are not the only parameters that need to be studied.
- 100% selectivity and recovery will not be achieved.
- Researchers should be congratulated for trying to incorporate systems thinking, but they are not taking into account actual conditions at SMR, coal gasification and biomass gasification plants. Into the WGS reactors, there is unconverted CH4 and impurities. Also, the off-gas from conventional PSA units is used to fuel the reforming reaction. Without this gas being available, the plant will have to burn additional fuel in the reformer. This will result in CO_2 emissions that cannot cheaply be sequestered. Slide 20 is misleading and incorrect.
- What is the conversion of CO in the WGS reactor?

- Modeling experiments should be conducted to determine the total conversion of CO in the water gas shift reactor. Even though the temperature is higher than conventional low-temperature WGS, the removal of product hydrogen will shift the equilibrium to the right. But the researchers must determine to what extent.
- Not using the retentate to fuel the reformer is a big mistake. You're losing the energy in the unconverted CO, CH4, and unrecovered hydrogen. It would be very unfortunate to sequester these energy-containing compounds with the CO_2. The researchers should investigate systems designs that would solve this problem.
- The project addresses the cost reduction of the hydrogen production from fossil fuels through the development of membranes with high hydrogen flux at high temperatures.
- The approach is sound and logical.
- Some consideration should be given towards addressing challenges in the commercial manufacture of the applicant's (Eltron) hydrogen membrane.
- Comparisons with other membrane types should be done on an equal basis (i.e., similar physical conditions).
- The membrane development work here would benefit from having a well-defined total system engineering model.
- A good systematic approach was proposed and implemented.

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

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

- A project that began in 2000 should have performed a full economic analysis by now. Recommend no further funding before establishing economic viability.
- Verbal statement about mass transfer limitations in the catalytic membrane reactor was very interesting. Good lesson learned. Should elaborate on this. Does this mean that you are planning on using this membrane only for separation? Have you considered installing static mixing impellers inside the membrane to increase the contact probability between the hydrogen and the membrane?
- Why did the membrane need to be regenerated when you were running at 80% hydrogen and 20% helium? This is obviously not due to adsorption of CO on the membrane surface.
- Adsorption of CO on membrane surface is an important finding. To combat this, will you flush with pure hydrogen? How often will depend on economics, but please realize that experimental data are required. How long were experiments run in Slide 13?
- Very good that experiments were conducted without sweep gas.
- Scale of Y-axis (same measured results) is significantly different between many of the slides, e.g., 10, 11, 12, 15. The different parameters that lead to the different results should be shown on the graph. Should perform parametric experiments to obtain results that can be compared across experiments and applied to further analysis.
- The performance of the purification process has to be improved since the hydrogen recovery is around 95%. Unfortunately, this can not be achieved without additional purification step which increases the cost of the process.
- The performance of the water gas shift catalyst and membrane in the presence of sulfur was not evaluated.
- The project appears to be progressing well on schedule and has identified barriers to meeting objectives together with strategies to address these barriers.
- The tolerance of the membranes to impurities was not sufficiently discussed.
- Outstanding membrane discovery and development work, as reflected by reported hydrogen performance data.
- Good process made in several key aspects including hydrogen flux improvements and membrane material improvement to lower the operating temperature.

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

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

- The companies that are listed certainly form a good network. Presentation should give details on how much funding goes to each partner, what the role of each partner is, and how the project team is coordinated.

- The project lists three industrial partners and one national lab. It is unclear what work was performed by each participant.
- Collaboration with engineering firms is cited but there seemed to be a reluctance to report on the real life performance application parameters.
- More integration with end-users of the engineering firms would be desired to seek R&D inputs.

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

This project was rated **3.1** for proposed future work.

- Future work lacks reliability/durability testing. Fossil applications are unpredictable if there is a need for thermal mechanical testing to predict long-term reliability.
- If the project is scheduled to end Sept 30, 2005, are the plans shown for FY06 proposed? Is there any funding for this?
- Not enough information on remainder of FY05 work was given. What is meant by "performance verification?" Verify what? Will hydrogen purity be verified, as stated in the barriers that are being addressed? How about conversion? Total hydrogen recovery? There are a lot of key pieces of information missing from this five-year old project.
- Need to determine why membrane loses functionality over time. Chemical changes to membrane or clogging?
- Need to study permeability as a function of distance along membrane. Economic analysis is not possible without these data. Good that you realize that there is a trade-off, but you're not even doing the experiments to begin to understand that trade-off.
- The future work plans to integrate the coal gasification system with WGSR and membrane. But, it does not address the increase of the efficiency of hydrogen recovery and catalyst and membrane poisoning by sulfur.
- Future plan is well focused on the construction and operation of bench (1.3.lb/day) and pilot (5 lb/day) units.
- The reported on very high quality membrane research/development work should continue.
- There will be a new five year plan to continue development work.

<u>Strengths and weaknesses</u>

<u>Strengths</u>
- Interesting materials.
- Good laboratory facilities.
- Good potential for new high flux membrane.
- The development of a membrane with high hydrogen flux under the reaction conditions.
- The project appears to have developed a hydrogen separation membrane that warrants further development and investigation. The characteristics of the membrane appear to supersede other types of membranes.
- Highly innovative, successful membrane development.
- Long term membrane performance data were presented. Membrane performance data at high pressure were presented. Progressive improvements in hydrogen flux of membranes were presented.

<u>Weaknesses</u>
- Team needs someone who can do analysis work. This research has gone on blindly too long. Cannot appropriately design experiments if you don't know what you're trying to achieve.
- Too many figures of merit have not been studied: 1) hydrogen purity, 2) CO conversion, 3) hydrogen flux as a function of feed throughput, without additional hydrogen added in, 4) total hydrogen recovery.
- The hydrogen recovery obtained by the membrane decreases the efficiency of the process, which inhibits a higher reduction of the cost of hydrogen production.
- The performance of the applicant's membrane should be more accurately quantified with "apples to apples" comparisons with other membranes.
- The PI states that the project is 85% complete, with plans to build and operate a bench and pilot scale test unit as part of its future work. It is unclear if the construction and operation of these two test units will be completed with the funds provided for the original project ($2.8 million).
- Project costs are high in comparison to other projects that have comparable accomplishments.

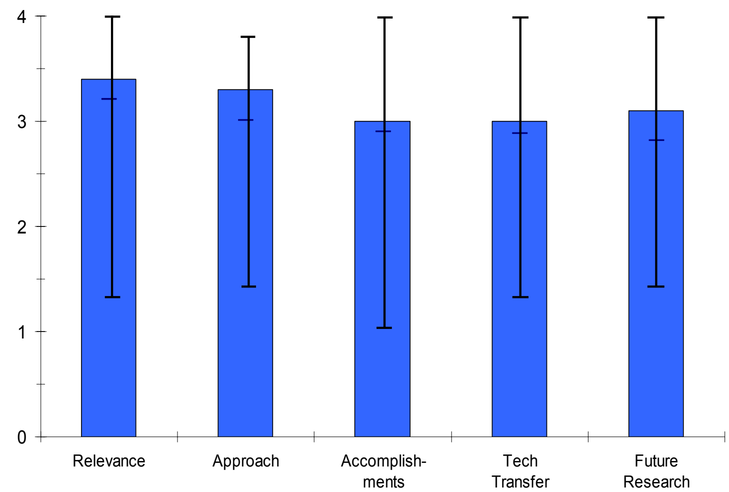
- An apparent lack of a total system engineering model to serve as a context within which guiding economics could be derived.
- The "guard bed" used in the experimental work and future deployment was not discussed adequately. No conclusions and milestone were presented. Module assembling and its associated engineering issues were not adequately discussed (i.e., capacity per stacked module).

Specific recommendations and additions or deletions to the work scope

- More emphasis on long term testing with thermal cycling.
- Need to present results on hydrogen purity.
- Need to perform total plant CO_2 balance. This should take into account the emissions from the reformer combustor. Slide 20 does not show the full emissions.
- Need to do some cost analysis. References to cost studies are presented out of context (i.e., not necessarily representative of the current work) and not based on Hydrogen Program standards.
- Need to present results with true syngas (includes not only CO but also methane and other impurities). A guard bed won't solve all impurity problems.
- Continue the project but now progressing to an engineering 'unit process' development mode. Needs total system design with economics.
- Give quantitative estimates on the membrane cost estimates. Expand work on the sulfur tolerance of membranes. Expand work on membrane performance under cycling conditions. More work on the CO effects on membrane performance. More fundamental study on the phases of palladium in membrane under testing conditions.

Project # PD-12: Scale-up of Microporous Inorganic Hydrogen-Separations Membranes
Bischoff, Brian; Oak Ridge National Laboratory

Overall Project Score: 3.2 (9 Reviews Received)



<u>**Brief Summary of Project**</u>

This Oak Ridge National Laboratory project will investigate the scale-up of microporous inorganic hydrogen separation membranes for use in coal gasification systems. The candidate membranes are based on those developed on the DOE Office of Fossil Energy Advanced Research Materials Program, which are robust, have high hydrogen flux, and high separation factors. This project will investigate the scaling factors for fabrication of approximately one-meter long tubular membranes, the effect of composition of the coal-derived synthesis gas which is the feed material to the membranes, temperature and pressure of operation, compatibility of the membranes with the synthesis gas, total gas flows, hydrogen gas flow through the membranes, the cut (fraction of total gas that passes through the membranes) of the gas, and membrane system design and configuration.

<u>**Question 1: Relevance to overall DOE objectives**</u>

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

- A cost-effective coal gas derived hydrogen production technology responds to Hydrogen Fuel Initiative RD&D needs and the proposed work is consistent with DOE program goals.
- The project technical strategy does not include any discussion of a development path leading to scale-up and commercial maturity or any success criterion such as how to achieve DOE hydrogen cost target.
- Considering the 50 yr experience base, a list of risks and barriers and planned accomplishments to overcome key technical obstacles is appropriate.
- It is not clear what differentiates the proposed technology, i.e., how it is techno-economically superior to, existing and proven commercial separation technologies, such as PSA.
- This project is funded by FE and relevant not only to coal, but also biomass gasification as well as for CNG distributed reforming.
- Would be good to specifically address this in presentation.
- What benefits does this technology offer over conventional separations technology?
- Barriers not given in slides.
- The project, if successful, supports the critical goal for improved, lower cost separations.
- This project supports the President's Hydrogen Fuel Initiative to accelerate the introduction of hydrogen as the primary energy carrier in the USA.
- The project clearly supports the President's Hydrogen Fuel Initiative and fits in well with the RD&D Plan objectives.
- Consistent with the object of generating hydrogen from fossil fuel gasification stream.
- Offers a promising alternative technology to carry out hydrogen membrane separation. Will not be able to achieve high purity hydrogen.

Question 2: Approach to performing the research and development

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

- Data indicates high operating temperature favors both flux and hydrogen selectivity, higher than ideal warm gas clean up temperature of approximately 300 deg C.
- The material exhibits the expected temperature dependence for its performance beyond the ideal warm gas clean up conditions; the PI needs to look at this issue (on how to achieve commercially relevant flux at warm gas clean up conditions).
- The delivery condition (T, P) of the PSDF coal gas slip stream is not discussed, nor the clean up procedures.
- The PI clarified during the review that the 0.4-5 nm pore size is a generic scheme; actual pore size will be tuned to allow selective diffusion of hydrogen (KE ~0.3 nm) while retaining CO_2 on the feed side.
- The project just began but is based on significant background capabilities.
- The project should conform to the HFCIT defined barriers and targets which are quantitative with milestones if there are no similar metrics in the FE program.
- Economic analysis should be done throughout project to provide research direction.
- Application of the existing technology developed at ORNL to this particular need is a very good way to start.
- Proposed larger (1 meter) scale is appropriate and encouraged.
- Very good that the project will screening materials using compatibility tests to determine effects of different gasifier environments.
- PI seemed a bit unconcerned about leaks.
- The project addresses the cost reduction of the hydrogen production from coal through tests in pilot plant scale of hydrogen separation membranes.
- The approach is technically sound and logically focused toward reaching the final goal.
- It is very hard to see how practical hydrogen, CO, H_2S, etc. selectivities might be realized using microporous membranes.

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

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

- Tasks have been initiated. Planned tasks are conducive to achieving project goals. The work and schedule are consistent with DOE Program requirements. A major accomplishment is making spherical SS powders of uniform size and narrow size distribution. Sulfur tolerant materials have been identified as well as high temperature (> 500 deg C) material. Powder sintered SS tubes fabricated and module design in progress.
- Better separation at high temperature is important and needs to be incorporated in the gas conditioning plan. For example, will wet scrubbing need to be incorporated in the process prior to separation to remove contaminants and, if so, will the gas be heated back up to the optimum temperature?
- The gas purity is 95% which will presumably not be adequate for fuel cell applications. What is the technical approach for increasing purity?
- Kudos for acknowledging that you will get less than 100% selectivity. All membranes will suffer from this, but your willingness to discuss this will mean that you are more likely to achieve success and design the best "system." This might include some further hydrogen purification; please make sure to take this into account in design.
- Good use of results from previous research.
- The project was recently initiated and has made good progress; seems to be a little behind schedule.
- The project just started and then this criterion was not evaluated.
- The project only started in Dec 2004, but several preparatory project plan tasks have been initiated.
- Project has just started. Initial data on hydrogen: CO_2 selectivities of ~2:1 is not very encouraging.
- Contract just started.

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

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

- ORNL is working with NETL and Ames to successfully execute the tasks. PSDF facility will be used for long term tests with candidate materials. Meetings among technology partners have been held and continuing.
- The Partnerships being established with Southern Company, Pall, and NETL are promising but as yet undefined. The technical interaction with Pall on metal interfaces needs to be directed towards the eventual commercial scale of operation due to the importance of cracking in large scale systems.
- Good ideas on collaborators. This should be the very first thing that you accomplish. Seems that it should have been done before the project plan was finished, as different partners could bring unexpected capabilities. Organizing collaborators is not on the project schedule.
- Firm commitments from Pall, Southern Company and the commercial gasifier operator need to be established.
- The project is establishing partnership with industries.
- The project lists all its partners at the outset of the presentation and clearly identified their roles.
- Collaboration with Pall and NETL.
- Track records on prior experience of ORNL in membrane technology transfer area were not addressed.

Question 5: Approach to and relevance of proposed future research

This project was rated **3.1** for proposed future work.

- Future work plan is consistent with achieving proposed task objectives.
- The project will benefit from an experimental plan with explicit performance criteria. What will be the impact of trace contaminants besides sulfur species on the surface, such as phospine and arsine?
- The commercial scale of the system should be known and used to determine tests of physical stability at target operating temperature.
- Will you suffer from adsorption of CO, CO_2, etc. on the membrane?
- Plans presented on slides 17, 18, and 19 show excellent foresight.
- Would be rated a 4 if there were firm commitments in place from the commercial partners for fabrication and testing plans.
- The applicants future work plan is well thought-out and focused toward the construction and testing of membrane modules at a commercial gasifier facility.
- The project schedule should include some flexibility to accommodate any unforeseen failures or challenges encountered during the implementation of this project.
- No specific input, ideas were provided for realizing the needed >>2:1 hydrogen: CO_2 selectivity for the membrane.

Strengths and weaknesses

Strengths

- The project goals are consistent with DOE Program requirements of technology R&D for planned transition to hydrogen economy. The project aims to develop a technology to cost-effectively separate hydrogen from industrial gases, such as from a coal gasifier. The proposed effort builds on significant prior knowledge base available to the PI, and successful project outcome is highly likely.
- This new project rests on strong capabilities in membrane development.
- ORNL expertise in this area is a significant strength. Capability in this area will significantly help this project achieve success.
- Use or previous success in this area should be commended.
- The development in pilot scale of a hydrogen separation membrane with mechanical, thermal and chemical stability.

- The project only began in Dec 2004, so milestones and accomplishments are not addressed. The work effort is a logical continuation of work performed in the past under a different project, where the current effort seeks to eventually demonstrate at the pilot scale, the efficacy of a membrane system to separate hydrogen from a coal-based syngas
- The strength of the program lies in exploiting the very considerable technology base at Oak Ridge on microporous membranes. Hopefully some (perhaps recently declassified) new knowledge could be applied to address the hydrogen:other gases high selectivity challenge.
- Progress in membrane fabrication areas was presented.

Weaknesses
- The work is routine data gathering using known techniques. The work lacks innovative approaches; differences from current state-of-the-art are not explained, nor clear.
- It is not clear how the completion of the future tasks will expand the knowledge base to advance the hydrogen production technology beyond current state-of-the-art.
- It is not clear why the title and purpose of the project is scale-up using prior expertise and technical know-how, because hydrogen separation materials are not yet selected (or available) for scale-up.
- Recognizing that this is funded by FE, the EERE cost and performance targets should be addressed in the work and in future presentations.
- Is 95% purity good enough, given competing technologies that are being developed?
- Project plan needs to be revisited once collaborators are in place.
- Project should bring analyst in early on to help identify economic viability and areas that should be focused on in the design of the system.
- The extent of hydrogen recovery and the purity of hydrogen obtained by using these inorganic membranes can reduce the efficiency of the process and the cost of hydrogen production.
- A participation agreement between all concerned parties is unclear at this point, i.e., CRADA or other contract vehicle with Pall. All agreements should be quickly established to avoid any project delays or show-stoppers.
- The weakness is the inherent limited selectivity of microporous membranes, which the PI clearly recognizes.
- The background data discussion on membrane performance was inadequate. Inadequate discussions on follow-on step needed to achieve high hydrogen purity.

Specific recommendations and additions or deletions to the work scope

- None.
- It is recommended to improve the hydrogen selectivity of the membranes before scale-up.
- A suggestion: Could known totally selective dense hydrogen transport membrane materials be somehow utilized in conjunction with the present microporous membranes to achieve the required (not necessarily infinite) hydrogen, CO_2, H_2S, etc. selectivities?
- Need to develop quantitative membrane performance criteria which must be met in order to advance the testing from bench to larger scale units. Long term life membrane testing is needed. Need to obtain membrane performance data in the temperature and pressure ranges which match the feed stream from coal gasification step. Investigate the effects of membrane thickness/membrane pore ratio on membrane performance.

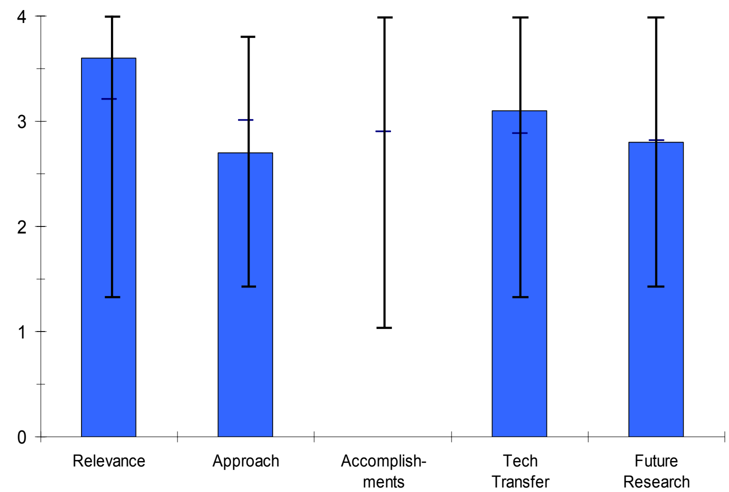
Project # PD-13: Low Cost Hydrogen Production from Biomass Using Novel Membrane Gasification Reactor

Lau, Francis; Gas Technology Institute (GTI)

Brief Summary of Project

The Gas Technology Institute project team (Arizona State University, National Energy Technology Laboratory, Schott Glass and Wah-Chang) will evaluate a novel concept of direct hydrogen production from biomass using a membrane reactor in a gasification process. The integrated gasifier and membrane reactor system is expected to meet or exceed the DOE's cost target of \$2.50/Kg H_2 for hydrogen production from biomass. The project will identify preferred candidate membranes (metal, ceramic, and glass), synthesize the materials, fabricate the membranes, test membrane performance, assemble a membrane module and demonstrate hydrogen production in a bench scale biomass gasification unit.

Overall Project Score: 3.1 (7 Reviews Received)



Question 1: Relevance to overall DOE objectives

This project earned a score of **3.6** for its relevance to DOE objectives.

- The project goal is to produce pure renewable hydrogen using a separation membrane integral with a biomass gasifier. This addresses renewable hydrogen production.
- No timeframe was presented.
- Does not specify candidate biomass type; nevertheless, highly relevant to a large class of non-agricultural biomass.
- Addresses DOE barriers as well as cost.
- The project, if successful, supports the critical goal of improved separations and a one-step shift reactor would lower costs of hydrogen production from biomass.
- The project does support the hydrogen RD&D plan.
- This project supports the President's Hydrogen Fuel Initiative to accelerate the introduction of hydrogen as the primary energy carrier in the USA.

Question 2: Approach to performing the research and development

This project was rated **2.7** on its approach.

- Although the approach is sound, gasifier technology is difficult.
- Membrane selection, development, and demonstration in only 2 years seem overly ambitious.
- Novel approach simplifies process, reducing capital costs.
- Seeking hydrogen production efficiency gain over conventional gasification.
- Cyclone System - is it low cost? Won't recycling of cyclone rejects build up in gasification chamber?
- Attempts to provide pure CO_2 output stream (for sequestration).
- Multiple fronts for membrane work. Need some decision points -- what are the show stoppers?
- The PI stated that the "types of membranes we have selected are 100% selective for hydrogen" -- on what basis is this assertion made?
- The scope of task 1, "to synthesize and test ceramic, metallic and multi-phase membranes," is far too ambitious given that numerous organizations have been working for years to develop successful membranes. What is the plan for coordinating with or building on these efforts?

- The approach appears to be sound for a new project.
- Increased emphasis should be placed on membrane development, testing and evaluation early on in the project which will impact the overall cost and efficiency of the project.
- The project addresses the cost reduction of the hydrogen production from biomass by developing a membrane reactor which combines gasification, with reforming and shift in one step.

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

This project has not started and therefore was not scored on accomplishments.

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

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

- The Team seems to cover the necessary expertise. However, the capabilities/businesses of the partners are not fully described. What is Wah Chang's core business?
- Partnerships appear effective. Should consider picking up a partner to validate sequestration potential.
- Are there any other DOE projects that may contribute to or benefit from the membrane work?
- Rated a 3 because it is unclear to me that this team is connected well enough to the organizations/expertise who have been leading work in the membrane field (such as Pall, Eltron, IdaTech, ORNL, SNL, etc.)
- This program appears to have a good diverse team.
- The collaboration with industry/university/laboratory exists and the tasks of each partner are clearly defined.

Question 5: Approach to and relevance of proposed future research

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

- The program has not officially started but the plan is logical.
- No timeline provided.
- Where are the go/no-go decision points?
- Material Synthesis & Testing Development should be highest priority; otherwise, well detailed with discussion of steps and methods.
- Project not yet started. Tasks are appropriate.
- There needs to be a major go/no-go decision before any work beyond Task 2.
- No proposed schedule was presented.
- This project appears to have a good overall plan.

Strengths and weaknesses

Strengths
- Promising process for hydrogen production from wood, waste, and other cellulose type biomass.
- Development of membrane/catalysts that can operate at gasifier temperatures would enable this and other projects.
- Reduction of capital costs worthy of effort.
- Strongly focused on DOE hydrogen from biomass targets. Work may prove to be applicable to other feedstocks/projects.
- The project appears to have a very competent and experienced team.
- The initial technical approach appears to be sound.
- Cost reduction of hydrogen production from biomass due to the elimination of steps.

Weaknesses

- Schedules, decision points, lacking in material presented.
- Extensive lab work would be necessary to prove feasibility of operations.
- Need decision points. Membrane work will be challenging -- need to define criteria for success, hydrogen purity, etc.
- Performance critically related to availability of robust membrane.
- The critical importance of the membrane in this project puts its development and evaluation on a critical pathway.
- The membrane that is selected will need to be demonstrated in a very difficult operating environment.
- Coke and sulfur resistance of membrane and catalyst under the reaction conditions.

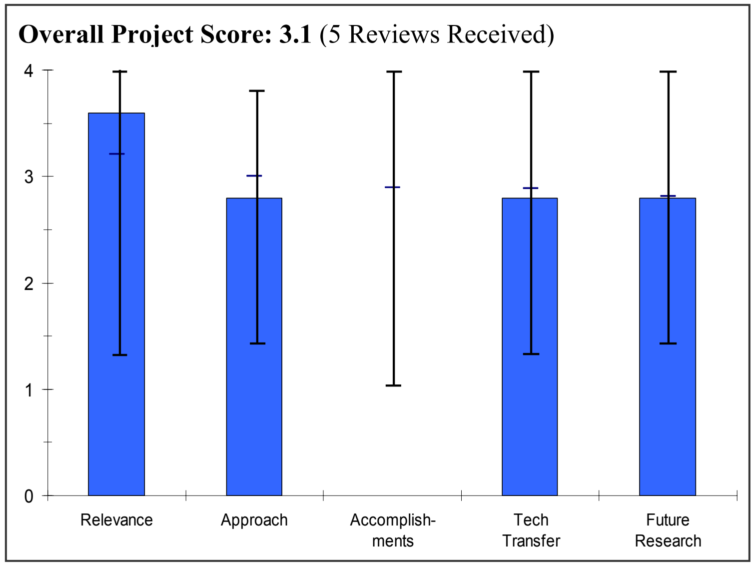
Specific recommendations and additions or deletions to the work scope

- Prioritize membrane/catalyst development with go/no-go at some point before proceeding.
- Detailing of project plans with timeline and decision points.
- Consider taking on a partner to demonstrate sequestration potential.
- Make sure this project takes advantage of any other DOE membrane work that is applicable.
- There needs to be a major go/no-go decision before any work beyond Task 2. No proposed schedule is presented.
- Consider further focusing scope of Task 1 to target on particular membrane materials that show promise.
- Emphasize membrane development and testing early in the project.

Project # PD-14: A Novel Slurry-Based Biomass Reforming Process
Vanderspurt, Tom; United Technologies Research Center

Brief Summary of Project

This United Technologies Research Center/University of North Dakota Environmental Energy Research Center project will provide a route to low cost hydrogen from biomass. This is a hydrogen permeable membrane enabled process where the cellulose and hemicellulose in slurred biomass are hydrolyzed to soluble sugars that then undergo solution phase reforming to hydrogen and CO_2 over a proprietary catalyst resistant to catalyst poisons.



Question 1: Relevance to overall DOE objectives

This project earned a score of **3.6** for its relevance to DOE objectives.

- Hydrogen from renewable (biomass) would advance DOE's goals and objectives.
- Good alignment with DOE program.
- Capable of cellulose and sugar operation
- Focused on DOE costs and efficiency goals for hydrogen. Different approach to hydrogen from biomass compared to other DOE projects.
- Project is fully relevant to the goal of developing options for producing hydrogen from biomass.
- The project does support the hydrogen RD&D plan.

Question 2: Approach to performing the research and development

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

- This seems to be primarily a catalyst development program culminating in a bench-scale reactor demonstration.
- The system efficiency go/no-go decision in FY2006 is appropriate but may not be valid without experimental data on catalyst behavior.
- Should modeling and catalyst development run in parallel?
- Potential for success enhanced with molecular/atomic catalyst design tools.
- Both wood and sugar stream should be tested as feeds.
- Barriers seem to be understood. Possible integration with other projects should be examined.
- The initial feasibility analysis should be carefully and thoroughly conducted so that a go/no-go decision can be made on the basis of realistic expectations for success.
- The approach appears to be sound for a new project.
- The first go/no-go decision appears to occur prior to the completion of the catalyst development stage.
- The development of an efficient, stable and durable catalyst is the key to both the economics and practicality of this overall project.

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

This project has not started and therefore was not scored on accomplishments.

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

This project was rated **2.8** for technology transfer and collaboration.

- Involvement of a (energy) company with deep experience in fuel processing/reforming to assist in reactor design and/or a catalyst company would strengthen the program.
- Great synergy potential through collaboration.
- Unclear what relationships exist with other catalyst developers -- a lot depends on finding the right catalyst.
- Get a chemical or fuel company involved in the project -- who would be operating such a plant if successful?
- This program appears to have an adequate team.

Question 5: Approach to and relevance of proposed future research

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

- The program has not officially started. The vast majority of the presentation focused on catalyst discovery.
- Could use additional go/no-go points, especially during the catalyst development.
- The schedule for the initial analysis seems to be rather lengthy -- can't this time be shortened? Research on catalyst and hydrolysis should be performed concurrently with initial analysis if funding permits, as the results may feed into the analysis.
- More go/no-go decision points are needed (in years 2 and 3).
- This project appears to have a good overall plan but may have underestimated the difficulty in developing an efficient, long-term catalyst.

Strengths and weaknesses

Strengths
- Potential for feeds from cellulose or sugar intensive biomass.
- Good fit with DOE program.
- Employment of advanced molecular/atomic catalyst design.
- PI has good background and experience in catalyst development for the water gas shift reaction.

Weaknesses
- UTRC should involve more partners with specific expertise in fuel processing and reactor design.
- Catalyst development should precede plant and process design.
- Project plan could use additional go/no-go points, particular during with catalyst development phase.
- Not clear if potential challenges with pumping the slurry are addressed.
- The catalyst development will be a major undertaking given the difficult operating environment and it is key to the overall economics and practicality of this proposed process.

Specific recommendations and additions or deletions to the work scope

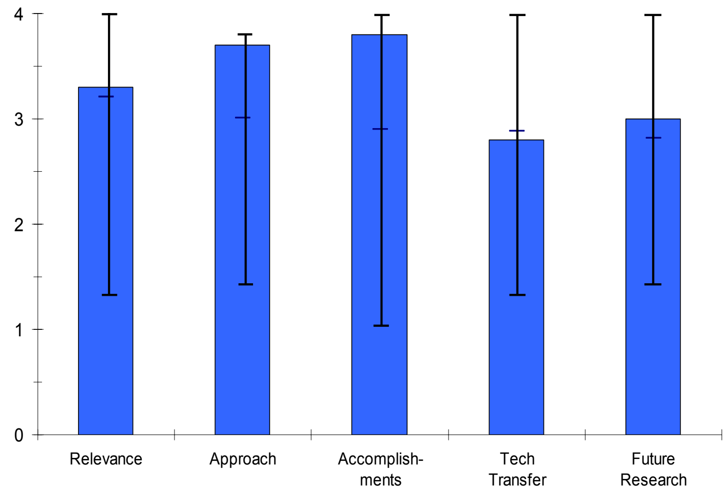
- Add a direct front-end agricultural biomass feed.
- Add go/no-go points in initial catalyst development work.
- Consider delaying design phase to during or after initial catalyst development.
- Another go/no-go decision point might be appropriate to address success or lack thereof on catalyst work if critical to success of project.
- More go/no-go decision points are needed (especially in years 2 and 3).
- Emphasize catalyst development and testing early on in the project and move ahead of go/no-go decision.

Project # PD-15: Maximizing Photosynthetic Efficiencies and Hydrogen Production in Microalgal Cultures
Melis, Tasios; University of California, Berkeley

Brief Summary of Project

In order to maximize photosynthetic efficiencies and hydrogen production in microalgal cultures, the University of California, Berkeley, is using molecular engineering to enhance photosynthetic solar conversion efficiencies and biomass/hydrogen production capabilities under mass culture conditions. The adopted approach applies DNA insertional mutagenesis and screening to isolate truncated chlorophyl antenna relevant transformants. Biochemical, genetic and molecular analyses of the transformant cells is then accomplished, followed by DNA sequencing to identify genes that confer a truncated chlorophyll antenna size (enabling the entire culture to better utilize available light).

Overall Project Score: 3.5 (6 Reviews Received)



Question 1: Relevance to overall DOE objectives

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

- Addresses only one barrier. There is not enough information on how this work impacts other projects and DOE's objectives.
- Very long term research, with good potential if a large number of biological and engineering unknowns are solved.
- The aspect of light efficiency in the context of the overall impact on hydrogen production could have been elaborated to further highlight the importance of this problem and the overall significance of the team's findings.

Question 2: Approach to performing the research and development

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

- The project has a clear focus on reducing the chlorophyll antenna size.
- The approach is thorough with not only identifying gene but also the functional characterization.
- Fundamental research project that is a long way from determination of technical feasibility.
- The approach concerning the identification of mutants and their characterization is well thought out and outstanding. The proposed path concerning the over-expression of the Tla gene product could provide some really significant results. With respect to the work proposed for the characterization of gene product itself, albeit rational, it is not clear it will provide any insights into the function. It may be very useful at this stage to develop a working hypothesis for Tla function that could be approached experimentally.

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

This project was rated **3.8** based on accomplishments.

- Good progress in reaching overall project goal; however, results are not shown in terms of hydrogen production amounts achieved.

- The program has made consistent and significant progress from year-to-year towards meeting the goals.
- Fundamental understanding of the behavior of the microorganism is progressing.
- Clear cut results have been shown that directly impact barriers that are being addressed.

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

This project was rated **2.8** for technology transfer and collaboration.

- More detail on collaboration with partners would be helpful to evaluate the potential impact of the project.
- Using NREL and ORNL to leverage their systems analysis and engineering capabilities.
- Is it possible to collaborate with other institutions to accelerate program?
- Little real collaboration exists.
- The coordination with the NREL group exists, but a greater focus on the overall implications of lowering the efficiency of light harvesting in cells to the overall potential impact on hydrogen production in bulk cultures would make this coordination more clear.

Question 5: Approach to and relevance of proposed future research

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

- Quantitative goal is not defined on future work slide. Is it the 30% long-term goal specified earlier in the presentation?
- The plan for future work is aimed at providing data which will aid in future engineering of the Chlamydomonas reinhardtii.
- Focus is on incremental elucidation of fundamental information.
- The proposed path concerning the over-expression of the Tla gene product could provide some really significant results. With respect to the work proposed for the characterization of the gene product itself, albeit rational, it is not clear it will provide any insights into the function. It may be very useful at this stage to develop a working hypothesis for Tla function that could be approached experimentally.

Strengths and weaknesses

Strengths
- Good progress in meeting project objective.
- Systematic approach to addressing the barrier of light utilization.
- The successful identification and characterization of a mutant strain that produces a lower complement of antenna molecules.
- The proposed experiments concerning the over expression of Tla with the potential for even lower production of chlorophyll molecules.
- The PI helped draft the DOE HFCIT roadmap and is working directly to overcome the technical barriers as defined by DOE.

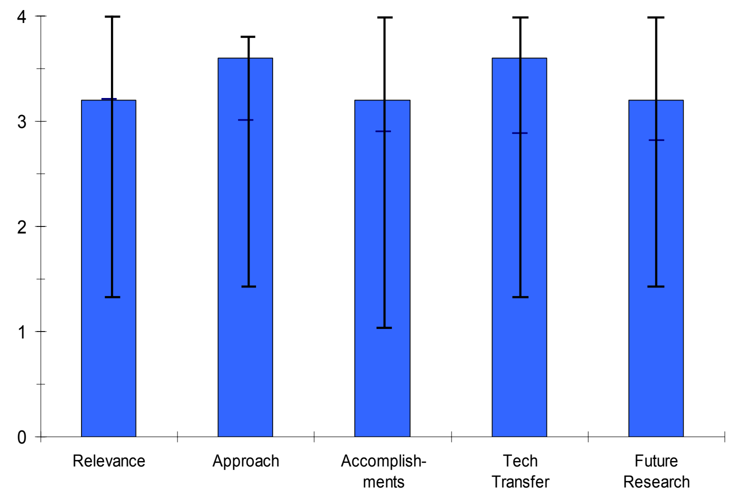
Weaknesses
- Progress towards DOE goals is uncertain since actual hydrogen production from algae is not established.
- The lack of defined goals or hypotheses in experiments aimed at the characterization of Tla.
- The lack of a clearly articulated set of implications concerning the impact of hydrogen production.
- It is not clear how their partners fit in and how they actually work together.

Specific recommendations and additions or deletions to the work scope

- Document progress against the DOE targets as the project proceeds.
- Develop a working hypothesis for Tla function.

Project # PD-16: Biological Systems for Hydrogen Photoproduction
Ghirardi, Maria; National Renewable Energy Laboratory

Overall Project Score: 3.3 (5 Reviews Received)



Brief Summary of Project

The goal of this National Renewable Energy Laboratory project is to develop hydrogen photoproduction technologies based on microbial water-splitting processes. The project is organized into three tasks: engineer an algal hydrogenase that is resistant to oxygen inactivation; develop and optimize a physiological method to produce culture anaerobiosis and subsequent hydrogen production activity in algae; and introduce bacterial hydrogenase with increased oxygen resistance into a water-splitting photosynthetic cyanobacterial system.

Question 1: Relevance to overall DOE objectives

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

- Aims first at making known biological hydrogen generating systems more robust, and in coupling a more robust system to photo oxidation of water. In these ways, addresses Barrier Z: continuity of hydrogen photoproduction.
- Authors argue that their approach addresses long-term hydrogen production goals; not clear why a biological means of hydrogen production should be a better or cheaper long term alternative to other means.
- Discussion of feasible target yields of hydrogen, even theoretical limits, would be helpful.
- Addresses only one barrier.
- The engineering of an oxygen insensitive hydrogenase enzyme could make the use of algae for hydrogen production more practical. The structural characterization of the algal hydrogenase could provide some interesting insights.
- Project addresses the challenge of continuous hydrogen production for biological system.

Question 2: Approach to performing the research and development

This project was rated **3.6** on its approach.

- Producing an O_2-stable hydrogenase is a high priority and rightly central to the approach.
- Current focus is on O_2 channeling to the active site, the hypothesized mechanism of O_2-instability. Some comments:
  a. Proposed double-mutant studies will resolve issue of extent O_2 channeling contribution to active site stability.
  b. Unclear whether pursuing further modeling of O_2 access channels will yield new information.
  c. More comprehensive study of other possible stability determinants may be in order if closing both predicted O_2 channels does not greatly enhance stability.
  d. Using more O_2-tolerant and crystallographically characterized FeFe-H2ase from C. pasteurianum as target for mutagenesis is very reasonable. Is there a plan to study and "improve" O_2 tolerance of semi-O_2-stable NiFe hydrogenase?
- Introducing an O_2-tolerant hydrogenase into a photosynthetic organism is one of the project's ultimate aims. This is an ambitious goal. A clearer set of incremental goals and plans would be helpful.
- PI has clear understanding of technical approach and pathways necessary to achieve goals.

- The long term possibilities of utilization growth under sulfur deprivation are difficult to predict. Developing strategies for metabolic engineering could be more fruitful.
- While the three different approaches were seen as "disjointed" in previous annual review, the multiple approach has a higher likelihood for success.

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

This project was rated **3.2** based on accomplishments.

- Heterologous (E. coli) expression of several Fe-only H_2 cases has been accomplished. This is an excellent advancement.
- A cyanobacterial hydrogenase knockout has been prepared: also a significant and necessary preliminary achievement.
- Coupling hydrogen production to photosynthetic water oxidation using native cyanobacterial electron carriers represents the ideal situation; however, current work shows this may not be very efficient. Is there a practical plan for overcoming this barrier? This could be an especially difficult issue, as reduced mediators such as methylviologen are themselves unstable in O_2.
- Algal immobilization has been demonstrated to enhance hydrogen production. This is a conceptually simple yet important result.
- Progress is shown for all subtasks; however, improvements from previous year results are not specified in the presentation so it is difficult to assess results.
- The identification of the gene products involved in hydrogenase expression is a highly significant achievement and will provide for significant advancements in the context of manipulating the enzyme to enhance the process.
- Identified O_2 pathways that deactivate the hydrogenase. Algae immobilized and hydrogen production increased relative to previous production rate in suspended cultures.

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

This project was rated **3.6** for technology transfer and collaboration.

- Several, mostly academic, collaborators are listed.
- Enlisting participation from a crystallographer and molecular modeling group is appropriate. Participation from a microbiologist with expertise in the appropriate metabolic systems could also be useful.
- Excellent use of collaborations and partners to further research.
- The project is well integrated with Berkeley and Oak Ridge groups.
- Collaboration occurring on all subtasks. Collaboration occurring among DOE Program's biological hydrogen production projects. An integrated system is planned with UC Berkeley and ORNL.

Question 5: Approach to and relevance of proposed future research

This project was rated **3.2** for proposed future work.

- The work is very exploratory and, possibly as a consequence, not much in the way of contingency planning is articulated.
- Long-term aspect of work means that progress towards DOE goals is slow.
- The proposed studies involving the mutagenesis of the hydrogenase enzymes, the expansion into the possibility of using other hydrogenases with desirable properties, and studies aimed at probing the effectiveness of cyanobacteria for hydrogen production will directly explore methods to advance the overall goals.
- Milestone is well defined in the upcoming year for each subtask. PI should have further-out-year plans as well as a "percent completed" grasp on the project.

Strengths and weaknesses

Strengths
- Plan for directly coupling sunlight to hydrogen production, without production of waste CO_2, goes to the heart of the aims of the Hydrogen Initiative.
- Work will push forward basic studies of hydrogenases, an area that has traditionally been characterized by slow progress and difficult-to-handle molecules/systems.
- Basic issues addressed -- mediators of O_2 tolerance in hydrogenases, species and strain variability of hydrogenases, coupling of hydrogenases to electron-carriers -- are of broad relevance, and likely common to any serious effort toward microbial hydrogen production.
- Innovative idea of fiberglass support produced good results. Demonstration of actual hydrogen production is significant in ability to relate the project to overall DOE objectives.
- Significant progress concerning the ability to express hydrogenase heterologously for mutagenesis studies on the hydrogenase enzyme.
- The established team is making good progress.

Weaknesses
- Work in places appears to aim at solving difficult engineering goals before the basic science is firmly in place.
- The unclear justification of the future efficacy of sulfur deprivation as a growth variation for hydrogen production.
- The responses to previous reviewer's comments could have been addressed in a more specific and substantive manner.

Specific recommendations and additions or deletions to the work scope

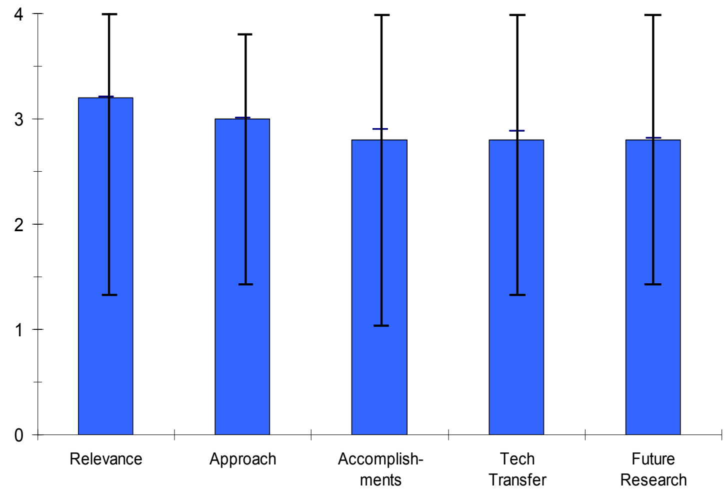
- None provided.

Project # PD-17: Creation of Designer Alga for Efficient and Robust Production of Hydrogen
Lee, James; Oak Ridge National Laboratory

Brief Summary of Project

In this project, Oak Ridge National Laboratory will create a designer alga by inserting a proton channel into the algal thylakoid membrane. This work will move toward overcoming the low rate of hydrogen production in photobiological systems. Success of this work will have a significant impact (a 10-fold improvement) on technology development in the field of renewable hydrogen production from water.

Overall Project Score: 2.9 (6 Reviews Received)



Question 1: Relevance to overall DOE objectives

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

- Clean production of hydrogen by biologically coupled water oxidation/proton reduction is certainly relevant to DOE's objectives.
- The proposed mode of hydrogen generation may not be efficient enough to be useful in the short term.
- This project addresses a key barrier to photobiological hydrogen production.
- Very long term fundamental effort.
- Addresses rate of hydrogen production technical barrier.
- The overall goals of this work interfaces well with the overall goals and work being conducted in the NREL and UC Berkeley groups.

Question 2: Approach to performing the research and development

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

- Whether the proton channel will correctly assemble needs to be tested before progressing to new channel gene designs.
- A proton channel seems to have a strong possibility of toxicity. Even if the algae survive, stably maintaining the channel-encoding plasmid may be difficult. Fairly strong selection pressure may have to be exerted to keep the plasmid in the host.
- The natural level of expression from the hydrogenase promoter may or may not be well-matched with the optimal number of proton channels.
- A thorough investigation of inhibitor studies should be performed to document the scientific basis for the issue and the technical approach. Is it really necessary to design, from scratch, a proton channel and its corresponding gene, or are there other, simpler solutions already available in other organisms?
- Fundamental nature of this effort makes assessment of technical feasibility unrealistic at this stage.
- Approach utilizes modeling and experimental methods. Approach to insert a proton gradient channel addresses four issues affecting the hydrogen production rate.
- The approach is creative, but the implications of the expression of the channel and the recovery of cells during the switch between aerobic and anaerobic metabolism may provide a significant barrier. There is a need to attempt to address this in a more substantive manner.

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

This project was rated **2.8** based on accomplishments.

- The goals for the past year have been met. A channel has been designed, based on known channels. Two gene constructs have been made. These are very modest goals relative to the overall goals of the project.
- Seems to have gotten somewhat sidetracked from the major objective.
- Need to refocus on the proton channel effort and ensure that sufficient basis is developed to understand the potential impact on the full system, including oxygen generation.
- The results to date provide the groundwork for the experimental work proposed.

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

This project was rated **2.8** for technology transfer and collaboration.

- Collaboration with investigators at NREL and UC Berkeley should be helpful for work with photosynthesis and algae, respectively. How active a role these investigators play is not clear at this stage.
- Publications in peer-reviewed literature will be essential for validating approach and results.
- Good cooperation with partners and coordination with other labs working in this area.
- The project is well integrated to the overall goals of utilizing algae for hydrogen production and complements and clearly complements the work at NREL and UC Berkeley very well.

Question 5: Approach to and relevance of proposed future research

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

- The path ahead is clear: the designed constructs are to be inserted into appropriate hosts and tested for channel production (and enhanced anaerobic hydrogen production).
- If the present set of constructs does not work, contingency plans are not clear. Project is described much more like a pilot project than an ongoing investigation.
- Need to work closely with photobiological teams to ensure timeline and activities align with overall approach.
- Should establish quantitative targets for out years.
- The future research direction is sound and the tools are in place to evaluate outcomes.

Strengths and weaknesses

Strengths
- A reasonable rationale for building a channel for dissipating protons in photosynthetic systems has been articulated.
- The materials for carrying out the primary proposed experiment are designed, assembled, and ready. All that remains is to test them.
- Proton channel addresses four issues pertaining to the rate of hydrogen production.
- This is a creative idea that could make a significant impact.
- Well integrated in the overall goals and work at other labs.

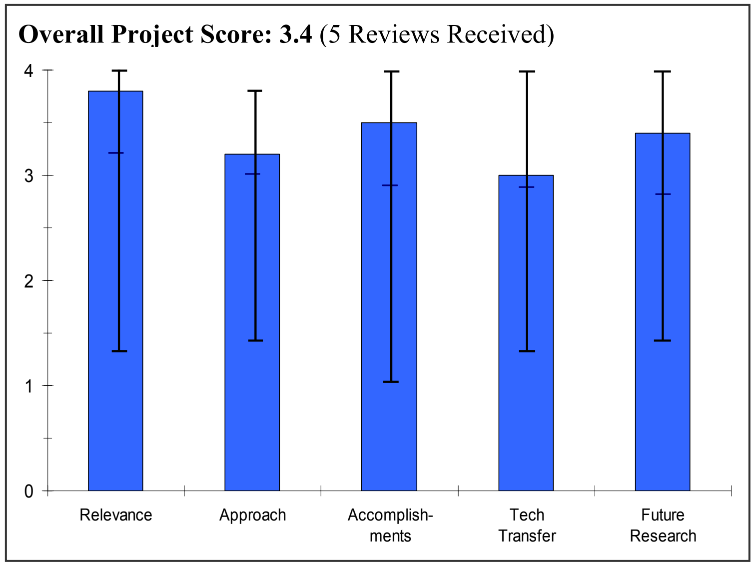
Weaknesses
- Project is very limited in scope: more of a proof-of-principle experiment. Not clear how the approach can/should be revised if the first efforts fail.
- More consideration should be given to the "switch" of the direction of proton flow through the channel with regards to meeting the DOE target.
- The lack of a clear idea concerning the practicality and implications of switching to anaerobic metabolism and the recovery rate of cells.

Specific recommendations and additions or deletions to the work scope

- Before significantly ramping up proton channel efforts, sufficient basis needs to be established and validated by the peer community.

Project # PD-18: Fermentative Approaches to Hydrogen Production

Maness, PinChing; National Renewable Energy Laboratory



Brief Summary of Project

This National Renewable Energy Laboratory project will develop fermentation technologies to convert renewable biomass resources to hydrogen. This project will screen and select for microbes that can efficiently convert cellulose and the various sugars in hemicellulose directly to hydrogen thus lowering the feedstock cost. Metabolic engineering of a selected model microbe is being performed to improve its hydrogen molar yield. Addressing both the feedstock cost and the hydrogen molar yield will enable fermentation technology to be competitive in the long term.

Question 1: Relevance to overall DOE objectives

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

- Strongly addresses issues of hydrogen production yield and use of lower cost feedstocks.
- Begins to address direct and efficient use of agricultural/waste feedstocks.
- Fermentation is articulated as an intermediate strategy, for use as costs of glucose production from biomass gradually lower and may also be useful as a flexible and low-tech option for fuel production from low value feedstocks.
- The project is fully relevant to the goal of biological production of hydrogen from biomass.
- There is a clear need to explore the production of hydrogen from biomass.

Question 2: Approach to performing the research and development

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

- Screening available cellulolytic strains for cellulose degradation capacity and ease of growth is a straightforward strategy.
- The technology for efficient screening (for cellulose degradation and hydrogen production) has been developed and is in place.
- Given the increasing rapidity of microbial whole-genome sequencing, may not be necessary to restrict screening to sequenced organisms.
- Approach to metabolic engineering of chosen strain is not described.
- It is not clear how the microbes are being selected for screening or how extensive the screening effort will be.
- Focus on cellulose feedstock versus glucose will improve the chances that the project will achieve cost H_2 production cost goals.
- Project is building on work with C. Thermocellum, which shows promise for direct fermentation of cellulose.
- For metabolic engineering perhaps a concern is not only the presence of a genome sequence but also that the organism be amenable to genetic manipulation.

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

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

- Progress described since Oct 2004, is impressive.
- Bioreactors for studying cellulose degradation and hydrogen production are well developed.
- Nine strains have been screened, but the anticipated scope of the screening effort is not clear. How were these nine chosen, how well do they represent the diversity of cellulolytic organisms, and how many more (if any) will be screened?
- Not clear what barriers to metabolic engineering strategies are anticipated, or how these will be handled. Presentation more focused on progress to date. Next phase may be significantly more difficult.
- Ability to reclaim solid lignocelluloses products from corn stover is encouraging; approach seems well suited for reclaiming "waste" solids produced from biomass processing to glucose.
- New project.
- Good progress on screening tasks
- New project -- in light of this, very good progress.
- Really nice groundwork has been laid in the early stages of the project. The overall concept is sound but there may be barriers in metabolic engineering.
- Project started in FY05 so design and planned work is good.

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

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

- Limited collaboration is mentioned.
- Consultation with a microbiologist or biochemist with (other groups with) expertise with the relevant microbes and/or metabolic pathways may be useful for the next stage of targeted mutagenesis.
- There was little information on the extent of collaboration with other institutions/projects.
- Good collaboration with other university researchers.
- No collaboration with industry.
- New project -- collaborations just beginning to develop; very good start.
- Looks like partners and sources for target organisms have been identified. Not clear the role of all partners.
- Described intra-project collaboration as well as collaboration among other DOE- funded projects.

Question 5: Approach to and relevance of proposed future research

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

- Details of the strategy for metabolic engineering of the selected strain were not described in the (brief) presentation.
- Lacks quantitative goals for optimization of fermentation parameters and molar yield of hydrogen.
- The future research direction is sound and the tools are in place to evaluate outcomes.
- The future work proposed is sound; perhaps a higher premium should be placed on the practical features of the organism and not the presence of a genome sequence since presumably a sequencing effort for a highly amenable organism could be justified. The team may want to rethink the emphasis on an organism that can utilize the more recalcitrant forms of biomass since it is not necessarily true that these organisms will be most effective for the less recalcitrant forms. The use of a thermopile may be impractical if there are options due to energy required for heating.
- Excellent specification of milestones in all future years of the project.

Strengths and weaknesses

Strengths

- Important problem of direct and efficient conversion of biomass to hydrogen is addressed.
- Impressive and rapid progress has been made so far.
- A logical schematic approach is outlined.
- Baseline level of hydrogen production (from a non-engineered, natural cellulolytic strain) is already very good.
- This is a creative idea that could make a significant impact.
- Very good value given the small size of the DOE investment.
- Solid groundwork has been laid and good preliminary progress has been made.

Weaknesses

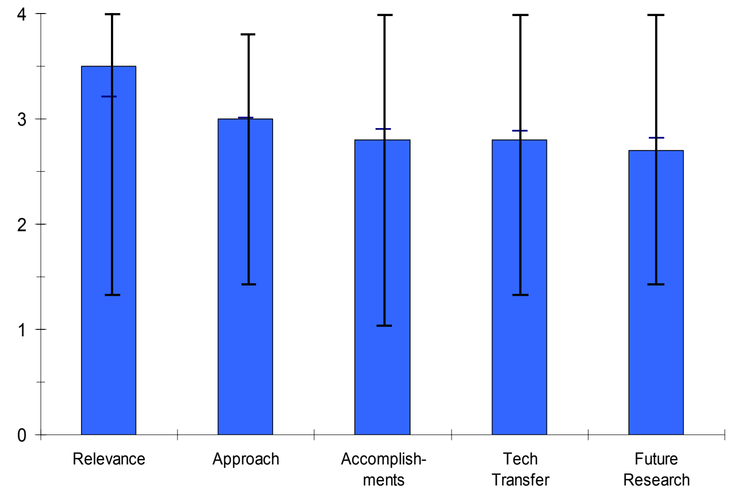
- More discussion of the metabolic engineering strategy would be useful, as this could present significant difficulties
- Perhaps some additional considerations need to be made concerning the priorities of the organism selected as discussed in comments on proposed research.
- The implications of carbon dioxide production in this process were not discussed.

Specific recommendations and additions or deletions to the work scope

- None provided.

Project # PD-19: Hydrogen Reactor Development and Design for Photofermentation and Photolytic Processes
Blake, Dan; National Renewable Energy Laboratory

Overall Project Score: 3.0 (6 Reviews Received)



__Brief Summary of Project__

The objective of this project at the National Renewable Energy Laboratory is to identify materials of construction for reactors that can be used for solar production of hydrogen from water by photobiological or photoelectrochemical processes. This application will likely require large area reactors with demanding specifications for the performance of materials in the outdoor environment. Most of the potential designs will require transparent coverings that have low hydrogen permeability. Accelerated and outdoor weathering testing of materials is underway and key optical and physical properties for photolytic reactor applications are being evaluated.

__Question 1: Relevance to overall DOE objectives__

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

- Addresses long term goal of harnessing solar energy for hydrogen production.
- The project aims at assisting DOE sponsored hydrogen initiative with the identification of solar reactor concepts and developing reactors for photobiological and photoelectrochemical hydrogen production.
- This is clearly a project that must be undertaken in the context of the overall goal of using photosynthetic organisms to produce hydrogen.
- Addresses some key issues on materials of construction and design of reactors for low cost hydrogen via photofermentationn and photoelectrochemistry.

__Question 2: Approach to performing the research and development__

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

- Current work focused on selection and testing of reactor construction materials. This is a natural first step. The technical approach taken is very straightforward and has been effectively executed.
- Possible reactor designs described only schematically; not clear how well developed these plans are.
- The approach of material selection, assembling database on reactor design, and weathering tests are based on sound concepts.
- The approach is well balanced and is integrated with the ongoing research efforts.
- At this point it appears that the groundwork has been laid in terms of cataloging the available information concerning materials potentially available and their properties. The development of prototype reactors compatible with the growth of algae is complementary to the development of growth methods and is justified to be conducted in parallel to this work. The value of doing the work in house was fairly well justified.
- Very good approach.
- Starting with comprehensive data gathering and cheap weathering tests is a good cost-effective approach.
- Most elements of the approach are sound, but the low level of funding only permits a modest amount of work to be done. New work needed in reactor design and modeling as well as significant experimental testing of materials.

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

This project was rated **2.8** based on accomplishments.

- Technical accomplishments are adequate but overall progress seems slow. Timeline for project is quite long.
- The project started in 2003 and only 1% of the goal has been accomplished.
- Selection of polymer material has been attempted by conducting weathering tests and hydrogen and oxygen permeability.
- These preliminary studies should set the course for achieving the goal of designing solar reactors.
- It appears that the footwork and cataloging of potential materials has been accomplished and basic engineering considerations have been addressed.
- Accomplishments are in line with the funding and resources provided. A substantial increase in both will be required to address the critical questions.

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

This project was rated **2.8** for technology transfer and collaboration.

- Collaborations perhaps not necessary or appropriate at this stage, but will be important to establish for next phase.
- Nuclear Filter Technology is serving as an industrial partner.
- Fits well and is a necessary component of the overall concept of harnessing hydrogen producing photosynthetic organisms.
- Excellent job collecting and analyzing info from a variety of sources.
- Insufficient resources.

Question 5: Approach to and relevance of proposed future research

This project was rated **2.7** for proposed future work.

- Presentation slides and/or FY2004 Progress Report do not give much information about proposed future work. Therefore, difficult to evaluate future plans.
- The proposed research of identifying reactor concepts and design is important, but lack of details makes it difficult to assess the merit of future research.
- No specific strategy for minimizing the gas permeability of polymers.
- A reasonable and rational plan for future work is proposed.
- Issue of interaction of material of construction with microorganisms is not analyzed.
- Could bugs lower solar transmittance?
- Plans are modest compared with scale of task. DOE should seriously evaluate it's commitment to this effort at this time.
- The PEC and photofermentation approaches for hydrogen are longer term options, but validating the possibility of an efficient, effective reactor built out of affordable materials is a question that should be addressed sooner rather than later.

Strengths and weaknesses

Strengths
- Very reasonable first steps being taken toward project goal of photoreactor development.
- Project goal well within the defined goals of the hydrogen initiative.
- Carried out weathering and permeability tests for a range of polymers and identified possible candidates.
- Fits well into the overall plan and is a necessary element for using photosynthetic organism to produce hydrogen.
- Breadth of overview.
- Focus on key issues with respect to bioreactor performance

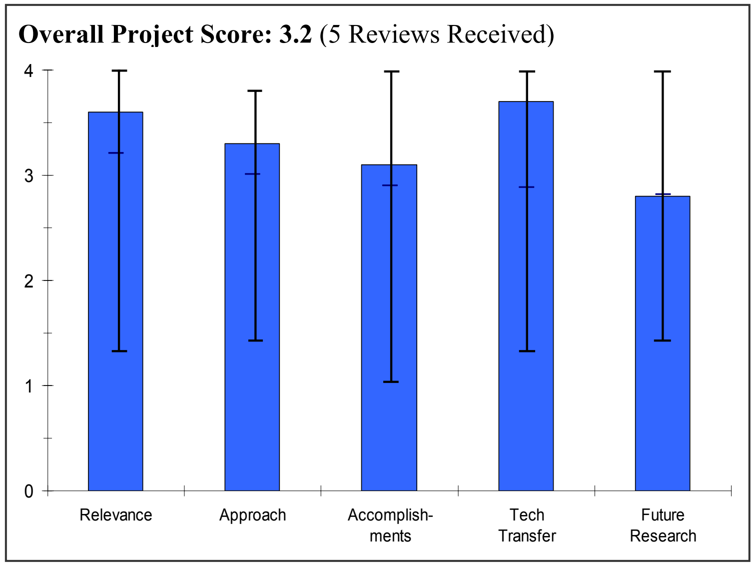
Weaknesses

- Pace and timeline of project seems somewhat slow.
- No detailed outline for designing reactors or conceptual design to address any of the problems highlighted in the presentation.
- The considerations of the heat generated and the thermal conductivity of materials was not addressed very well. It is not clear how temperature will be maintained and how maximizing light intensity and maintaining growth temperatures that are compatible was not adequately addressed.

Specific recommendations and additions or deletions to the work scope

- The research efforts should also include the problems associated with temperature control and influence of electrolytes and catalysts on the degradation of polymer materials.
- Add biocompatibility of various materials.

Project # PD-20: Photoelectrochemical Hydrogen Production: SHGR Program Subtask
Miller, Eric; University of Hawaii



Brief Summary of Project

In this project, University of Hawaii is developing cost-effective photoelectrochemical processes for efficient hydrogen production. Critical components of this work include the design, fabrication and testing of stable multi-junction photoelectrodes that incorporate low-cost thin-film materials and are suitable for use in commercial-scale systems.

Question 1: Relevance to overall DOE objectives

This project earned a score of **3.6** for its relevance to DOE objectives.

- The proposed research on photocatalytic hydrogen production using metal oxide (tungsten trioxide) based semiconductors is quite relevant to DOE Hydrogen Fuel Initiative.
- This is a very well thought-out project that seeks to develop a thin-film oxide photoelectrochemical device for electrolysis of water. The project is highly relevant to the DOE goals, and represents one of the more promising approaches to inexpensive electrolysis.
- Long term effort that could have significant impact.

Question 2: Approach to performing the research and development

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

- The approach of extending the photo response with nitrogen doping is interesting.
- Issues related to charge trapping and charge recombination within the hybrid electrode need to be addressed.
- Minimizing the loss of photogenerated charge carriers at the interface is important towards achieving the goal of 2% efficiency.
- Band energy and redox potential considerations need to be made while evaluating the photocatalysts.
- The approach is straightforward, and shows careful planning with respect to the logical development of large-scale WO_3 films.
- Good thinking about future manufacturability.

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

This project was rated **3.1** based on accomplishments.

- The project has shown satisfactory progress by demonstrating the feasibility concepts.
- "Hybrid Photoelectrode" based on low temperature reactively sputtered films has been demonstrated. The authors have also succeeded in extending the response of the oxide semiconductor into visible by nitrogen doping.
- It is not clear if achievement of 4 to 7 % solar-to-hydrogen efficiency, with large-scale WO_3 films, is within reach. The present performance is only 0.7% -- not very remarkable.
- Efficiencies are still low, but progress is being made.

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

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

- The researcher has a well established collaboration with the research groups at UNLV, University of Colorado, and other institutions.
- Partnership with MVSystems and Intematix has also been identified.
- Good interaction with NREL and several universities. In particular, the research team has developed a strong collaboration with MVSystems, a major developer of thin-film deposition equipment.
- Good list of collaborators.
- Past related effort has a history of strong collaboration.
- Strong collaborations now in place with MVSystems, Intematix, and NREL.

Question 5: Approach to and relevance of proposed future research

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

- The PI plans to implement a materials discovery and development plan to reach solar-to-hydrogen efficiency of 4 to 7%. Although bandgap engineering might help this effort, the PI should address some of the basic issues that lead to the loss of photogenerated charge carriers. Effort in this direction is lacking.
- Future research plans call for a 4% to 7% solar-to-hydrogen efficiency device. However, there is little discussion of other aspects of the proposed device, e.g., suitability for large-scale manufacture. Also, there is an inadequate cost analysis for large-scale systems.
- Unless the efficiency can be increased significantly soon, there seems to be no end to the "tweaking."
- Emphasis should be on new materials discovery. Current set of materials being examined seem to be hitting performance plateaus.

Strengths and weaknesses

Strengths
- Ability to assemble a photocatalyst assembly and effort to extend the photo response into the visible via bandgap engineering.
- A good collaborative research partnership.
- Methodical work with a systematic approach to development of the WO_3 large-scale films.
- Good combination of skill sets in thin film fabrication, evaluation of devices as photocells and photoelectrodes, and characterization.

Weaknesses
- A better understanding of the energetic considerations for hydrogen and oxygen production (band energies and water redox potentials) is needed while exploring new catalytic systems.
- The value of solar-to-hydrogen efficiency is based on current measurements. Actual hydrogen evolution data is necessary to justify the claims. (Define acronyms next time -- the term STH is not well defined in the presentation).
- Progress to date is not particularly remarkable. More discussion of this status would be interesting.

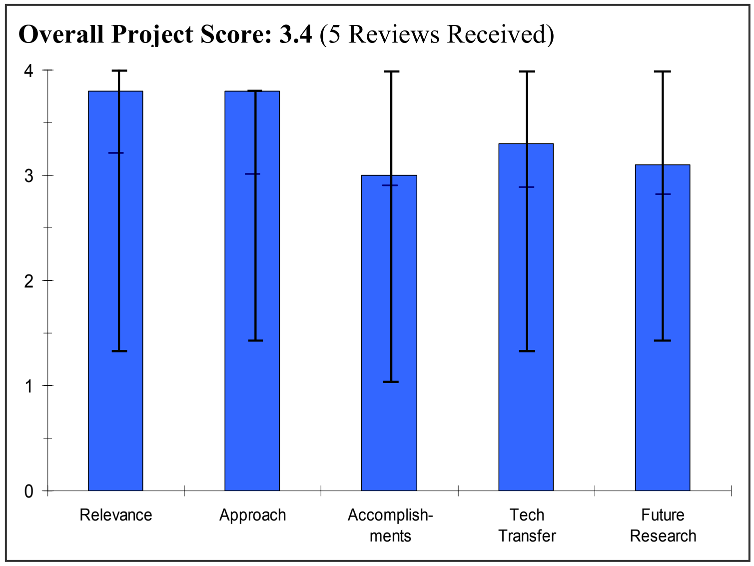
Specific recommendations and additions or deletions to the work scope

- A colloidal approach of synthesizing WO_3 particles and deposition as thin films can provide a low temperature film casting method. Similar method has been employed in casting TiO_2 films for solar cell applications.
- Spectroscopic investigation to identify charge recombination/separation process at different stages of modification can provide insight into the loss of photogenerated charge carriers.
- None suitable at this point in the project.

Project # PD-21: Photoelectrochemical Water Systems for Hydrogen Production
Turner, John; National Renewable Energy Laboratory

Brief Summary of Project

The goal of the National Renewable Energy Laboratory's research is to develop a stable, cost effective, photoelectrochemical-based system to split water using sunlight as the only energy input. The work during this year focused on identifying and characterizing new semi-conductor materials that have appropriate band gaps and are stable in aqueous solutions.



Question 1: Relevance to overall DOE objectives

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

- The development of photocatalytic systems using low bandgap semiconductor materials for the production of hydrogen supports the DOE hydrogen R&D initiative.
- Innovative and technically risky approach to achieving high solar-to-hydrogen efficiency through the use of III-V multijunction. This project builds on the very high efficiency and, in particular, the very high voltages of multijunction III-V devices. In addition, the approach is interesting because multijunction devices allow tailoring of the bandgap -- a quality that is well-suited to electrolysis.
- Project may provide a long term source for hydrogen, but it is not likely to impact production in the next two decades.

Question 2: Approach to performing the research and development

This project was rated **3.8** on its approach.

- PI is knowledgeable of the basic scientific issues and is developing a database resource to support future work.
- The PI has employed a multifaceted approach to improve the photocatalytic efficiency of III-V semiconductors. Both the bandgap engineering and computational modeling approaches are sharply focused towards achieving higher efficiency for photocatalytic hydrogen production.
- Technical barriers for the development of high potential difference (voltage) devices are aggressively pursued. The project is carefully thought-out and is quite feasible, though risky. In addition, there is a very good mix of experimental results and computational methods for bandgap tailoring.
- Adding materials modeling and simulation (in addition to the NREL computational activity) would help understand what is happening (such as corrosion rates) and provide direction to the research approach.

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

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

- Nitrogen doping has been employed to achieve bandgap control of GaP semiconductor catalyst and extend the response into the visible.
- The photocorrosion issue has been addressed using GaPN semiconductor systems.
- GaPN/Si multijunction devices have been demonstrated and characterized. The potential for these devices to achieve high STH efficiency is quite high. NREL has a remarkable record of development of multijunction III-V devices, which clearly benefits the present work.

- Much scientific progress, but little progress measured against technical program goals.
- Very good progress, but industrial partner involvement and more emphasis on computational techniques might have resulted in more progress.

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

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

- Collaboration with partners is apparent.
- The researcher has a well established collaboration with the research groups at Colorado School of Mines and University of Colorado.
- Partnership with MVSystems and Midwest Optoelectronics has also been identified, though their roles were not described.
- There is good collaboration between NREL, Colorado School of Mines, and University of Colorado.
- Seeing more cooperation in workers from other institutions pursuing similar goals.
- There is mention at the beginning of the presentation that two industrial partners have been brought in, but there is no evidence that they participated in the project.

Question 5: Approach to and relevance of proposed future research

This project was rated **3.1** for proposed future work.

- The approach of developing new catalyst materials and multijunction semiconductor systems with energy control provides a sound basis for continuing the proposed study.
- Matching of bandgap energetics remains a problem in matching the redox potentials of water splitting reaction. The proposed approach of bandgap grading and CIGSS type materials are new efforts in this direction.
- Future research will attempt to improve the GaPN/Si multijunction device and also the CIGS device. The research appears to be moving in a useful direction. Plans for future work appear to follow a logical path.
- This area needs a fresh set of approaches to new materials identification (see below).
- Future plans for materials modeling is good, but need to look outside of NREL for additional expertise to supplement the strengths of NREL.

Strengths and weaknesses

Strengths
- Good understanding of the research problem and unique strategy to tackle the problems.
- Highly competent research team with experience in high efficiency devices, several different device configurations, and good use of combinatorial approach to the design of improved devices.
- Great understanding of what the research results should be.

Weaknesses
- Too many slides in too little time.
- Fundamental understanding of the dynamics of charge separation and interfacial charge transfer in new catalyst is necessary to understand the efficiency limiting factors.
- It is not clear in the viewgraphs why presently existing high efficiency multijunctions, and for that matter high efficiency silicon devices, are not considered in this research. A cost/performance comparison of these semiconductor device technologies would be interesting.
- Many of the proposed paths to develop efficient and stable PEC materials have been deeply mined. This is an area that needs a fresh approach to identify new classes of candidate materials.
- Limited internal computational activity continues to be a leading weakness of this project.

Specific recommendations and additions or deletions to the work scope

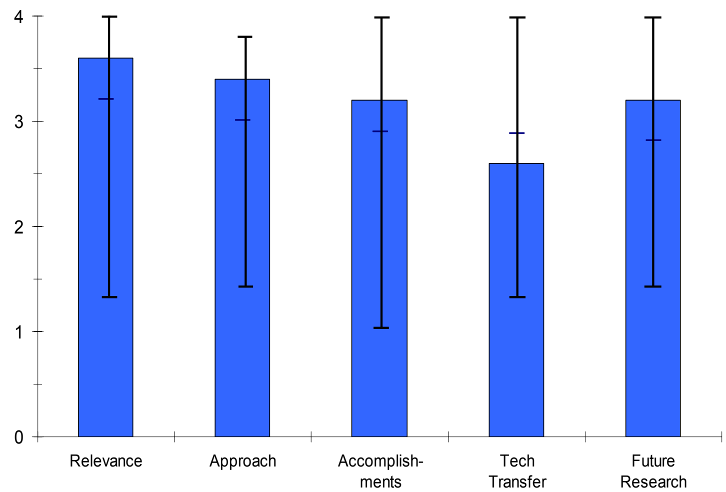
- Energetic considerations should be made while designing new catalysts.
- The researchers should make an effort to collect hydrogen evolution data.
- Spectroscopic investigation through collaborative effort is needed to elucidate the charge transfer dynamics in newly developed materials. (Collaboration with the spectroscopic team within NREL is a possibility).
- Impressive list of presentations at the scientific meetings. Should also make an active effort to communicate the results via scientific publications.
- No changes appear necessary at this point.
- Team with another organization to strengthen the materials computational efforts.

Project # PD-23: Low-Cost, High-Pressure Hydrogen Generator
Cropley, Cecelia; Giner Electrochemical Systems LLC

Brief Summary of Project

Giner Electrochemical Systems, LLC has an overall project goal of developing and demonstrating a low cost, high-pressure water electrolyzer system, which will eliminate the need for a mechanical hydrogen compressor, increase electrolyzer hydrogen discharge pressure to 5,000 psig, and demonstrate a 3,300 scfd high pressure electrolyzer operating on a renewable energy source. Past year (Jan 03-Mar 04) tasks included the development of lower cost materials and fabrication processes for stack components, fabricating and demonstrating an electrolyzer stack and system producing hydrogen at 2,000 psig, and designing and fabricating a test stand for 5,000 psig operation.

Overall Project Score: 3.3 (5 Reviews Received)



Question 1: Relevance to overall DOE objectives

This project earned a score of **3.6** for its relevance to DOE objectives.

- This project fits well with DOE's goals for production of hydrogen.
- Hydrogen by low-cost, high-pressure electrolysis fully supports DOE goals and objectives.
- Clearly tied to the objectives of high-pressure operation and a lower system cost.
- Definitely targeted at meeting goals and objectives of HFCIT program.
- Cost model still in the "big picture" stage -- needs detailing.
- Good progress in cost reduction efforts.
- Analysis of cost factors clearly identifies areas where improvements can be made.
- Program addresses cost reduction of capital equipment.
- Program attempting to reduce operating cost.
- All of the above are positive, but may not be enough to achieve target unless all benefits obtained.

Question 2: Approach to performing the research and development

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

- The approach is sound to start with an existing project and re-engineer to optimize cost and output pressure.
- Objectives are highly focused on those areas that have the greatest opportunity for quick success.
- One of the stated project objectives is to demonstrate an electrolyzer operating on a renewable energy source but the presentation addresses only electrolyzer issues which are all independent of the source of the electricity.
- Demonstrating improvements and innovative designs is key to achieving the objectives and understanding system trade-offs.
- Utilizes a multi-faceted approach to lower component costs and improving system performance.
- Demonstrating long-term durability and operability will be essential.
- Emphasis is on development and demonstration of a high pressure water electrolyzer.
- Focus of current work is on making incremental improvements to a prototype electrolysis system that reduce cost and complexity and improve performance.
- Program approach consistent with driving down cost.
- There may not be enough margins in cell stack cost reduction to hit cost targets, margin appears very small.

- Key to success appears to be new supported membrane approach to drop operating cost., i.e. cost of electricity.
- Data suggest operating cost may be the same, i.e., may not get reduction in operating cost.

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

This project was rated **3.2** based on accomplishments.

- Good progress is being made in reducing unit costs after first arriving at an understanding of the overall economics involved.
- Good leveraging of past work and other existing work in other programs to obtain some synergy.
- Progress is steady.
- This project continues to show strong progress in achieving objectives.
- Clearly focused on achieving the technical targets and on understanding system trade-offs.
- Demonstrated cost reductions for some components and improved performance in some areas.
- Economic model developed that ties cost of hydrogen to cost of electricity.
- Seeking to improve dryer system efficiency and operability.
- The project does not report operating cost saving by going to advanced membrane equivalent to 2 mil Nafion.
- Project dependent on reducing cell stack cost, reducing part count may help, but only fractionally since individual cells will be larger and expensive materials elimination benefit not completely achieved.
- Claim to reduce area in approach, but data says they are increasing area of cell to reduce part count. Need to resolve approach.

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

This project was rated **2.6** for technology transfer and collaboration.

- Collaboration appears to not be very practical in what is largely an engineering effort.
- GM and the Center for Technology Commercialization are involved in the project.
- There is no obvious involvement of stack component developers or suppliers.
- Good partnership on component supply; could use help on the renewable integration aspects of the project.
- Not clear what the role of the two partners are; nothing was revealed in the presentation. GES seems to be a one organization shown on this project.
- Did not report what interactions were with partners. Assume there were none.

Question 5: Approach to and relevance of proposed future research

This project was rated **3.2** for proposed future work.

- Future plans are consistent with the objectives of the project toward resulting in a successful conclusion.
- Next steps are logical and consistent with the overall project objectives. Contingencies (dryer) are addressed.
- Need to benchmark the out year milestones to the DOE technical targets.
- Performance and durability testing of the total system will be necessary to evaluate success.
- More of the same -- reduce costs/complexity, increase efficiencies and performance (e.g., higher outlet pressure).
- Future work should resolve if part count is reduced by increasing cell area. This could be easily graphed to take into account additional materials of larger area cell, but reduce number of parts.

Strengths and weaknesses

Strengths
- Well thought out approach showing strong progress.
- A seemingly well-organized industrial development/demonstration project that is making respectable progress, albeit at an incremental pace.
- Good understanding by team of electrolyzer properties and design.

Weaknesses

- May be relying too much on low-cost electricity to achieve the targets. May need to push limits on system capital and operating costs to be competitive.
- Little apparent collaboration; nothing much said about exploring tie in to renewable power supply.
- Cost of electricity dominates the cost of producing hydrogen. It may be difficult to get < \$0.036/kWh electricity except at specific locations

Specific recommendations and additions or deletions to the work scope

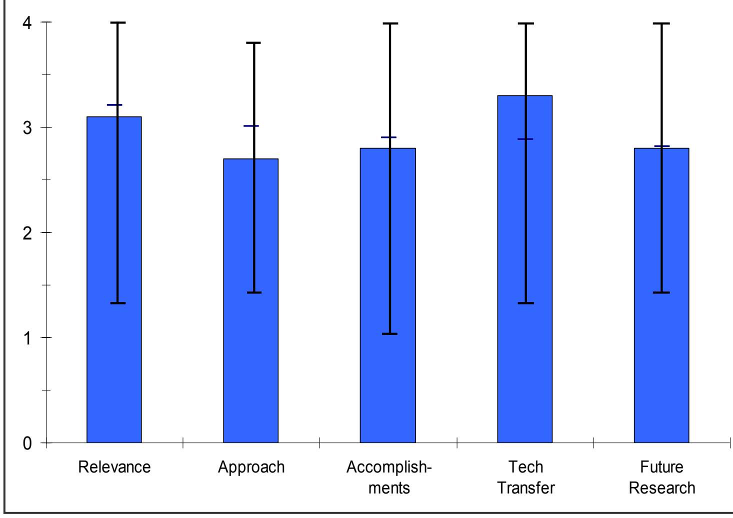
- Find a partner that can help with the dryer issues.
- For future reviews prepare a prior year to current year progress comparison to help gauge performance in the budget year.
- Program should also consider reducing cost of inefficiencies.

Project # PD-24: High Temperature Solid Oxide Electrolyzer System
Herring, Steve; Idaho National Laboratory

Brief Summary of Project

Idaho National Laboratory is currently researching and developing high and ultra-high temperature processes to produce hydrogen through chemical cycle water-splitting technology or other non-carbon-emitting technology utilizing heat from nuclear or solar sources. The project is seeking to develop energy efficient, high-temperature, regenerative solid-oxide electrolyzer cells (SOECs) for hydrogen production from steam; reduce ohmic losses to improve energy efficiency; increase SOEC durability and sealing with regard to thermal cycles; minimize electrolyte thickness; improve material durability in a hydrogen/oxygen/steam environment; and develop and test integrated SOEC stacks operating in the electrolysis mode.

Overall Project Score: 2.9 (9 Reviews Received)



Question 1: Relevance to overall DOE objectives

This project earned a score of **3.1** for its relevance to DOE objectives.

- Good mention of technical barriers.
- This project addresses the requirement for high volume production of low-cost hydrogen. A major DOE program goal.
- This could yield low-emission hydrogen production from domestic resources.
- Project aims at the development of energy-efficient, high-temperature, solid oxide electrolysis cells (SOECs) for hydrogen production from steam.
- Project will allow a higher efficiency production of hydrogen from electrolysis.
- Most aspects of the project align with the President's hydrogen vision the RD&D plan objectives. This project address issues with reducing capital costs and improving system efficiency for high temperature electrolyzers.
- A development and demonstration project focused on cost and efficiency improvements to the solid-oxide electrolyzer cell (SOEC
- The program is not addressing the quality/usefulness of the hydrogen being produced; stated purity of 90% is not suitable for fuel cells

Question 2: Approach to performing the research and development

This project was rated **2.7** on its approach.

- Appears well thought through. Good follow-on from 2004 to 2005. Good schematic description.
- The approach involves using nuclear reactor generated low-cost electricity to produce high volumes of hydrogen by high temperature solid-oxide electrolysis.
- The approach appropriately focuses on materials selection for critical component to achieve long-life time durability.
- Targets need to be defined for making hydrogen production via this route a competitive alternative. What cost and performance targets need to be met to make it more economical to choose hydrogen production over selling electricity to the grid?
- Project well designed, technically feasible, promoting technological integration with nuclear energy.

- The presentation does not spell out how the stated barriers are being addressed, i.e. capital cost, efficiency, electricity emissions, and electricity cost.
- The approach is generally well thought out and effective, but it was difficult to determine how the results would help achieve the DOE cost or efficiency targets.
- Development and testing of small scale SOEC stacks supported by paralleling engineering design and analysis.
- Plan is for staged development of progressively larger systems leading to a megawatt scale demonstration.
- The PI did not mention any plans or methods of overcoming the barrier of capital cost although it was listed as an area to be addressed.
- The PI stated that this is a program spanning several years into the future, yet no details of a plan to get there are apparent.

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

This project was rated **2.8** based on accomplishments.

- Good progress made.
- Technical progress has been good thus far with the demonstration of a 10-cell electrolyzer stack operating at 900^{o}C for a "short" time.
- Good modeling effort and progress in materials testing.
- Project started in early 2004, with already good achievements.
- The project appears to be well below the DOE target efficiency and there is no assessment of cost.
- The project has shown significant progress toward its objectives and to overcoming one or more technical barriers.
- Making good progress with small cell stacks; supporting some paralleling materials development.
- Since no plan/milestones have been presented as to how technical progress is being measured, it is difficult to judge the level of accomplishment
- No mention of the stated accomplishments as they pertain to the goals of the DOE program.

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

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

- Good description and acknowledgement of partners.
- Strong national laboratory team with appropriate industrial collaboration.
- Good collaboration, including industry partner.
- Good publication record.
- Project puts together an impressive number of institutions and researchers.
- Good collaboration between the partners.
- Excellent collaboration with partners.
- Clear description of the role of partners and their contributions.
- A good level of publication and data transfer.

Question 5: Approach to and relevance of proposed future research

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

- Good timeline and integration with nuclear program.
- Future plans must focus on demonstrating long-term durability at the short stack level before moving to scale-up of experimental systems.
- A more robust plan for durability testing of materials, including the effects of thermal cycling is necessary.
- Needs to undergo a technoeconomic feasibility study.
- Needs firm, quantitative out-year targets.
- Project shows a well defined timeline.

- The project is well mapped out for developing into the 200kW and 1MW demonstrations. However, there is a need for periodic assessments against goals for go/no-go on the demonstrations.
- The future plans look reasonable, but should describe how the results will help achieve cost or efficiency targets.
- Plans are consistent with project progression towards stated demonstration goals; the project appears to be on schedule
- No effective research plan was presented addressing possible decision points or contingencies, only a timeline.
- More experiments on system stability and scalability are needed.

Strengths and weaknesses

Strengths
- Well thought out and planned. Good results from work done so far.
- Strong complimentary team.
- Project objectives.
- Project approach.
- Project achievements in the short term.
- Collaborations with other institutions.
- The SOEC development is well planned.
- Approach is straight forward.
- Strong engineering design/implementation team.

Weaknesses
- Must develop a direct measurement method to monitor and verify hydrogen production in place of the "indirect" measurement currently in use.
- Given the increasing demand for low-cost, low-emission electricity, and the high cost of hydrogen delivery, it seems unlikely that hydrogen production would prove to be a competitive option over straight electricity generation and/or distributed electrolysis. A scenario and targets need to be defined where this type of centralized hydrogen production would be a viable option.
- Need to document approach to address the stated barriers.
- The devices are tested in a furnace to achieve 850 degrees. Are there Generation IV nuclear plants available to actually install this device for test today? Are there any plans to build any of these reactors?
- Need to describe how these experiments and tests will improve the technology and help the industry reach the DOE cost targets.
- Not enough information presented to gauge fully developed SOEC capital and operating costs, anticipated efficiencies, and cost of hydrogen.
- There is no detailed overall plan apparent from the presentation.
- The quality of the hydrogen being produced is not being addressed or checked.
- There is no mention of how the hydrogen will be captured at the output of the process so that it can be utilized.
- Unclear what were specific advances; how do achievements of the project compare with the state of the art
- No data on longer term performance on the system.

Specific recommendations and additions or deletions to the work scope

- PI could consider the possibility of a direct measurement of the hydrogen production rate, with a suitable analytical method for high temperature; the method used so far is indirect and combine electrical and dew point measurements.
- Another suggestion is to change the colors related to the electrolyte/insulator temperature contours, so that the red reflects the higher temperature zones.
- Document progress against the DOE targets as the project proceeds.
- Are there any effects of radiation from the nuclear energy or is the electrolysis sufficiently de-coupled from the nuclear energy system?
- Recommend more attention to studies that address the concern expressed above regarding cost and efficiency projections.

- For future reviews prepare a prior year to current year progress comparison to help gauge performance in the budget year.
- An analysis of the gas stream exiting the bench top process should be performed and any separation or cleanup addressed prior to any scaling up of the process.
- Add: materials stability under high temperature electrolysis conditions (corrosion, etc.).
- Add: economic and efficiency comparison of HT SOEC with IGCC (natural gas power plant) - high efficiency conventional electrolysis combo.
- Add: analysis of materials performance under the process conditions.

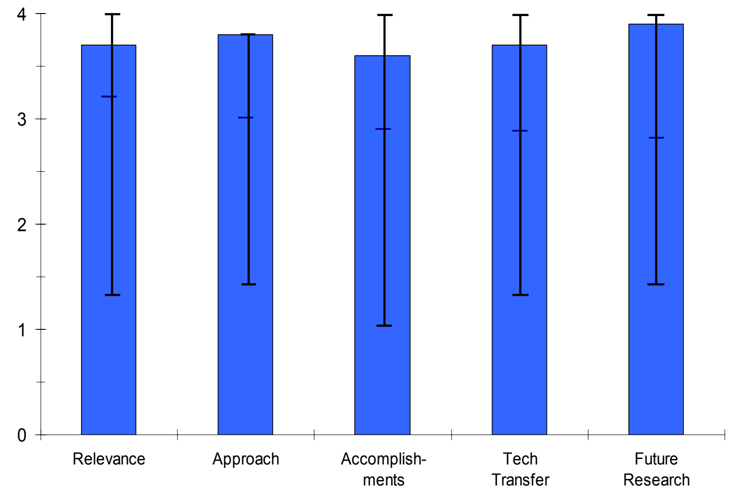
Project # PD-25: Renewable Electrolysis Integrated System Development and Testing

Kroposki, Ben; National Renewable Energy Laboratory

Brief Summary of Project

This National Renewable Energy Laboratory project examines the issues with using renewable energy to produce hydrogen by electrolyzing water. Objectives are to characterize electrolyzer performance under variable input power conditions, test and evaluate the electrical interface with renewable (PV, Wind, Hydro, Geothermal, etc.) and/or hybrid/grid power (dedicated hydrogen production, electricity/hydrogen cogeneration), design and develop shared power electronics packages and controllers to reduce cost and optimize system performance, and develop and verify integrated renewable electrolysis systems (via performance modeling, simulation and testing; and addressing Safety, Codes and Standards requirements).

Overall Project Score: 3.7 (6 Reviews Received)



Question 1: Relevance to overall DOE objectives

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

- Highly relevant to the DOE HFCIT Program.
- Good focus on integrating renewable electricity sources.
- Renewable electrolysis to produce hydrogen supports DOE's Hydrogen Program goals and objectives.
- Project goal is to develop and test a renewable electrolysis integrated system for power production and to use hydrogen as an energy storage alternative.
- The development of wind and photovoltaic (PV) combined with electrolysis systems is significant towards a hydrogen economy.
- Focused on meeting HFCIT RD&D cost and production rate goals with connection to renewable driver.
- This project is highly relevant to DOE objectives. Unlike many other projects, it is strongly engineering oriented, and addresses system problems inherent in a variety of hydrogen generation approaches. This is necessary work for the successful implementation of large-scale hydrogen generation from renewable.

Question 2: Approach to performing the research and development

This project was rated **3.8** on its approach.

- Very solid and comprehensive approach to tackle some difficult issues.
- The project includes analysis of integration of renewable (wind, solar) power with an electrolyzer, including assessment of when the power produced should be fed to the grid and when it should be used to generate hydrogen and system testing with PV arrays and wind turbines.
- The full system tests will help power electronics assessment and design.
- Project well planned and designed.
- Project integrates hydrogen production and the storage of that hydrogen for energy use.
- Addressing the renewable integration and the power electronics design/cost is a significant step towards making these systems practical.
- Developing roadmap for renewable-based hydrogen production

- Includes systems engineering, modeling, analysis, system integration and component development, and characterization testing and analysis.
- The approach is a reasonable mixture of modeling and small-scale demonstration. The empirical data from the demonstrations serve to both guide and validate system theory.

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

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

- Progress is significant in each of the tasks.
- Testing of the electrolyzer with a PV array has been completed. Testing with a wind turbine has been started.
- Longer test runs should be considered to evaluate controls over wider power ranges.
- The project appears to be close to the 2005 DOE target for efficiency, but there is no cost data presented.
- Numerous encouraging technical accomplishments, particularly with respect to integration tests.
- This project is very productive for the size of its budget.
- Technical accomplishments include a variety of systems oriented demonstration-scale (several kW) experiments and a variety of modeling exercises. These impressive results suggest the robustness of hydrogen generation systems to fluctuations in current. Technical barriers to systems problems are being identified and aggressively addressed by this research.

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

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

- The project is making excellent use of many relevant resources among industry partners.
- The Team includes an electrolysis manufacturer, systems analysts, and power companies.
- Project assisted in organizing a Utility Hydrogen Workshop (Sep 2004)
- Project shows close cooperation with other institutions.
- Several well chosen collaborations; the roles of the collaborators were clearly spelled out.
- Considerable research coordination has been demonstrated with both industry and academia.

Question 5: Approach to and relevance of proposed future research

This project was rated **3.9** for proposed future work.

- Future plans are consistent with the goals of the project and are responsive to past reviewer comments.
- Continued and expanded testing of complete systems will follow systems engineering, modeling, and analysis.
- Project well planned, the key technical barriers shall be addressed in the proper time.
- Good approach at looking at AC to AC power electronics.
- Good approach to add to data on PEM electrolyzer by testing alkaline electrolyzers in the future.
- Future plans follow logically from what has been accomplished thus far
- An expanded program with increased funding seems justified for this team -- they are getting the kind of results that can be used to build public confidence in the hydrogen economy.
- More aggressive interfacing and testing is planned for the duration of the subcontract. Future work clearly builds on past progress.

Strengths and weaknesses

Strengths

- Project goal: integration of electrolysis and wind energy.
- The approach to systems integration for making hydrogen from renewable electricity and addressing the appropriate barriers.
- Development of the power electronics.

- Well focused project; performing very well, especially considering the funding level; one of the best presentations.
- Well thought-out train of work; very straightforward sequence of research efforts; impressive empirical results; close coordination with modeling efforts; clear project schedule chart.

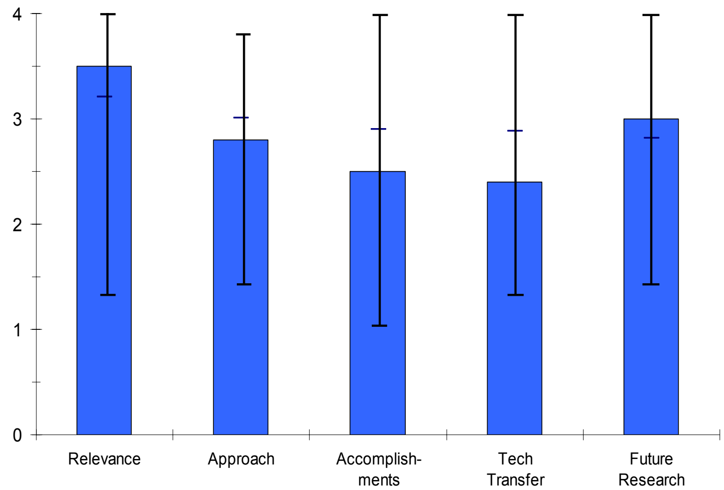
Weaknesses
- Technology transfer: few publications or presentations so far.
- Increased funding of this project should pay large dividends
- While there is considerable interfacing with wind machines, there appears to be only very limited interfacing with photovoltaic arrays. This is unfortunate because photovoltaics are a likely candidate for future large-scale electric supply for hydrogen generation.

Specific recommendations and additions or deletions to the work scope

- It is suggested that the PI includes in the project scope issues related to the storage (and use) of hydrogen, at the moment the hydrogen produced is being vented.
- Focus on system costs.
- Document progress against the DOE targets as the project proceeds.
- Fund this project to the fullest, this is the kind of R&D that will get us to a deployed hydrogen economy.
- For future reviews prepare a prior year to current year progress comparison to help gauge performance in the budget year.
- In future work, increase the emphasis on photovoltaic array-based systems.

Project # PD-26: Alkaline, High Pressure Electrolysis
Ibrahim, Samir; Teledyne Energy Systems Inc.

Overall Project Score: 2.8 (4 Reviews Received)



Brief Summary of Project

The goal of this Teledyne Energy Systems Inc. project is to advance water electrolysis technology and develop an electrolytic hydrogen generator, designed for production of >10,000 units per year, with the following features: hydrogen delivery at high-pressure (5,000 psig); relatively inexpensive hydrogen generation and pressurization; production capacity of 10,000 scfd; high conversion efficiency; and reliability and durability with low maintenance cost.

Question 1: Relevance to overall DOE objectives

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

- Water electrolysis to produce hydrogen supports DOE goals and objectives.
- Electrolysis is a key technology for the transition and long-term viability of the hydrogen economy. Reducing cost and improving efficiency will be key to market competitiveness.
- Supports HFCIT RD&D goals related to hydrogen compression, storage, dispensing, and cost.
- Emphasis on safety, manufacturing economics, delivery goals, durability.

Question 2: Approach to performing the research and development

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

- Safety analysis is important.
- Use of electrolysis to 1,500 psi followed by compression to 5,000 psi is conservative.
- The approach is sound, but it is difficult to judge likelihood for success without more information on cost and performance. Should be benchmarking progress towards the DOE technical targets.
- Parts reduction will be important to manufacturability of components.
- Trade-off studies, safety analysis, modeling
- Eventually fabricate and test a deliverable high pressure, alkaline electrolysis unit.
- Approach identifies top level problems but does not give details of how program will proceed.
- Approach does not identify major cost features and does not identify what are the critical components to improve technology.

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

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

- Progress made in areas of system design and analysis and safety analysis. Reporting of progress was overweighed in the safety area and underweighted in system analysis.
- Need to tie trade off in high pressure operation back to total system cost, including operating and maintenance. How much does elimination of one-stage of compressions save?
- Need to revisit the conclusion to keep operating pressures < 1000 psi. Rupture disks, relief valves, etc., can enable safe operation. Decision should be tied to cost and operability.

- Not clear that any "out of box" approaches are being employed. Small, incremental improvements will not achieve the targets.
- Safety is being addressed in great detail.
- Design related trade-off studies are in progress.
- It seems that thus far close to $1M has been spent but all of it has been on paper studies -- no test results were reported.
- Systematic safety analysis is beneficial.
- Programs appears slow to develop experimental data and is emphasizing pressure control system; does not appear to be main objective.

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

This project was rated **2.4** for technology transfer and collaboration.

- Although there is teaming, the roles of the various team members play and/or their expertise are not clear.
- There are three partnering organizations, but it's not clear how involved they have been to date.
- Partners identified but no interaction with other projects reported.
- Hardware trade study not reported.

Question 5: Approach to and relevance of proposed future research

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

- Planned work follows logically.
- Plans are good, but need to focus on achieving the system cost targets.
- Testing, component optimization, and more design work in the remainder of FY 2005
- Fabrication and delivery of a working prototype in FY 2006 -- they have much to do in the next 18 months.
- Program does not build on past progress because trade studies not done or not reported.

Strengths and weaknesses

Strengths
- This is a team with a long history in electrolysis and a strong understanding of the technology.
- Employing strong approaches to reviewing safety and performance.
- This particular project has put considerable effort into the analysis of safety/system control issues--the results/findings have broad implication and application in the HFCIT production arena of projects.
- Good effort on safety analysis.

Weaknesses
- Need to pay more attention to the total system costs and trade-offs, including balance of plant.
- They don't seem to be off to a fast start, other than the safety analyses, with little to get enthused about.
- Program not reporting information.

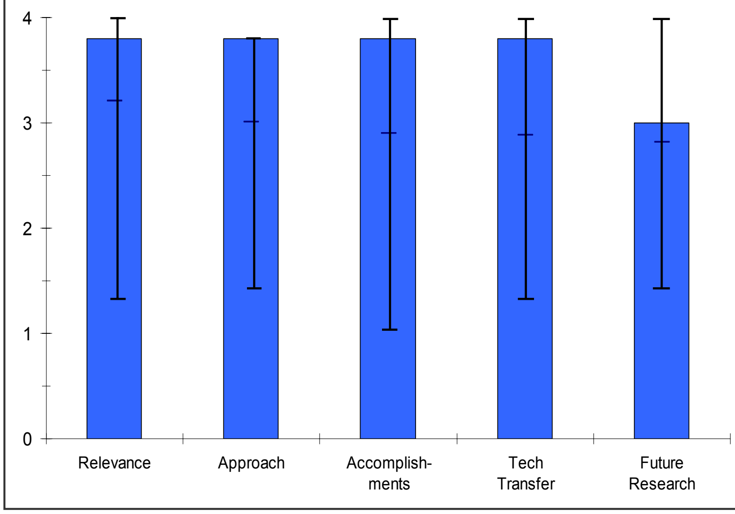
Specific recommendations and additions or deletions to the work scope

- The pace of actual testing, component optimization and manufacture/assembly needs to be stepped up.
- For future reviews prepare a prior year to current year progress comparison to help gauge performance in the budget year.
- Program should be required to report more data.

Project # PD-27: Sulfur-Iodine Thermochemical Cycle
Pickard, Paul; Idaho National Laboratory/Sandia National Laboratories

Brief Summary of Project

Overall Project Score: 3.6 (4 Reviews Received)



The Sulfur-Iodine (S-I) thermochemical cycle is being investigated as a potential method to produce hydrogen from water using nuclear energy. Current research focuses on lab scale experiments to demonstrate the basic reaction steps and candidate materials for the three major component reaction sections that make up the S-I cycle. The project will design, construct and test the three major reaction sections: the prime (Bunsen) reaction, the HI decomposition section and the H_2SO_4 decomposition section. Key issues being addressed include materials of construction for the high temperature corrosive environment, thermochemistry of the HI distillation steps and heat exchanger decomposer design for efficient heat transfer. The three reaction sections are being designed with the goal of performing an integrated lab scale experiment on the full S-I cycle.

Question 1: Relevance to overall DOE objectives

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

- Key element of Nuclear Hydrogen Initiative.
- Nuclear power production is potentially a very important source of heat for hydrogen production.
- High relevance project.
- Critical to understanding viability of "nuclear hydrogen" option.
- This is definitely a relevant project and different from others that is being done.

Question 2: Approach to performing the research and development

This project was rated **3.8** on its approach.

- Flow sheet analysis and lab experiments on individual process sections, then separate processes will be integrated.
- Challenges and issues are addressed in the approach.
- Approach is well understood and articulated by the PI.
- The project addresses key issues of the thermochemical cycle: materials suitability, thermodynamics, heat integration, and process modeling.
- It is nice to see experiments started and additional experiments being planned for S-I – its about time!
- The three reactions of the cycle appear to be equally focused.
- One uncertain issue is how design heuristics are handled in the PFD and simulations. For example, proper design protocol calls for a heat exchanger approach temperature of 10 to 20 deg C and a pressure drop through a heat exchanger of 1.5 to 2 psi. This results in a decreased efficiency and could be significant for complicated processes such as this that have a large number of unit operations.

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

This project was rated **3.8** based on accomplishments.

- Flow sheet analysis done.
- Analyzed options, selected best ones (more efficient, lower cost) for section construction.
- Have completed tests of some sections, e.g., sulfuric acid.
- Good progress on process selection; process simulation.
- Innovative approaches to designing the key process modules.
- Evaluating catalysts and how they actually behave is important for the H_2SO_4 dissociation reaction.
- Appears to be on track with accomplishments.

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

This project was rated **3.8** for technology transfer and collaboration.

- Matching effort from French CEA.
- Work of other projects was mentioned during PI's presentation.
- PI referred to later presentations, conveying impression that activities across projects are coordinated.
- Outstanding level of collaboration amongst multiple institutions.
- Excellent division of labor between partners; effort seems to be well integrated.
- Closer collaboration with materials fabricators recommended.
- Appears to be well aligned with partners.

Question 5: Approach to and relevance of proposed future research

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

- General future work plans were presented.
- Would be improved with more specific information and indication of funding resources required to do the work.
- On-going economic analysis not included (based on materials and design selections).
- Did not specifically mention iodine recycle rates and the impact of the kg iodine/kg hydrogen. At one time, this ratio was 6,000 kg iodine/kg hydrogen. Supposedly work by the French partner indicates a 5 fold reduction in iodine flow. Is 1,000 kg iodine handling per 1 kg hydrogen really sufficient? This needs to be a major initiative – continuing to find ways to reduce iodine handling.
- Continuing on experimentation is good.

Strengths and weaknesses

Strengths
- Excellent technical approach.
- Work is being accomplished by a well-qualified team with significant expertise.
- The team is tracking related and synergistic work at other organizations -- national labs, universities, industry.
- Completeness of the analysis.
- Thorough selection of technologies for process steps.
- Addressing materials compatibility issue early.
- Experimentally based approach targeting specific concerns.

Weaknesses
- Ideally, results of work on other projects -- e.g., materials analysis, characterization and selection (from UNLV, INL) -- would be completed and fed into this project before major funds are spent on building and testing an integrated system.
- Corrosion work should be rapidly moving to detailed studies of corrosion mechanism and understanding of corrosion protection mechanisms.

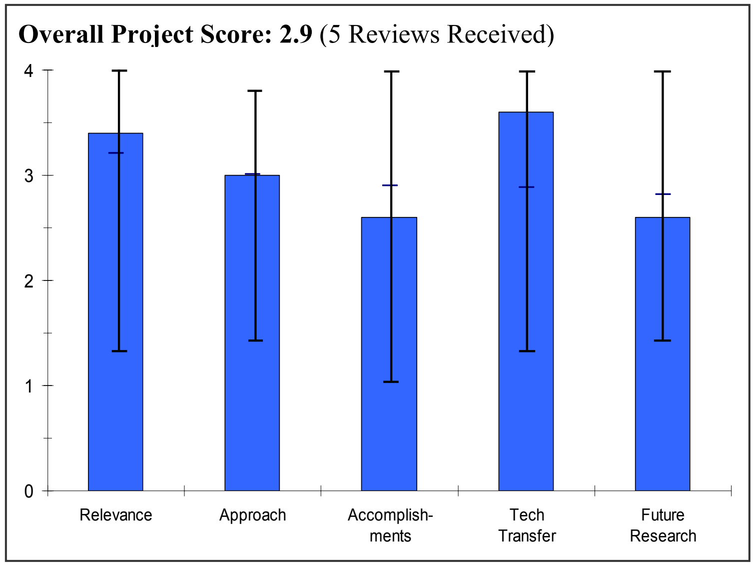
- Use of ceramics in large scale hydrogen reactors is questionable (risk of shattering; difficulty manufacturing).
- Lack of go/no-go point in the project timeline in case if suitable materials cannot be found.
- Identify iodine recycle and handling as an identified issue to be addressed.

Specific recommendations and additions or deletions to the work scope

- Be sure that PFD simulations and economics are based on real heuristics that include 1.5 to 2 psi pressure drops on heat exchangers and approach temperatures of 10 to 20 deg C.
- Be sure significant efforts are directed towards reducing the iodine handling and recycle issues relative to hydrogen.

Project # PD-28: Development of Solar-Powered Thermochemical Production of Hydrogen from Water
Perret, Bob; University of Nevada

Brief Summary of Project



The goal of this solar hydrogen generation research (SHGR) team project, led by the University of Nevada Las Vegas Research Foundation, is to define economically feasible concepts for solar-powered production of hydrogen from water. Task I objectives are to screen and select thermochemical cycles and systems; establish a thermochemical water-splitting cycle database; develop solar receiver/reactor design concepts for top cycles; and analyze and select the best systems for development. In Task II, the team will build on earlier CU/NREL work to study metal oxide reduction cycles, design an improved ultra-high temperature solar thermal receiver/reactor, and conduct fundamental kinetics and feasibility studies using the CU porous wall tube reactor coupled to the CU electric furnace and the NREL high-flux solar furnace. Task III objectives are to develop advanced multi-band gap materials and advanced materials for photoelectrodes immersed in an electrolyte to achieve high current density in a durable hybrid photoelectrode configuration conceived and designed by the University of Hawaii.

Question 1: Relevance to overall DOE objectives

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

- Renewable hydrogen is consistent with DOE goals and objectives.
- This project supports the large scale production of hydrogen using a renewable source (solar).
- The program can have a big impact on future hydrogen production but actual processes and overall efficiencies have not yet been determined.
- Project very relevant to hydrogen fuel initiative. Proposes an alternative to PV-electrolysis for solar hydrogen.

Question 2: Approach to performing the research and development

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

- Although very little experimental data has been generated, the approach of analyzing and ranking possible cycles provides insight into viable approaches and could reduce consideration of "wrong" cycles.
- The approach reviews and evaluates, based on the reported literature, existing solar cycles. Approximately two years has been spent on this activity.
- Is there a faster way to accomplish the screening of candidate cycles? The step-wise process of determining cycle efficiency potential and then determining whether the process can actually produce hydrogen seems time-consuming.
- Need to establish a cut-off for the screening of candidate cycles and focus in on conducting experimental studies of the cycle classes that show the highest potential.
- Do not see any economic analysis as part of the approach.
- Too much of the study has been spent on "paper study" as reported by previous reviewers.
- Excellent integration of detailed analysis of previous work with selective experiments to test theoretical premises.

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

This project was rated **2.6** based on accomplishments.

- Possible cycles have been selected and detailed analysis and minor experimentation have been initiated.
- Progress appears to be very slow, after two years experimental assessments are just beginning on a number of cycles to identify the best solar cycle.
- The project has evaluated a large number of candidate cycles and has developed an extensive database.
- Little experimental knowledge has been generated.
- Process down-select procedures should have been expedited.
- Very good narrow-down of all potential thermochemical cycles.
- Experimental results limited so far.

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

This project was rated **3.6** for technology transfer and collaboration.

- The team's expertise is very broad.
- A large team of academic, national laboratory, and industry partners is working on this project.
- Industry partners are listed, but it is unclear what collaboration is actually occurring
- The project has a good team.
- Excellent collaborative effort between multiple groups. Tasks are well split, and work is well coordinated.

Question 5: Approach to and relevance of proposed future research

This project was rated **2.6** for proposed future work.

- Future work should be accelerated to produce new experimental results to determine viability of this technical approach as soon as possible, rather than continued evaluation of multiple cycles. Focus should be concentrated on a single down-selected cycle.
- Need to establish go/no-go decisions and dates for down-selects.
- Future plan appears sound.
- Issue of materials selection for the reactor not addressed.
- Appropriate attention paid to the subject of system efficiency.
- An intermediate cost estimate based on current knowledge would be helpful.

Strengths and weaknesses

Strengths
- A strong, well qualified team to address the proposed concept.
- Good experienced team facing a large and difficult problem.
- Excellent integration of theoretical and experimental efforts.

Weaknesses
- Slow progress.
- Too much effort being expended on evaluation.
- Issue of materials of construction not adequately addressed.

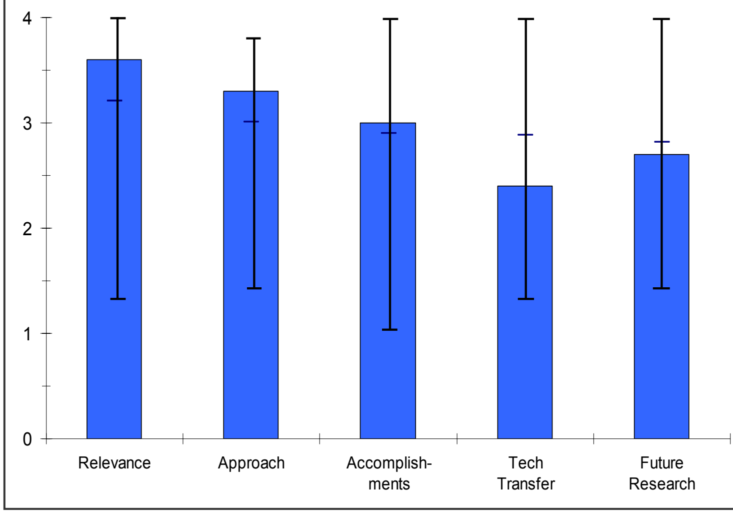
Specific recommendations and additions or deletions to the work scope

- Accelerate schedule.
- Recommend completion of paper study and downselect of best candidate processes so that economic comparison can be made to see if the proposed processes have any potential for producing large quantities of hydrogen meeting the DOE targets.
- Additional economic analysis would be helpful at this point.
- More in-depth study of materials suitable for reactor construction.

Project # PD-29: Alternative Thermochemical Cycle Evaluation

Lewis, Michele; Argonne National Laboratory

Overall Project Score: 3.1 (7 Reviews Received)



Brief Summary of Project

This Argonne National Laboratory project is concerned with identifying and evaluating potentially promising thermochemical cycles for producing hydrogen with efficiencies near that of the Nuclear Hydrogen Initiative (NHI) baseline cycles. The project consists of two phases: identification of cycles with particularly promising features such as lower temperature requirements, potentially high efficiencies, compatibility with current materials, and/or the promise of low capital costs; and evaluation using a to-be-developed scoping methodology based primarily on thermodynamic data and, to a limited extent, current engineering methods. The results of this updated study will be used to select the most promising alternative thermochemical cycles for the NHI program.

Question 1: Relevance to overall DOE objectives

This project earned a score of **3.6** for its relevance to DOE objectives.

- The project studies the nuclear production of hydrogen.
- A valuable low cost complement to high cost projects that comprise the Nuclear Hydrogen Initiative.
- Knowledge gained in this project will be applicable to not only nuclear-based hydrogen production but also solar-based hydrogen production.
- Directly addresses DOE program goal of H_2 production from non-fossil fuel sources.
- Good relevance - it is important to find less chemically aggressive cycles than S-I and Ca-Br.
- An identification of thermochemical cycles to be further investigated is important.

Question 2: Approach to performing the research and development

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

- A comprehensive survey was done, which indicated 4 major cycles to be studied.
- Thermochemical cycles other than sulfur-iodine and sulfur-bromine are being considered and analyzed with this project.
- Literature search and paper study are reasonable for the resources devoted to this project.
- Flow sheet analyses will be done on most promising cycles.
- Clear documentation and communication of methodology should be given sufficient (more) attention.
- Technical barriers are recognized and addressed.
- Excellent approach in starting with literature review and not reinventing the wheel.
- Great that researcher has access to proprietary information that can be "included" in assessment. Shows that this is not just a literature review of past work.
- Identification of inconsistencies in efficiency calculations should cause researchers to re-evaluate cycles identified in literature as promising.
- Proposed standard efficiency calculation is a valuable addition to this research area.
- Key objective of this work should be the one listed near the end on slide 5, i.e., identify critical R&D needs for selected cycles.

- Not clear when future work items are planned. First slide shows that this project ends at the end of this fiscal year.
- Approach is literature search to identify potential cycles quantify energetic where possible, and develop objective criteria for evaluating and ranking the cycles.
- Considering the white paper nature of the project the approach is adequate -- potentially leading to identification of new thermochemical cycles.
- Critical view of previous literature reports is commendable.
- There seemed to be some overlap with the solar thermal cycle evaluation, although this is a nuclear application. Nonetheless, the chemical side of the cycles being evaluated is the same.

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

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

- Project well documented and well described.
- Cycles of greatest interest, based on reasonable factors such as process efficiencies, have been selected.
- Completeness of information is limited by non-availability of proprietary data (presumably not in PI control).
- Appropriate caution in interpretation of data, such as idealized efficiencies, discussed by PI.
- New project.
- Excellent literature search.
- Excellent finding that efficiencies of cycles are determined using inconsistent approaches.
- Part of progress should be guidelines for R&D (not just paper assessment of chemical viability). Is this the extent to which you plan on making R&D recommendations?
- Identifying four cycles for further study is good.
- It is unclear what kind of statistical analysis was used, if any, to say one process is better than another with a certain degree of confidence.

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

This project was rated **2.4** for technology transfer and collaboration.

- Project presents good interaction with other institutions.
- Two International Nuclear Energy Research Initiative partnerships.
- Some collaboration with French CEA.
- Project could be improved with more robust coordination, which would require more funding and staff resources.
- Collaboration with industry and universities is lacking. The proprietary nature of the work is a barrier to open collaboration.
- Don't know what CEA or INERI are – not explained well. To an audience unfamiliar with your acronyms, recommend detailing partners' capabilities.
- Who will you be providing R&D guidance to?
- Who will you be providing data from this study to?
- Some collaboration in place with CEA. However, it was apparent from the session that several other groups in U.S. are doing similar work and it would make a lot of sense for these groups to pool their efforts.
- Seemed okay, however, the suggestion at the end that this work be combined and included with the big solar data base analysis is good.

Question 5: Approach to and relevance of proposed future research

This project was rated **2.7** for proposed future work.

- Details on future work plans and resource requirements were not covered.
- Excellent and needed start.
- A timeline for proposed work would be nice.
- What is meant by "Integrated Demonstration" on slide 24? This seems like a very ambitious addition to the existing project.
- Insufficient discussion of potential future developments.

Strengths and weaknesses

Strengths

- Project goals: studies on the hydrogen production from nuclear energy.
- Technology transfer: collaboration with other institutions.
- Project approach.
- Low cost.
- Type of work that's important as a check on high cost technology R&D.
- Reasonable figures of merit for identifying promising cycles.
- Good critical survey of reported results.
- Useful tool for future work on thermochemical cycle development.

Weaknesses

- Insufficient collaboration, communication of methodology and comparing results with others doing similar work.
- Too many acronyms not familiar to the Hydrogen Program.
- Possible duplicative efforts in this area include Sandia (see PD-27), University of Colorado (PDP-44), and UNLV (PD-28).
- Issue of materials compatibility not addressed.
- Economic aspects are not addressed.
- It seems like a lot of what was done was repetitive with the solar program lower temperature cycles.

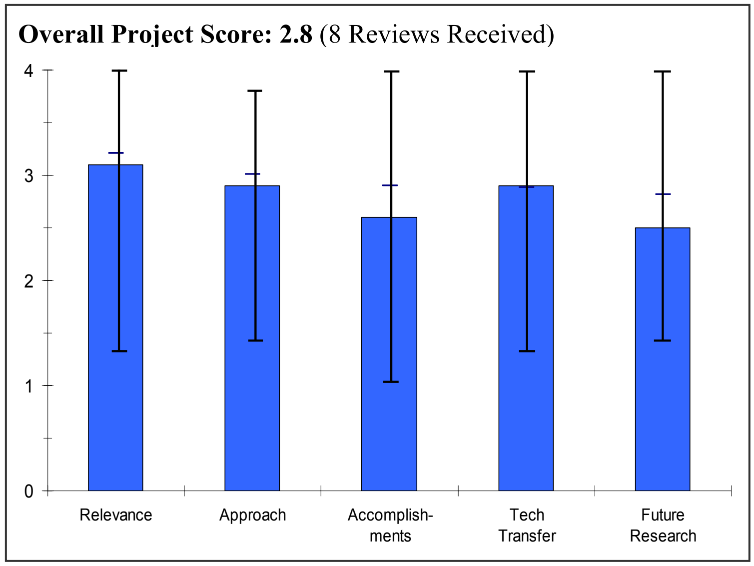
Specific recommendations and additions or deletions to the work scope

- If this work is continued, should add specific activity to seek out other organizations that have accomplished similar analyses and developed priority lists for thermochemical cycles, e.g., NREL.
- Make recommendations on future developments. Recommend the select cycles for experimental verification and identify key characteristics to be studies.
- Combine data base with that of solar project instead of a separate Excel file for this.

Project # PD-30: High Temperature Heat Exchanger Development

Hechanova, Tony; University of Nevada, Las Vegas

Brief Summary of Project



This University of Nevada, Las Vegas Research Foundation project will perform research and development of high temperature components involved in thermochemical separation and high temperature electrolysis of water to provide technical information on candidate materials, working fluids, and components to inform decision-makers in their selection of concepts to demonstrate. Candidate working fluids (gases and liquid salts) and materials will be identified and tested for their performance at high temperatures (up to 1,000ºC) and resistance to corrosive environments (such as sulfuric acid and hydrogen iodide) encountered in sulfur-iodine and other cycles. Efforts will also be conducted in component design, fabrication, and performance of metallic alloys, ceramics, membranes, and catalysts.

Question 1: Relevance to overall DOE objectives

This project earned a score of **3.1** for its relevance to DOE objectives.

- The project should be put in perspective with the quantitative metrics in the HFCIT R&D plan targets so that progress can be evaluated.
- The project consists of a set of sub-projects, whose objectives is the development of high temperature heat exchangers, crucial to the production of hydrogen from nuclear energy.
- Important technical information may be provided by the project.
- Contributions will be indirect, i.e., technical results will benefit other projects that directly address/achieve DOE's goals.
- Project not structured in a way to maximize potential for relevant results.
- The program can have a big impact on future hydrogen production and supports the Nuclear Hydrogen Initiative in NE.
- Presenter discussed the barriers from the Nuclear Hydrogen Initiative R&D Plan.
- The project supports a relatively narrow segment of the President's Initiative. Considering the funding level, a broader scope would be expected.
- The project is indeed extremely relevant.
- Presentation did not demonstrate relevance.
- Presentation did not identify the specific problems the group is facing in heat exchanger development; rather presentation reported group activities.
- Very relevant assuming S-I is relevant.

Question 2: Approach to performing the research and development

This project was rated **2.9** on its approach.

- This is a large project with 6 activities and many materials. It is not clear how the budget is distributed among the partners. Barriers for each element should be addressed.
- Impressive and ambitious set of projects, focused on the key technical barriers of nuclear hydrogen.

- Seven distinct work packages, for the most part, are independent of the others.
- Materials testing, test designs, coupon tests, standard test equipment are routine, not leading edge or advanced.
- This project has many partners and very broad scope from analysis to design to prototype fabrication. It may need to be reviewed by smaller subsets.
- Very empirical approach. More focused experimental program is needed.
- Much of the basic work could be performed by private labs at lower costs and with higher quality of results.
- Low temperature testing does not provide much useful info, tests should be conducted under conditions similar to reaction conditions.
- Most tests are very short term.
- Approach is unfocused.
- Approach did not identify the specific corrosion related problems.
- Approach involves unfocused tests, e.g. why does measurement of strength of SiC composites matters in heat exchangers? Creep is the problem and not strength.
- What is the criterion by which SiC composites have been chosen for such high temperature application? Do not assume that internal material interfaces in such a composite shall remain intact during operation.
- Numerical simulations for stress analysis were performed but what was the purpose? Stress analysis alone does not provide failure assessment and predictions. There was a stress of 10 MPa listed as an upper bound, but no justification was given. Why does such a number has any importance whatsoever?
- There are a large number of materials considered-- super alloys, ceramics etc. The question is what the criteria are. Material selection seems to be random, without using any operational relevance information, such as toughness or creep resistance requirements.
- It was not clear that an ASTM standard was used in the coupon tests or not and if a control coupon was used. If such standards were used, they need to be identified so the audience buys into the corrosion research.
- Fabricated SiC coupons will perform based on their method of manufacture. Purity and density will play a role. Instead of using these types of coupons, recommend using pieces of actual product (i.e. sections cut from SiC tubes) that meets product quality specs by a manufacturer. This would help to eliminate variability in the experiments.

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

This project was rated **2.6** based on accomplishments.

- UNLV-Roy: Seven materials are to be evaluated but no results are presented from the analyses that are to be used in the project. The ties to the GA work should be reported in detail.
- GA: Only pictures on the coupons are presented and conditions of the test and relevance to eventual application are not given.
- MIT: No results are shown. No rationale for approach is given, especially cost analysis.
- UCB: Goals and results are well presented.
- Ceramatec: Goals and results are will presented.
- UNLV- Chen: important program element, but needs to be integrated with experimental results and targets.
- The individual projects present relevant achievements.
- Listings of technical accomplishments provided.
- Little or no linkage of accomplishments with potential affects on hydrogen production using nuclear thermochemical cycles, e.g., how might results of this project affect process designs?
- Good progress appears to be made by many collaborators.
- Results of materials testing for ID05SS12 unimpressive.
- Relevant temperature range not tested.
- Test time not sufficient (100 hrs vs. 40,000 hrs needed) (SS12 and SS15).
- Little practical use from adding 30 wt% Pt to structural materials (SS15).
- Very interesting proposed solution from Ceramatec.
- Overall progress is minor, much greater progress would be expected considering project's 18 months duration and funding level.

- Unfortunately, from the presentation, one cannot infer whether there was even a single result reflecting a systematic study toward material selection, operation, and failure mechanisms. Perhaps this is due to the fact that project is new.
- So far, the project's approach seems to be rather empirical.
- Corrosion results are based on the color of the specimen rather than on failure of the specimens. This is rather primitive. It was mentioned that components will be sent to GA for testing, but no details were mentioned on what the objectives are, e.g. whether the plan is to look for fracture of aestivation films, or look for creep strains ahead of a crack, or determine such parameters as threshold fracture resistance, etc.
- Good for a project still in the beginning state, for the most part.

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

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

- This is a large team and obviously working together, which should be increased in the future.
- Project itself has a number of participants.
- Interaction with Oak Ridge National Lab was mentioned -- a plus.
- PIs working on related projects evidently coordinate with those working on this project, and are counting on its results.
- The project has a good team.
- Quarterly meetings and weekly communication.
- Good student interactions.
- Need to work more closely (and sooner) to determine why results from different partners are not consistent or contradict.
- Even though many parties are involved, work does not seem to be divided logically between many of them.
- Some of the duplication of skills and testing could be eliminated.
- It seems that the group is uncoordinated and each section proceeds independently of the others.
- Seems like there was good collaboration among the parties.

Question 5: Approach to and relevance of proposed future research

This project was rated **2.5** for proposed future work.

- UNLV- Roy: No discussion of next steps.
- GA: Not clear that testing plans approach reaction conditions. Will accelerated exposure testing be done, as well as ASTM tests?
- MIT: Not clear how this work is to be integrated with other partners.
- UCB: Moving toward practical system development.
- Ceramatec: Moving toward practical system development.
- UNLV-Chen: Good plans.
- Continued funding is expected, but evidence of specific milestones, directions was not included.
- In general, future seems to be more of the same.
- The overall plan shows the program continuing to FY08 but most of the individual future plans only show work through FY06.
- Individual work packages seem to be well-planned.
- The overall integration/linkage is less clear.
- Some of the work seems to be simply testing lots of materials without clear direction.
- I believe the project needs major reconsideration. The PIs need to get together and lay out a plan of objectives, problem identification, plan of approach, and communication program.
- They are on the right track.
- It is unclear why a standard shell and SiC tube heat exchanger will not work, recognizing that the MEMS type will have improved heat exchange.

Strengths and weaknesses

Strengths
- Work at UC Berkeley and Ceramatec is targeted and showing good results. CFD work at UNLV is showing good results.
- Project relevance to the DOE Hydrogen Program.
- The PI presents adequate experience for the success of the project.
- Good experienced team facing a large and difficult problem.
- No strengths in this project, as was presented, apart from its extreme relevance to the President's Initiative.
- It seems to be a well integrated group that involves industry, academia, and government labs.

Weaknesses
- The presentation had to cover too much work in too few slides and time, so it may be that the UNLV and GA experimental work is under reported. Also, budget for the individual activities were not given so it is difficult to evaluate the level of effort.
- Suggest that the UNLV and GA work be performed and reported in the context of the target process conditions and that accelerated aging tests are done.
- The HFCIT program metrics should be used as guidelines since they are quantitative and have a time line for implementation.
- No information on how much funding is accounted for by each major project participants.
- Funding resources for project PD-31 seem to cover some of the same work as this project. Clarification of the relative responsibilities between these two projects would be helpful.
- Too broad of a program for this type of review.
- Project is too empirical.
- Distribution of work between different labs does not seem thought out.
- Relatively little payback considering cost and project length.
- Focus on S-I process is high risk. What if another process is chosen by DOE?
- As is mentioned above, the project lacks coordination. Materials are chosen randomly and there are no criteria to suggest candidate materials of relevance? For instance, the PIs need to ask questions of the sort: is creep an important mechanism for failure? If yes, they need to suggest why chosen materials x, y, or z are appropriate, and then proceed with testing and modeling. Strength should not be a choice criterion.
- Modeling, e.g. stress analysis, reflects no failure mechanism approach. The way stress analysis was presented was just a numerical exercise with no specific purpose whatsoever.

Specific recommendations and additions or deletions to the work scope

- High project costs demand good budget management.
- Recommend program undergo separate reviews on each separate task, and that this be done at NE.
- Much of the materials testing work (especially the lower temperature part) could be outsourced to a contractor with experience in materials testing. This would most likely save time and money.
- More emphasis on testing under reaction conditions.
- Look at processes other than S-I.
- Project needs refocusing. The PIs need to state clearly their approach, objectives, and plan of action. It seems that everything so far is taking place in a very empirical way. There is no road map toward problem identification and proposed problem solutions. There are no criteria of operation and related material failure concerns, apart from corrosion issues. It should also be remembered that corrosion is related to how a component is loaded. Will proposed corrosion tests to be done at GA reflect the specific heat exchanger operation conditions?
- Verify use of ASTM standardized test methods.
- Contact Saint Gobain about their off the shelf SiC heat exchangers and test specific materials (SiC) in this program.
- Look at lifetime studies, particularly for any CVD SiC films which tend to wear off.

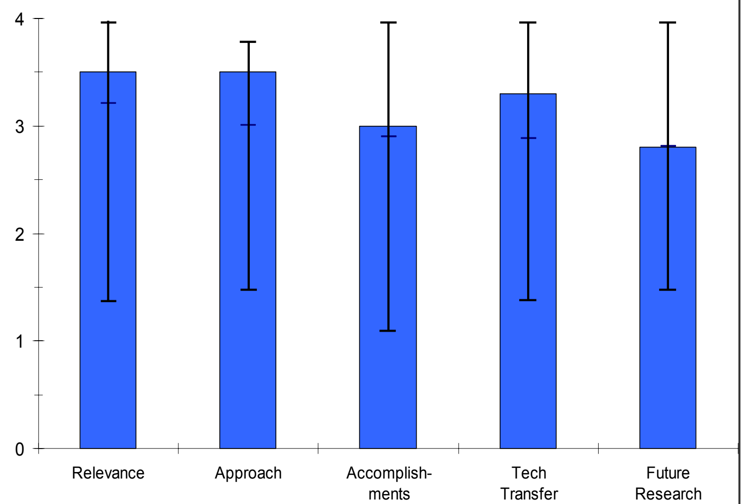
Project # PD-31: NHI System Interface and Support Systems

Sherman, Steve; Idaho National Laboratory

Brief Summary of Project

The Interface with Nuclear Reactor project, otherwise known as the Systems Interface and Support Systems area within the DOE's Nuclear Hydrogen Initiative, concerns the development of a thermal interface between a high temperature nuclear reactor and a hydrogen production plant; the definition and development of balance-of-plant components for a nuclear hydrogen production plant; and the definition of infrastructure and support systems requirements for a nuclear hydrogen production plant. All activities are directed towards developing the technology within the scope of the project to a sufficient level to support decisions concerning the pilot-scale and engineering-scale nuclear hydrogen production plants.

Overall Project Score: 3.2 (4 Reviews Received)



Question 1: Relevance to overall DOE objectives

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

- Does not describe how goals and milestones in the Hydrogen Posture Plan will be accomplished.
- Project aims to develop a high-temperature heat transfer network to enable the linkage of a high temperature nuclear reactor to a nuclear hydrogen production plant, and thus is critical to the Hydrogen Fuel Initiative.
- A key contribution to future hydrogen production at nuclear plants is provided by this project.
- Appropriate integration of Nuclear Hydrogen Initiative activities is enabled by this project.
- Applicable to nuclear-based hydrogen production. While this area could be very large, it's unfortunate that researchers are not trying to find links to other hydrogen processes and technologies.

Question 2: Approach to performing the research and development

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

- No description on the options and approaches to overcome stated barrier on high temperature materials.
- Project consists of a set of sub-projects, to accomplish the linkage of a nuclear reactor to a nuclear hydrogen plant.
- Definition of other projects' activities are guided and helped by this work.
- Focus is on "system interface."
- Currently is mostly lab-scale work.
- Interesting study of process design where hydrogen plant is not directly on-site at nuclear plant.
- Excellently coordinated project between partners.
- Have not seen much mention of safety. Impacts on nuclear plant and impacts due to near-contact with nuclear materials should be mentioned.

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

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

- Doesn't address progress against stated barriers -- only analysis activity in those areas but not what was found/concluded.
- This is a very costly project. There has been significant technical accomplishments and progress so far.
- Initial study of nuclear plant/hydrogen plant spacing has been done.
- Accomplishments based on using advanced analytical and assessment tools.
- Accomplishments of UNLV (PD-30) included in presentation by this PI.
- Too many items to track. Recommend linking accomplishments to listed barriers. A timeline showing what has been accomplished would be useful.

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

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

- No indication that nuclear power industry has been contacted, consulted or otherwise involved.
- An interface between DOE and other nuclear thermochemical cycle project teams provided by INL.
- Excellent team, with good coordination.

Question 5: Approach to and relevance of proposed future research

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

- Milestones to complete design in the barriers area provides little insight/confidence that they will be overcome.
- Description of future work (FY06 and later) includes types of work being done by UNLV and associates, described in project PD-30.
- Moving to designs, balance of plant, permitting for pilot scale operations.
- Projecting large resource requirements.
- Unrealistic to talk about work to 2017 for one single project. Need more details on timeline if plan is to make significant accomplishments each year.
- Suggest a link to other aspects of hydrogen future development.
- Need better estimate of costs.

Strengths and weaknesses

Strengths
- Project relevance and approach.
- Project is vital to insuring a well-structured, comprehensive, properly integrated program to assess and develop technologies needed for eventually producing hydrogen at nuclear plants.

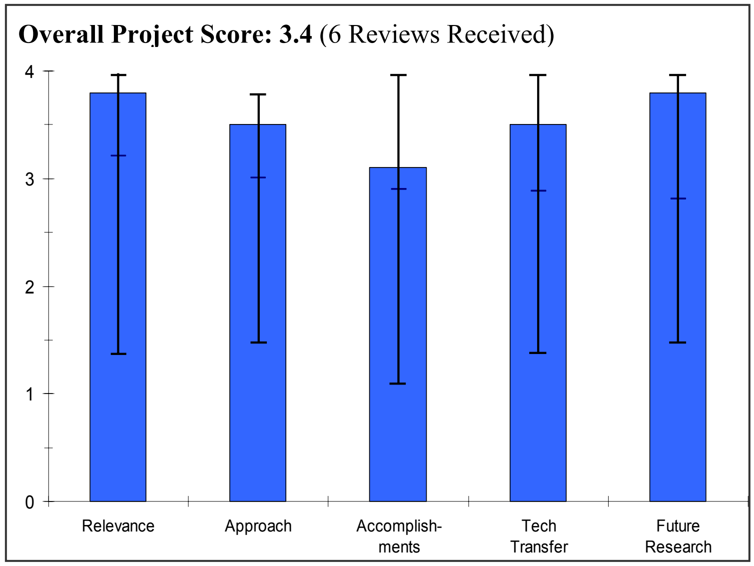
Weaknesses
- No industry involvement or even notification was indicated. Approach and future research describing milestones for completing testing, analysis, design are not an effective way to describe if barriers are going to be overcome. No discussion on scope and technical trade-offs and options. No description of the reactor/ plant interface concept.
- High project costs and long time frame make project management difficult.
- Funding resources for project PD-30 seem to cover some of the same work as this project. Clarification of the relative responsibilities between these two projects would be helpful.

Specific recommendations and additions or deletions to the work scope

- Keep good control on tasks and budged.

Project # PD-32: H2A Delivery Analysis
Mintz, Marianne; Argonne National Laboratory

Brief Summary of Project



This project, a joint collaboration of Argonne National Laboratory, National Renewable Energy Laboratory, Pacific Northwest National Laboratory and the University of California at Davis, is developing a set of Excel-based tools to examine alternative options for delivering hydrogen from centralized production facilities to stations or 'forecourts' for dispensing into hydrogen-fueled vehicles. Two tools, the Hydrogen Delivery Components Model and the Hydrogen Scenarios Model, are being developed. The Hydrogen Delivery Components Model estimates the contribution of individual major components (e.g., compressed gas tube trailers, liquid hydrogen trucks, small- and large-capacity compressors and storage tanks, pipelines, liquefiers, bulk liquid storage tanks, compressed gas and liquid terminals, and geologic storage facilities) to the delivered cost of hydrogen based on various design and scenario inputs. The Hydrogen Scenarios Model, which includes the Components model, estimates the contribution of an entire delivery pathway infrastructure to the cost of hydrogen under a particular scenario and calculates the discounted cash flow associated with that scenario.

Question 1: Relevance to overall DOE objectives

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

- DOE and others need a consistent program to normalize/validate vendors' information.
- It is important, but it is only a limited tool. Extrapolation on the results should be done (if) very carefully.
- Old studies have already show that liquid hydrogen is not the way to go. It should be removed from the beginning and use the resources in other more promising pathways.
- Project is developing analytical capabilities that are critical to assessing hydrogen production and delivery options.
- Provides needed public tool for assessment of delivery costs.
- This is the only public tool for delivery costs.

Question 2: Approach to performing the research and development

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

- Too great an emphasis on truck transport. Volumetric considerations alone demonstrate that gaseous truck transport makes no sense based on energy equivalent to gasoline. Similarly, liquid hydrogen truck transport has energy density and boil off concerns.
- Well thought out. Good progress made.
- Component model: There are technical correlations among the system components that are not addressed; for example, the production pressure with the plant storage pressure followed by the pipeline pressure and the fuel station pressure. The "generic contribution" can not be extrapolated.
- These models only cover current technology costs at the present time. Projections/analysis for future delivery technology costs need to be developed.
- Uncertainties about the scenarios and data should be quantified.

- Building on production H2A simplifies process and user training.
- Solid basis for calculations.
- Good efforts to validate and confirm.
- Scenario model useful for transition modeling

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

This project was rated **3.1** based on accomplishments.

- Lots of good learning capability.
- Based on previous comments, would hope by now that both parts of the model would be available for public use. But clearly understand the delays.
- Scenario model is behind schedule.
- Components model well done.
- Scenario progress good.

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

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

- Turn over to other PIs to use -- good work here.
- Other interested parties should be involved, especially from industries.
- I think that a couple of bullets on how this fits into the bigger H2A program would have been helpful. Unfortunate that H2A questions efforts did not prompt a broader perspective response during the Q&A.
- Wide involvement of national labs, industry, and academia.
- Good effort to get buy-in from technical experts.

Question 5: Approach to and relevance of proposed future research

This project was rated **3.8** for proposed future work.

- Very good path forward planned.
- What is the relationship between H2A and Hytrans? Are there linkages?
- See comments on other topics to review the current plan.
- Is a formal process for changing default values needed?
- Tracking of changes once initial model is published?

Strengths and weaknesses

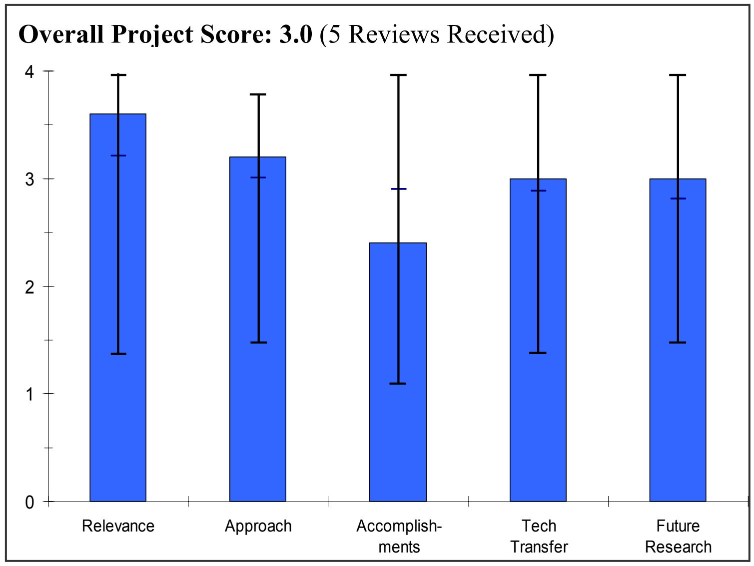
Strengths
- Good model to follow -- lots of work put into it. Good tool to use to "standardize" results of other projects.
- Sound approach.
- Transparency and simplicity.
- Large community of experts consulted.

Weaknesses
- None provided.

Specific recommendations and additions or deletions to the work scope

- Publish work/program, and begin to collect data.
- Formulate plan for model maintenance/modification.
- Consider carrier tab for components model.
- Consider fixed price in scenario models.

Project # PD-33: Hydrogen Permeability and Integrity of Hydrogen Delivery Pipelines
Feng, Zhili; Oak Ridge National Laboratory



Brief Summary of Project

This Oak Ridge National Laboratory project will provide a technical basis for the selection of high-strength steel pipelines for transfer of high-pressure hydrogen. The first task focuses on quantification of high- and low-pressure hydrogen permeation through base metal and weld metal regions of existing and new pipeline steels. The second task focuses on the effect of hydrogen permeation on the hydrogen embrittlement of the base metal and weld metal. In the third task, the optimization of the base metal and weld metal will be performed using the knowledge gained by the previous two tasks.

Question 1: Relevance to overall DOE objectives

This project earned a score of **3.6** for its relevance to DOE objectives.

- Good alignment of goal to provide hydrogen for high volume transportation potential.
- Investigates hydrogen embrittlement of steel pipe and welds..
- Unclear how "technical basis and guidelines to ensure integrity and safety" can be accomplished without the inclusion of a pipeline operator or regulator.
- The relevance to a hydrogen economy is clear but probably well in the future.
- The presentation leaned heavily on test chamber/safety, giving less opportunity for addressing the overall project objectives, accomplishments and prognosis.
- Pipelines cheapest delivery option.
- Hydrogen permeation is poorly understood. This project will provide insight into this.
- Understanding of relative importance of factors impacting embrittlement very important to program.
- Useful information for potential pipelining of hydrogen. Will support embrittlement work, but the embrittlement work itself will be even more useful.

Question 2: Approach to performing the research and development

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

- The information on structural integrity of hydrogen pipelines is certainly important to achieving a national network. However, given that hydrogen pipelines already exist, wouldn't much of this information already exist in some accessible data base or from the Energy and gas companies?
- Need more details on what types of mechanical tests will be performed.
- In looking ahead can the IHPV be designed to do natural gas/hydrogen mixtures?
- Addressing welding, steel impact, new steel tests with and without coatings, other materials (metals, composites, plastics?), and database of pipeline steels.
- Risk assessment -- why here, without a pipeline operator?
- The project objectives are relatively narrowly focused, which is good.
- There appears to be considerable duplication with the University of Illinois program (PDP-48).
- Determination of welding effects needed.
- Are high temperature measurements relevant to this problem?

- Need to tie permeability to embrittlement.
- The approach is consistent with the scope, but would be even better with broader scope.

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

This project was rated **2.4** based on accomplishments.

- Initial results look interesting. I look forward to getting details on why the XL65 steel performed better than the XL52. Assuming that these pieces of steel were already in use (dug up), was it simply a matter of aging as opposed to one being better for hydrogen permeability?
- How will you factor in the fact that some of the steel will be in different corrosive environments (like near the seacoast)?
- Established test units, GRNL IHPU Unit, SRNL low pressure, and identified steels for testing.
- Given future work, it doesn't seem like 60% done.
- No progress or future work on risk section.
- The work so far has validated some prior results -- not much new findings have occurred yet.
- As most buried pipelines do not suffer a wide temperature range in normal use, the value of high temperature testing is not clear.
- Design and construction progress reasonable considering the funding level.
- Work to date addresses only one of the three barriers to be addressed -- arguably the least significant barrier.

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

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

- Unclear how knowledge is being shared and received by this team with a broad spectra of interested parties. There is list of utilities that are providing materials, but will they also use the data?
- How about gas and energy companies -- will they review and comment on the information (beyond those involved in the DOE review)?
- Test equipment at labs excellent.
- Good slate of collaborators.
- Needs a pipeline operator for risk task.
- Could use refinery of ammonia partner for hydrogen management and risk assessment.
- There is an impressive list of project partners that can offer complimentary skills/knowledge -- steel, pipeline companies, welding institute
- Good selection of industrial and academic partners.
- Have an excellent collection of key collaborators.

Question 5: Approach to and relevance of proposed future research

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

- Recommend that consideration be given to gas mixtures since utilities will likely use existing and new pipelines for both if possible.
- No future work on risk? Or the steel database?
- Is the schedule too optimistic?
- Future work consists of a lot of highly technical activity of questionable value in the real world.
- Good plans for steels.
- Weld investigations important.
- Should adequately cover remaining barriers to be addressed.

Strengths and weaknesses

Strengths
- Addresses an important area that needs to be improved, be it for transportation, stationary power, or movement within plants.
- The test equipment is an excellent addition to the capacity to test hydrogen interactions with materials.
- Experimental capabilities.

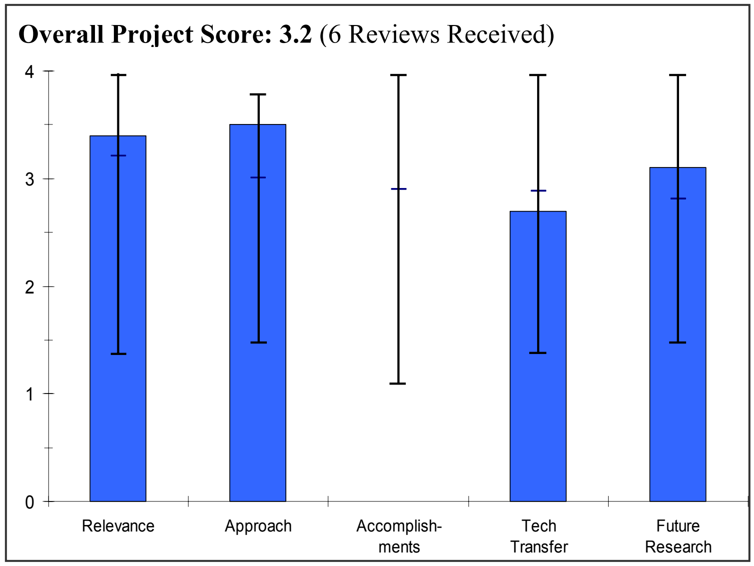
Weaknesses
- Seems behind schedule -- 60% seems optimistic.
- No status on database, management, or risk.
- How much value is there in investigating weld materials since welded areas are a relatively small part of pipeline surface area and weld metal becomes part of pipeline material anyway, i.e., no longer virgin material?
- The project should show why it has value, e.g., quantifying permeability with leakage volumes for a pipeline system and therefore degree of what is acceptable and what not.
- All this work benefits new pipeline construction but not necessarily using existing pipelines with hydrogen, that were formerly in use with another gas, e.g., natural gas.
- Need ties to other groups to measure effects of permeation.

Specific recommendations and additions or deletions to the work scope

- Need assurances that this information is not readily available from others.
- Clarify status of database, management and risk efforts. Drop if necessary.
- Needs additional collaborators for management and risk assessment, including a pipeline operator and a hydrogen intensive plant operator (petroleum refinery or ammonia plant).
- Future needs to get out of lab into real world, i.e., get to application not research.
- Do steel/pipeline manufacturers have some or a lot of this data already?
- Coordinate with other groups for embrittlement effects.
- Would be good if methods could be developed to resolve surface effects vs. bulk diffusion.
- Limit high temperature work. Focus on temperatures relevant for pipelines.

Project # PD-34: Reversible Liquid Carriers for an Integrated Production, Storage and Delivery of Hydrogen
Pez, Guido; Air Products

Brief Summary of Project



This is an Air Products-led, 3-year delivery project aimed at developing the engineering concepts to bring selected novel, reversible, liquid-phase hydrogen carrier systems into operative reality. These reversible liquid-phase carriers can be used to transport hydrogen from production sources to distribution systems where they can release hydrogen by dehydrogenation in stationary power applications or on-board for storage and vehicle fueling. The major effort will be to develop the conceptual design and initial prototype of an appropriate dehydrogenation reactor/heat exchange system for delivering hydrogen from the carrier. Additional efforts will be made to identify low-cost raw material sources and processing methods to enable economical synthesis of the carrier; to examine the requirements for incorporating a liquid carrier-based hydrogen storage device into a fuel cell power plant, and to develop a detailed conceptual design and economics for a liquid-carrier hydrogen storage and delivery infrastructure.

Question 1: Relevance to overall DOE objectives

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

- Innovative storage and delivery concept.
- This project has the potential to integrate delivery with on board storage with 6 wt% potential. However, the goals of hydrogen delivery optimization and onboard conversion are not necessarily identical. The project should have two sets of criteria for the two cases and specify the distribution of resources. This project should focus on dehydrogenation systems for fore court delivery and not for on board reforming. In that regard, the results should be benchmarked against a hydrogen delivery carbon carrier such as methanol or urea which has a significant weight fraction of hydrogen delivery potential. The technical and economic advantages over these alternative carriers should be specified.
- The fit with the Hydrogen Program unclear since on board reforming has been de-selected.
- Liquid carriers are the only delivery option that would leverage existing infrastructure.
- Potential paradigm-changing technology.
- Potential for meeting the hydrogen storage target while avoiding many infrastructure barriers.

Question 2: Approach to performing the research and development

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

- The approach is sound in identifying a potential hydrogen carrier that meets the 6 wt% requirement.
- This is a good time to get feedback from auto companies on plausibility (are there weight or material corrosivity issues under dehydrogenation temperature conditions?).
- The approach is on target but technical criteria were not given explicitly, although it is obvious that the PI has the criteria in mind. For example, vapor pressure is a key variable and was mentioned in the talk but not in the slides. The physical properties of the two forms should also be reasonably close (e.g., both liquids of similar viscosity) seems an important criteria but was not discussed. Recommend that the key variables of the system

be defined and candidate compounds screened by specific chemical and physical properties. It is not clear if there is a population of ten or a thousand compounds that should qualify for the system and be screened.
- The objectives are clear and well defined and linked with ST-14 program (material).
- How is recycle addressed in the approach activities?
- Very good mix of theoretical and experiments.
- Excellent use of theory to guide experiment.
- Approach appears sound, focusing on the fundamentals at this early stage.

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

This project just started and therefore was not scored on accomplishments, but the following reviewer observations were provided.

- If the 6 wt % has been reached (needs to be independently verified), then this is significant.
- Need more details on the properties of the carbazoles (will they add to the environment toxicity profile at a forecourt from leakage during filling/defilling? will it create waste disposal problems?).
- This is a new start but the PI presented some preliminary results which prove the concept. Suggest that the data presented in slide 10 on the packed bed results be unfolded to show the online variability or include estimates of variability such as confidence intervals. Is generation rate more steady at higher temperatures? It seems that the only reason to use a lower temperature would be for heat integration on board. This should be de-emphasized in favor of optimization of the forecourt dehydrogenation deployment scheme.
- The project has shown reasonable hydrogen production rates, at relatively reasonable temps/pressures, at least for production, but probably still insufficient for onboard use.
- Data on the recycling was thin.
- Proposed materials do not meet Program on-board storage wt% targets even as a raw material. How will this ever exceed the targets for a system?
- Good leverage off of storage project.
- Good candidates presented.
- Tailoring of dehydrogenation enthalpy is a significant achievement!
- Still very early to have any actual results at this time -- actually quite an accomplishment.

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

This project was rated **2.7** for technology transfer and collaboration.

- It appears that in the future more details will be forth coming on economic and design feasibility which will be included in the H2A model. Additionally a sister project is being funded under storage so there appears to be integration and knowledge sharing.
- Would like to see more details on other stakeholders that AP will systematically engage in assessing the feasibility of their approach (auto companies, and energy companies who run forecourts).
- The collaboration is good including a university, a national lab, and industry. Appears that the partners are more focused on the on board application. This is the role of UTC. The microchannel rector seems to be emphasized because of the on board application. Is this the reactor of choice for the forecourt option?
- There is very little outside collaboration indicated.
- Good partners.
- Have potentially useful collaborators, but not clear what their contributions have been.

Question 5: Approach to and relevance of proposed future research

This project was rated **3.1** for proposed future work.

- Future work lacks details on path forward on carrier development.
- The project is off to a very good start.

- The project should show preliminary economics now, not in 2007/8 -- this might suggest a go/no-go decision need.
- Co-production of power from hydrogenation (recycle) reaction a stretch unless this is a very large scale operation.
- There is very little connection between a packed bed reactor and a microchannel type. Is the project not effectively starting again?
- Advanced reactor program right direction and good partners.
- Prototype reactor vital to define system and make decisions on technology implementation.
- Plan appears sound -- the results will tell the story.

Strengths and weaknesses

Strengths
- Sound approach with a good plan.
- This system may be more applicable to forecourt production than onboard.
- Good capabilities.
- Scheme utilizes existing infrastructure.
- Comprehensive approach.
- Interesting concept.

Weaknesses
- One of the reasons for de-selecting on board reforming was the notion of a high temp/high pressure chemical plant under the hood -- this is no different. The temperature range for this device is closer to being reasonable but still higher than existing PEM fuel cells.
- The need for two tanks is very cumbersome for an onboard application.
- Need to focus on finding carriers that meet DOE on-board storage targets.

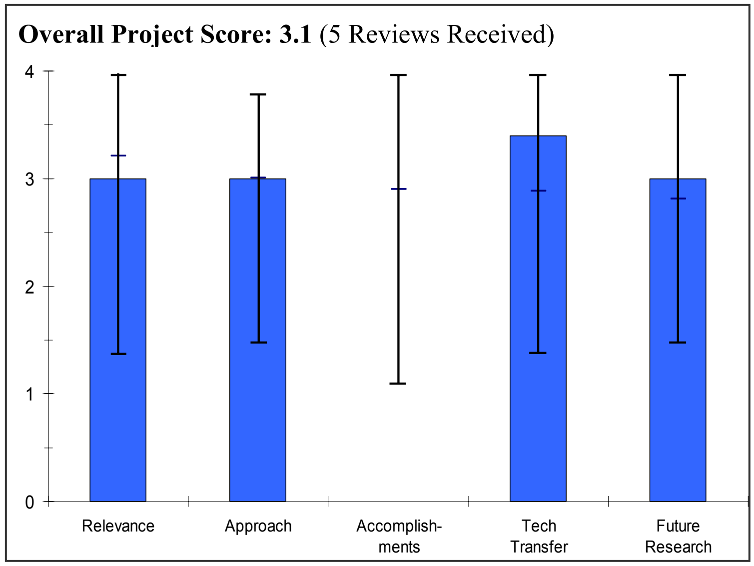
Specific recommendations and additions or deletions to the work scope

- The onboard option seems to be the favored path but the needs of the delivery area are better served by focusing on the optimization of that scenario.
- Is this practical at the scale required for a vehicle?
- How is variability of demand on a vehicle going to be addressed?
- What is the likely catalyst life/durability in reactor?
- Is the density/pumpability of liquid carrier in microchannel reactor going to be a problem?
- Does the carrier liquid present toxicity/flammability concerns?
- The liquid carrier only shows 3%, max 6.9% wt for original material -- this does not meet hydrogen onboard storage targets.
- If this project continues, there should be more emphasis on forecourt/bulk storage not onboard development.

Project # PD-35: Materials Solutions for Hydrogen Delivery in Pipelines
Das, Subodh K.; Secat, Inc.

Brief Summary of Project

This project focuses on an integrated approach to developing and testing new materials solutions to enable steel pipeline delivery of hydrogen at high pressures. The following two potential solutions to mitigating the hydrogen embrittlement of steels are being investigated: development of barrier coatings and in-situ deposition processes suitable for the protection of existing gas pipelines and newly added pipelines, and development of new alloys that have a better resistance to hydrogen embrittlement.



Question 1: Relevance to overall DOE objectives

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

- Addresses capital cost and embrittlement
- Minimizes embrittlement with coatings and pipe material and welding improvements
- Establishes baseline cost model
- Need to compare with existing H_2 pipelines
- Needs to be coordinated with PDP-48.
- Long term for new pipelines
- Good chance for impact
- Useful work to enable pipelines as a potential delivery pathway.

Question 2: Approach to performing the research and development

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

- Evaluates existing pipe under high pressure
- Finds or develops alternate alloys
- Develops coatings to minimize dissolution and penetration
- Evaluates selected coatings/alloy combinations
- Includes financial analysis
- Logical approach, tasks very well detailed.
- Why is a cost model needed when others exist already?
- The aspect of knowledge transfer to codes and standards may be valuable but probably is adequately covered by ASME
- Not sure how much existing data will be used vs. generation of new data
- Is 5000 psi testing relevant for 1000 psi pipelines?
- Coating processes must be simple/automated/cheap
- Is ABI test known to correlate well with embrittlement and other phenomena?
- Consistent with the objectives.

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

This project just started and therefore was not scored on accomplishments.

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

This project was rated **3.4** for technology transfer and collaboration.

- A good mix of collaborators already established.
- Excellent group of collaborators.
- Pipeline operator, labs, materials specialists and manufacturers, and standards group.
- Hydrogen pipeline operator (industrial gas company) would be a logical additional partner here.
- Considerable partnering/cooperation is indicated but serves to illustrate overlap of efforts with other programs as most of the participants are the same entities.
- Good set of partners with applied and fundamental expertise.
- Plans call for appropriate interactions.

Question 5: Approach to and relevance of proposed future research

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

- Future research work presented as a list subject to funds availability
- These lists need prioritization. What will happen if funds are short?
- Need a Gantt chart and specific decision points.
- The project does not show a clear correlation between metallurgy, coatings, etc., and cost analysis for pipeline construction.
- Many of the future program items are very generic and self-justifying.
- Generally good. Difficult to assess at this stage.
- Consistent with objectives.

Strengths and weaknesses

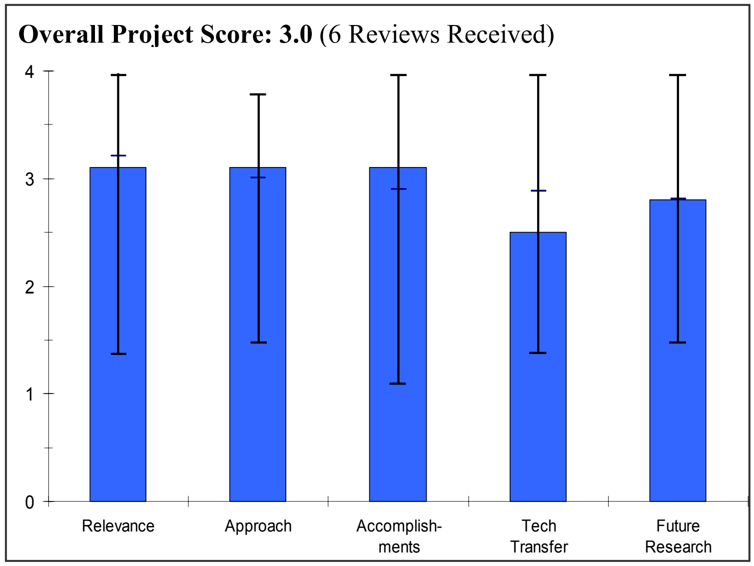
Strengths
- Great collaboration potential.
- Work is essential for proliferation of hydrogen pipelines, and they would need to meet same standards as natural gas lines.
- Technical capabilities.
- Attacking relevant problem.
- Valuable work to enhance pipelines as an option.

Weaknesses
- May be under funded, and plan needs to address impact of under funding.
- Future research work presented as a list to fund based on funding availability.
- Need more details on timeline and decision points.
- All this information (except possibly the coatings aspect) is already available.
- Coating technology difficult to implement on real pipelines.
- Need to be sure experiments are relevant to real pipelines.

Specific recommendations and additions or deletions to the work scope

- Include industrial hydrogen pipeline operator.
- Prioritize and Gantt chart the tasks.
- This project should be stopped, or at least merged with PDP-48 and PD-33.
- The project should address how the integrity of a mill-applied coating will be maintained during construction and welding? Will it be significant if not retained?
- The project should demonstrate much more relevance and application to the 'real world' so as to justify the importance of this work.

Project # PDP-01: Enhanced Hydrogen Production Integrated with CO_2 Separation in a Single-Stage Reactor
Fan, Liang Shih; Ohio State University



Brief Summary of Project

This Ohio State University project aims at developing an integrated process to produce a pure hydrogen stream from fuel gas mixtures via coal gasification and to generate a sequestration ready CO_2 stream. The high pressure, high temperature and high purity hydrogen is obtained by incessantly driving the equilibrium-limited water gas shift reaction forward using a metal carbonate to remove the CO_2 by-product. This process uses a patented high reactivity nanoporous calcium based sorbent, whose physical properties are tailored by using surface modifiers, for concomitant carbonation reaction of the calcium oxide which reacts with CO_2.

Question 1: Relevance to overall DOE objectives

This project earned a score of **3.1** for its relevance to DOE objectives.

- Hydrogen is produced through process intensification and enhancement of the water gas shift reactor -- a key. Enhanced hydrogen production and the integration of a carbon dioxide separation membrane into a single-stage reactor are important focus areas in FE's draft "Hydrogen from Coal RD&D Plan."
- The carbon dioxide stream would be ready to be sequestered and is a key focus area of FE's draft "Hydrogen from Coal RD&D Plan."
- FE has a goal of achieving $3 per gge by 2005; however, the researchers do not know if the costs will help FE meet the goal.
- Lowers the cost of hydrogen.
- Reduces greenhouse gases (CO_2 sequestration ready).
- A cost-effective coal based hydrogen production technology is responsive to the Hydrogen Fuel Initiative and the proposed work scope is consistent with DOE Hydrogen program goals.
- The project, novel in approach, has completed 50% of the work in the development cycle. However, the results presented so far do not indicate techno-economic potential for advancing hydrogen production state-of-the-art. During review the PI informed the reviewer that he will ask for a no-cost time extension for completing the tasks, and the remaining tasks are consistent with DOE program goals.
- The project objective does not include any discussion of a development cycle leading to scale-up and commercial maturity or any success criterion and how the R&D efforts can accomplish such a goal. A list of risks and barriers and planned accomplishments to overcome key technology barriers is appropriate.
- Without additional cost information it is uncertain how the project will result in the use of hydrogen as an energy carrier in the US.
- The project describes a novel approach for enhanced hydrogen production through the in-situ removal of CO_2 from the water gas reaction products. It supports the President's Hydrogen Fuel Initiative and fits in well with the RD&D Plan objectives. Work conducted so far has focused only on maximizing CO_2 removal -- hydrogen production is a consequential (and not the primary) focus of this project.
- Work was focused on the CO_2 sorbent chemistry including carbonation and calcinations.

Question 2: Approach to performing the research and development

This project was rated **3.1** on its approach.

- Using calcium carbonate solvent to react with carbon dioxide appears to be an effective way to "capture" carbon dioxide from the gas stream.
- Heat generated during the shift reaction is used during carbonation to improve system efficiencies.
- The limestone industry could supply the raw material from which the solvent is manufactured potentially lowering the costs that might accrue through other methods of CO_2 capture.
- Innovative WGS and carbonation.
- Systems integration needed (H_2S cleanup, calcinations heat transfer).
- The project aims to develop a novel approach to tie up the CO_2 using CaO sorbent and thus generate hydrogen from shifted synthesis gas. The $CaCO_3$ can be decomposed, CO_2 captured, and CaO recycled to the system.
- The technology is a high temperature operation, and not compatible with coal gasifier warm gas clean-up conditions, i.e., energy is needed. WGS reaction is also proposed at high T (600ºC).
- An overall process scheme has been presented and the WGS-CO_2 capture experimental set-up described.
- The de-coupled WGS reaction CO_2 sorption approach seems novel, but its scale-up and engineering design may be very challenging.
- The main weakness of the approach is the deactivation of the WGS catalyst in presence of H_2S produced during the gasification. This can affect the overall efficiency and then it does not reduce the cost of hydrogen production.
- The approach is technically sound and logically focused toward reaching the final goal.
- No data was provided to determine if the concept of in-situ CO_2 removal from the WGS reaction does improve hydrogen production.
- Proposed work scope is narrowly focused on sorbent chemistry.

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

This project was rated **3.1** based on accomplishments.

- It has been determined which temperatures carbon dioxide will react with the calcium carbonate solvent and is generally 600 to 700 degrees Celsius.
- The researchers are able to achieve equilibrium.
- Good progress on sorbent effectiveness, catalyst performance, and testing plan.
- Delays in pressure testing due to vendor equipment delay (no-cost extension to FY06).
- Sorbent surface optimization and CO conversion data using known catalysts and two sorbents have been presented. The data present CO conversion with CO_2 product removal at only early time scales and 80% CO conversion is observed for the short duration tests. The comparison of data with prediction is very insightful. Product (CO_2) removal does appear to favor improved production of hydrogen.
- As of now, the data base generated is not complete but, a stated before, the project PI will apply for a no-cost time extension.
- The extent of the deactivation of WGS catalyst was not studied yet. This can strongly affect the efficiency of the hydrogen production process;
- The cost of hydrogen production was not provided since the authors still did not measure the hydrogen purity obtained; therefore, the main technical barriers were not overcome yet.
- The project's major focus so far has been on the evaluation of sorbent characteristics to maximize CO_2 removal. Some work should have been done at the very outset to determine if hydrogen production is enhanced by this effort.
- Careful experimental work was conducted to prove several key points of the sorbent applications.

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

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

- The researchers are working with others to compare their product. For example, the researcher conducted lengthy negotiations with Toshiba to obtain data on their proprietary solvent. Boeing and GE are also potential collaborators.
- Collaboration indicated with B&W, Boeing, GE.
- All of the work thus far is done at Ohio State. During the review, the PI informed the reviewer that GE and Boeing have shown interest in the technology and Boeing is talking with Ohio State intellectual property office.
- There is no collaboration with industries or other universities. Technology transfer mechanisms were not described.
- Most of the work is done at the Ohio State University. There appear to be no outside collaborators at this point.
- Needs more interaction with industry to seek R&D inputs.

Question 5: Approach to and relevance of proposed future research

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

- The PI plans to study sintering effects and to use better equipment to test high pressure streams and hydrogen purity. The equipment that was scheduled for delivery from Germany had to be delayed due to the increase in value of the euro compared to the dollar.
- Significant future work planned for multicyclical testing (carbonation, calcinations, H_2S effects).
- The future research proposal slides were clearly explained by the PI. A test rig has been procured for high pressure tests and to determine the effect of H_2S. The description of future efforts contributing to expanding knowledge base or technical know-how was adequate.
- Study of the effect of H_2S on the catalyst activity and carbonation; hydrogen production, measuring the amount of H_2 in the exit stream; and multicyclical testing (carbonation, calcinations).
- Some effort should be devoted to determining the quality and quantity of hydrogen produced when using (and not using) the proposed concept.
- Good approach for further advancing sorbent chemistry/applications.

Strengths and weaknesses

Strengths

- The solvent developed appears to be much more reactive than other comparable solvents.
- Ambitious goals, steady progress.
- Removing a product from the WGS reactor by sorbent is an interesting approach although the product removal rate may not match the WGS reaction kinetics. The PI needs to address this issue of transport-kinetic coupling.
- The integration of water gas shift reaction and carbonation at the same reaction is an interesting approach for CO_2 sequestration.
- The project is a novel approach to remove CO_2 in situ from the WGS reaction. If successful, this would become a valuable process step to enhance hydrogen production. Future work is a logical continuation of work performed in the past.
- Good sorbent chemistry data were presented, including PCC (precipitated calcium carbonate) applications.

Weaknesses

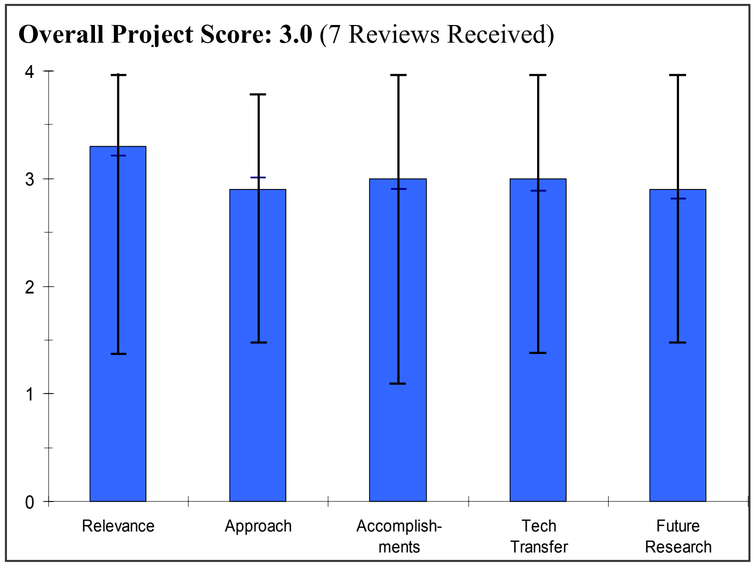
- A major weakness is that this research does not have an economic basis. Ohio State University is requesting a one year extension to evaluate the economics of the project. FE has a goal of achieving $3 per gge by 2005 (according to the poster); however, the PIs do not know if the costs will help FE meet the goal.
- More time may be required to accomplish objectives.
- The exothermic WGS reaction system is operating at high temperature; the effect of high temperature on conversion is not discussed adequately. In some cases, high temperature-WGS is used to shift only moderately cleaned coal gas, but almost always followed by a low temperature-WGS to maximize conversion. This project does not address this issue.

- The PI needs to address that product removal is overcoming the high temperature shift operation, i.e., the lower conversion is countered by the favored eqm towards more hydrogen formation.
- Hydrogen purification strategy.
- Unclear if this additional process step improves hydrogen production or not. Bulk of the work has focused on CO_2 removal. If future work proves that hydrogen production is not improved, the project may still be continued under a carbon sequestration program.
- Discussions on the effectiveness of combines sorbent/water gas shift catalyst system were inadequate, e.g., can the system handle a CO-rich syngas from coal gasifies? Acronyms (e.g. MSB, PCC) were not explained. Proposed coal-to-hydrogen technology is complex with the deployment of sorbent.

<u>Specific recommendations and additions or deletions to the work scope</u>

- FE should request that Ohio State promote the expensive test equipment (once it is received) to encourage other researchers to use the equipment for evaluating hydrogen quality.
- The PI should attempt to use the H_2A analysis tool during the present budget period.
- Possibly use the Aspen modeling for systems integration.
- Investigate sulfur tolerant WGS catalyst.
- The project can not be completed during the time scheduled (September 2005). There is a large amount of experiments that still have to be done. Furthermore, it is not sure that the project objectives will be reached after that. The authors attributed the delay to the difficult to acquire some of the equipments.
- Collection of data to determine if CO_2 removal during the WGS reaction does improve hydrogen production kinetics and hydrogen purity.
- Expand work on proving out the feasibility of sorbent carbonation/water gas shift (WGS) reaction system. Perform scoping economics study for the prose technology. Work on effectiveness of WGS catalyst in the presence of particulates from local gasifier.

Project # PDP-03: Integrated Ceramic Membrane System for Hydrogen Production
Schwartz, Joseph; Praxair, Inc.



Brief Summary of Project

In the current phase of this project, Praxair is focused on simplifying hydrogen production by combining the reaction and purification stages of hydrogen production into a single step in a single vessel which could significantly reduce the capital cost of producing hydrogen, Phase I analyzed and compared several different processes and, based on the likelihood of success, a two-stage process wherein each stage was comprised of a membrane reactor was selected.

Question 1: Relevance to overall DOE objectives

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

- Good concept to develop membrane. Good explanation.
- Success on this project will significantly benefit small-scale hydrogen production.
- This project supports the President's Hydrogen Fuel Initiative to accelerate the introduction of hydrogen as the primary energy carrier in the USA.
- Use of membranes for distributive hydrogen production is very essential for the success of the Hydrogen Program.
- The project is focused on small scale distributed hydrogen production.

Question 2: Approach to performing the research and development

This project was rated **2.9** on its approach.

- The project has a lack of focus on durability testing prior to scale up. Appears to be materials limited due to sensitivity to impurities. Metallic supports are more robust and should be evaluated as supports.
- Appears to be well designed with good progress.
- Use of previously developed support structures with application-specific membrane materials is an excellent approach.
- Excellent study of CO conversion as a function of hydrogen recovery.
- Matched thermal expansion of materials very insightful.
- In addition to effect of H_2S, suggest study of unconverted methane. Is there any chance of coking on the membrane surface, due to dissociation? CH_4 is relative stable, but with Pd at these temps, it would be worth addressing.
- Is there adsorption of CO on membrane surface?
- The project addresses the cost reduction of the hydrogen production through the development of hydrogen separation membranes integrated with WGSR.
- The three phase approach is a good plan. Phase I deals with technical and economic feasibility and therefore provides a good guide for Phase II development before system design and testing in Phase III.
- A sound step; by step approach was proposed.

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

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

- Is thermal cycling a potential issue for supports?
- More than halfway through – good that they have already incorporated lessons learned.
- Study of Pd-Ag membrane very useful to progress.
- Good experiments on hydrogen flux as a function of substrate manufacturing date. Shows keen understanding of variables that can affect performance.
- Good leveraging with other research efforts (membrane support, reactor).
- Excellent understanding of system design in last conclusion point on slide 24
- The membrane did not exhibit resistance to sulfur contamination.
- The team has a long list of barriers that have been successfully addressed: durability, impurities, flux, defects, selectivity, cost, operating conditions, etc.
- Good progress was made in substrate development and hydrogen flux.

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

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

- Have looked at DFMA partners.
- Not a large team, but seem to be making appropriate progress.
- Should discuss partnerships within Praxair that are already benefiting from the project as these are collaborations, too.
- The project involves collaboration between industry and research institute.
- Praxair is an engineering company with a good record of commercialization of similar technologies, including PSA for large hydrogen production and therefore is committed to commercializing this technology.
- Have plans to commercialize this technology upon successful completion from small-to-large scale applications.

Question 5: Approach to and relevance of proposed future research

This project was rated **2.9** for proposed future work.

- Future work lack focus on durability/reliability testing and thermal mechanical issue possibly due to ceramic support.
- Will incorporate with other DOE funded project. Good leverage with other projects.
- All plans shown on slide 23 are reasonable and necessary to achieve project success.
- Timeline given in slide 2 shows good project planning.
- The team has a good list of future activities, including continued performance improvement and integration.
- Integrated WGS/hydrogen separation operation will be conducted.

Strengths and weaknesses

Strengths
- Good progress made. Good list of future work and identification of last year's issues. Should continue work.
- Excellent project.
- The development in pilot scale of a hydrogen separation membrane with mechanical, thermal and chemical stability.
- Has pursued a sound step-by-step approach by identifying key problems and then finding solution (e.g. low cost ceramic substrate preparation).

Weaknesses

- Scale is fairly small. Good for transition, but economic pressures will be most intense during this phase of hydrogen economy development. Need study of applicable markets. Because DOE is helping to fund this work, applicable markets cannot be limited to company's current customer base.
- Approach gives little outlook on robust membrane.
- The extent of hydrogen recovery obtained by using these metallic membranes can reduce the efficiency of the process and the cost of hydrogen production.
- Quantitative experimental data presented were scarce.

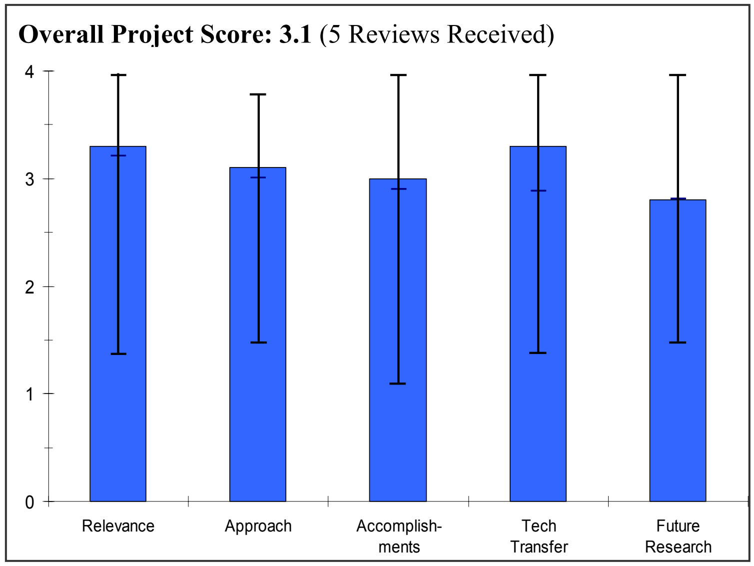
Specific recommendations and additions or deletions to the work scope

- Need a system and market study.
- The integration of membrane and WGSR has to be implemented taking into account specific catalysts. The performance of the integrated system has to be demonstrated in the presence of a real feed.
- Expand work to study the effects of H_2S on membrane performance, since biomass and coal will produce syngas with H_2S contaminant. Expand work on industrial partnership with industry on water gas shift catalyst incorporation into membrane reactor. Expand work on engineering considerations associated with membrane scale-up (e.g. seal).

Project # PDP-04: Low Cost Hydrogen Production Platform
Aaron, Tim; Praxair, Inc.

Brief Summary of Project

In this project, Praxair, Inc. is developing a low cost hydrogen production platform for the onsite generation of hydrogen. Their goal is to commercialize a cost effective, small scale, hydrogen production system using high volume packaging and design techniques. The system is based on traditional steam methane reforming (SMR) and pressure swing adsorption (PSA) process technology. The approach involves applying Design For Manufacturing and Assembly (DFMA®) techniques, as well as a high level of system design/integration, to lower the cost to produce hydrogen from small on-site plants. The program includes the construction and testing of component and complete system prototypes.



Question 1: Relevance to overall DOE objectives

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

- Good scope of work. Work linked to membrane development. Good discussion of poster.
- Project is fully relevant to achieving goals of developing low-cost hydrogen production capabilities for the transition.
- Important to validate current distributed reforming delivered cost of $3.00/gge and an overall efficiency of 65%.

Question 2: Approach to performing the research and development

This project was rated **3.1** on its approach.

- Good list of barriers identified.
- Sharp focus on more than one barrier.
- Component testing is a good approach.
- Is hydrogen compression and storage included in the project scope/economics? Suspect that 100-120 psi hydrogen will not be useful at a refueling station.
- Is 4.8 kg hydrogen per hour enough capacity for a typical refueling station?
- The approach relies too much on conventional technology.
- Apparent efficiency of the design appears to be low; this issue is not addressed explicitly.
- Insufficient attention paid to the issue of reliability.
- Turndown ratio of the prototype is too high for a real world refueling station.
- Start-up and shutdown robustness not explicitly addressed.
- Design decisions criteria and comparative data should be given when possible.

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

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

- Good progress made so far.
- Significant activity on addressing the DOE targets.
- Good cost analysis with documented assumptions.

- Good progress overall.
- The project needs to become data driven. It is important to document the specifics of system performance and quantify reliability by showing line charts for key variables, statistics and impact of variance of these variables on economics and efficiency numbers. Perhaps this is not the venue for so much detail, but it should be stated what the meta data needs to be to make such decisions i.e. describe the data base that will result from the testing program.
- The estimated cost for the system is a breakthrough for distributed production.

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

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

- Good list of partners identified.
- Good use of Boothroyd-Dewhurst and Diversified Manufacturing to assist in manufacturing analysis.
- Work with manufacturing companies for DFMA improvements is impressive.
- Praxair has included DFMA partners to develop the system and commercialize it. This is a significant aspect of the project.

Question 5: Approach to and relevance of proposed future research

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

- Good efforts so far. Future work looks feasible.
- System development and operation is the logical next step.
- Need to show how hydrogen compression and storage will be integrated into the system's design.
- Future plans inconclusive.
- Longer term testing should be included in the test plan as funding allows.

Strengths and weaknesses

Strengths
- Good poster explanation with nice layout.
- Manufacturing focus and addressing several barriers.
- Solid compact reformer development program.
- Sound conservative design and resulting low cost estimates for reaching HFCIT distributed production goals.

Weaknesses
- While safety has been addressed, it appears to be less focus on safety than other technical aspects of the project. One example is that the Hazop has not been completed prior to manufacturing study was done. Results of Hazop may alter the mechanical design.
- Unclear how much it adds to what we already know from the work of others (APCI, H_2Gen, GE, etc.).
- Need more information to support conclusions in economic analysis.
- Data analysis plan should be included in the project and linked to performance validation objectives.

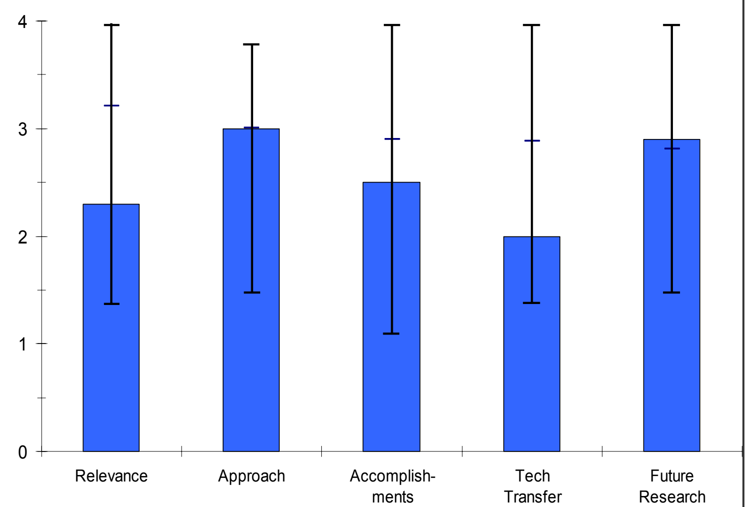
Specific recommendations and additions or deletions to the work scope

- Consider further safety assessment including adding a third-party safety partner to the project team.
- Need to document progress against the DOE targets as the project proceeds.
- Add improved PSA performance.
- More data on reliability and start-up/shutdown testing.
- Component testing and integrated system run times should be extended to times consistent with an appropriate experimental design for reaching decision about performance.

Project # PDP-05: Solid Oxide Fuel Cell Carbon Sequestration
Bessette, Norm; NiSource Energy Technologies, Inc.

Brief Summary of Project

Overall Project Score: 2.6 (6 Reviews Received)



NiSource Energy Technologies, Inc., a subsidiary of NiSource Inc., is engaged in research and development of a solid oxide fuel cell (SOFC)/carbon sequestration technology whereby separate exhaust pathways are provided for spent fuel and air. This enables the SOFC the flexibility to either direct the exhaust back to the fuel input to provide steam for reforming hydrocarbon fuels or further oxidize the exhaust gas stream into carbon dioxide and water vapor. The remaining water vapor can be condensed, leaving a pure carbon dioxide stream, which could be used for chemical processing, oil/gas recovery enhancement, or simply re-injection into the ground to avoid carbon emissions. If successful, this development would support the ability of SOFCs to run virtually free of such emissions.

Question 1: Relevance to overall DOE objectives

This project earned a score of **2.3** for its relevance to DOE objectives.

- Creating affordable hydrogen fuel cells.
- Reduce greenhouse gas emissions (CO_2 sequestration ready).
- Good concept to sequester CO_2 with SOFC.
- Carbon containment is certainly desirable, but is it necessary at this point of development of SOFCs?
- SOFCs have significant materials problems -- this project just adds additional materials challenge to the mix.
- The project includes technology development that supports aspects of the hydrogen vision, but is not directly tied to achieving the objectives or overcoming the barriers outlined in the RD&D plan.
- Not clear how this links to the Hydrogen Fuel Initiative as this approach does not make hydrogen. This seems more relevant to the Future Gen Clean Coal initiative.
- Sequestration of CO_2 with a small SOFC system does not seem to be a feasible proposition.

Question 2: Approach to performing the research and development

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

- Fuel cell technical barriers addressed (stack design, materials development).
- Acumentrics has to develop their own membrane, which has not been tested/demonstrated.
- The proposed approach seems reasonable, but since the CO_2 is going to be collected why not just collect the unreacted fuel cell effluent, contain it and dispose (and/or) use it for some other purpose?
- Preventing back pressure buildup that would adversely impact SOFC performance could be a problem.
- This is a good approach for accomplishing the project objectives.
- Clearly a qualified team.
- Approach of using oxygen transfer membrane to oxidize residual fuel in SOFC anode waste gas has high likelihood of achieving technical success. However, one wonders if a different approach that captures some of the significant energy available in this stream would be of greater value. It would be helpful to see an evaluation of this option against use of an oxygen transfer membrane to produce a pure oxygen stream that

could be combined with the fuel cell anode gas and combusted in an engine where one could extract some energy from the fuel stream, and still retain the feature of producing a sequesterable CO_2 stream.
- Main issues addressed well.
- Reliability of the system (considering not a good track record of SOFCs) needs more attention.
- The system is very complex, combining a lot of complex processes. This increases reliability risk.

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

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

- Project recently started (11/2004).
- Pre-reformer used so far.
- Developed closed end tubes and double-chamber manifold.
- So far only 5% progress but appears to be on track.
- This project has just started and is only 5% complete -- this criteria should probably not be evaluated. The major challenges associated with this project have not been addressed yet.
- Slow start; only 5% complete.
- Technical progress in redesign of flow scheme, manifolding, and components of SOFC to capture and isolate the anode waste gas stream. Work has not yet started on selection and testing of the mixed oxygen ion/electron conductors needed to make this concept work.
- Would be helpful to get better understanding of the tools that will be used to characterize the oxygen transfer membranes before and after use in this application.
- Project just commenced.

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

This project was rated **2.0** for technology transfer and collaboration.

- Not demonstrated.
- There was no indication of collaborations within this project. It appears to be a totally self-contained project. Apparently any resulting technology would be integrated into the presenter's existing SOFC product line.
- Appears to be some collaboration, but PI did not provide details.
- NiSource is sole collaborator.
- More in-depth collaboration with other (OTM) developers needed

Question 5: Approach to and relevance of proposed future research

This project was rated **2.9** for proposed future work.

- Electrochemical oxidizer development.
- Demonstrate full-scale and a 2000 hour endurance test.
- Given the stated objectives of the project, the plans for future work appear to be reasonable and adequate.
- Would benefit from enhancing partnership development to implement the technology into a practical system.
- Next steps in the work are clear -- design, synthesize and test oxygen membranes in this application.
- Provided that the unit can be stable in operations, the direction is good.

Strengths and weaknesses

Strengths
- Good mechanical design.
- Good concept and approach.
- Existing SOFC technology and hardware jump starts this project.
- Industry partner has strong SOFC capability.
- Potentially very high efficiency combined heat and power.

Weaknesses
- Materials development pending.
- Partners to develop components have not been identified.
- Relevance of this project is questionable given the current SOFC state-of-the-art.
- Geared towards power generation and carbon capture, not on hydrogen production for transportation applications.
- The idea of purifying and sequestering CO_2 on such a small scale.
- Poor track record of SOFC creates risks when a combination with another unproven technology (OTM) is planned.
- Unclear how this unit would be better that just a stand-alone SOFC combined heat and power.
- Unclear end use.

Specific recommendations and additions or deletions to the work scope

- Additional collaboration with SOFC materials developers may be beneficial.
- Eliminate CO_2 sequestration from the scope or increase the unit scale.
- Be more specific on where the technology could be applied.

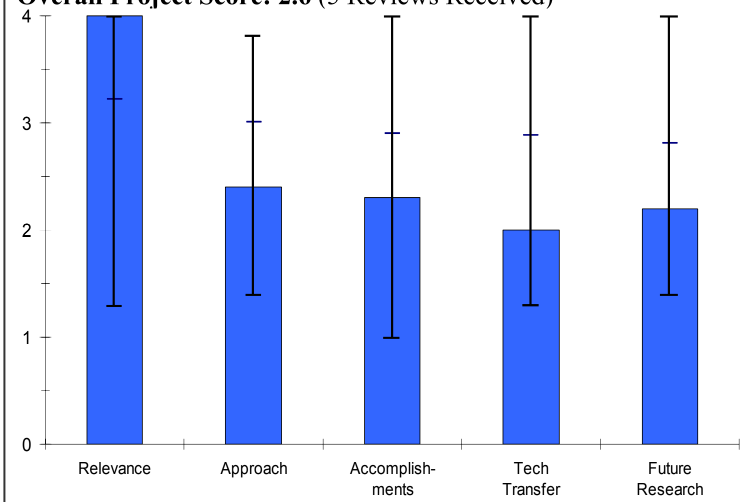
Project # PDP-07: High Pressure Distributed Ethanol Reforming

Ahmed , Shabbir; Argonne National Laboratory

Brief Summary of Project

This Argonne National Laboratory project will study the feasibility of high pressure steam reforming of bio-derived liquid fuels, such as ethanol, with simultaneous removal of carbon oxides. The high operating pressure allows hydrogen purification by a variety of techniques to produce pressurized pure hydrogen for ease in storage, distribution, and dispensing. The study includes theoretical modeling and efficiency analysis of alternative process designs, experimental reaction studies to determine operating parameters and kinetic data, and investigation of potential separation/purification membranes and other approaches.

Overall Project Score: 2.6 (5 Reviews Received)



Question 1: Relevance to overall DOE objectives

This project earned a score of **4.0** for its relevance to DOE objectives.

- Good synergy with PNNL low pressure ethanol project.
- The operation of the process is quite difficult for distributed production scenarios.
- No measures of progress in the objectives.
- This is a study that could have been worked into another project perhaps.

Question 2: Approach to performing the research and development

This project was rated **2.4** on its approach.

- PI has looked at potential barriers of soot formation.
- Better treatment on the catalyst aspects is necessary (20% methane formation is too high).
- It should finish the basic development (to find the right catalyst) before developing the kinetics and the reactor.
- It is certain that they can develop a reformer that will efficiently convert ethanol to hydrogen, the applicability of such a process to the needs of the hydrogen future is difficult to identify.
- The fact that ethanol is a bio-derived liquid does not justify this project. Ethanol can benefit hydrogen but only at a small scale. Whole biomass is more appropriate (and less costly and more efficient) at mid and large scales.
- PI does not intend to study the economics of this process within a system context.
- Excellent idea to condense CO_2 out after WGS.
- Excellent understanding of how to balance reformer fuel requirements and ethanol conversion. PI should be funded to apply this to other reforming operations
- Needs to be integrated into other programs.

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

This project was rated **2.3** based on accomplishments.

- So far, they are on track.
- Too much methane formation.
- Efficiency is far from the simulated possibility.

- While this is a newer project, literature evaluation and thermodynamics modeling should be commended. Excellent way to start a project.
- More work should be done to evaluate applicability of this process to mid and large central operations.
- High pressure process cannot be operated intermittently; PI does not understand importance of including storage.
- Not clear how this research will forward distributed hydrogen production from renewable feedstocks.

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

This project was rated **2.0** for technology transfer and collaboration.

- Good synergy with PNNL.
- More cooperation with other organizations may help.
- Buying catalyst from Sud Chemie does not make them collaborators.
- Suggest contacting existing ethanol reforming companies.
- PNNL listed as a collaborator on slide 2 but not on slide 14.
- This is all government-to-government.

Question 5: Approach to and relevance of proposed future research

This project was rated **2.2** for proposed future work.

- Appears to be on track.
- It should concentrate efforts on the reformation process prior to the separation membrane and the reactor itself.
- High pressure means larger, continuous, and monitored operations. Ethanol is best suited to small-scale operations because it is easier to transport and store. Ethanol is more expensive and less energy efficient to produce and deliver than whole biomass, and since you cannot take advantage of lower hydrogen delivery costs at the larger scale, is not justified.

Strengths and weaknesses

Strengths
- Good concept -- appears to have looked at potential barriers in addition to cost and efficiency.
- Researcher has strong capabilities in process mass-optimized and energy-optimized design. Excellent understanding of energy balance between reformer and water gas shift.

Weaknesses
- Additional emphasis on the catalyst and in the reforming process is necessary.
- Large scale process does not match up with chosen feedstock.

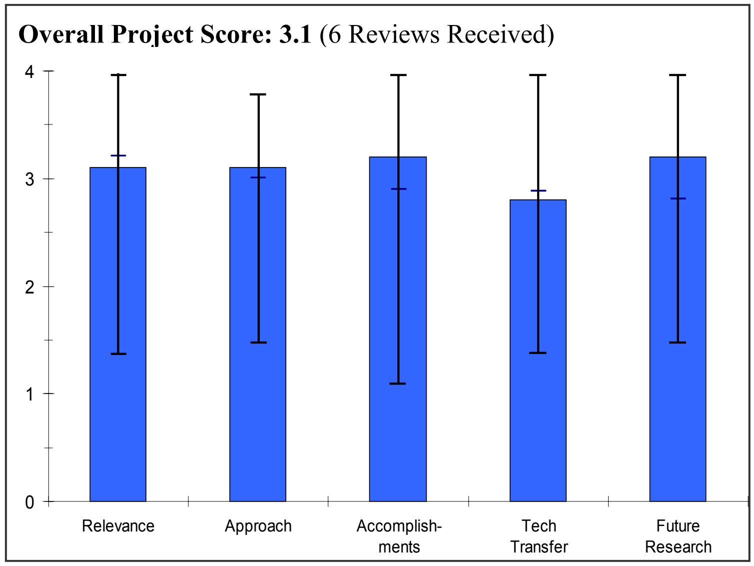
Specific recommendations and additions or deletions to the work scope

- Concentrate more on the reforming process (catalyst and operational aspects) tests before design the reactor
- DOE should perform a parallel and more detailed review on this project.
- Suggest keeping capability but applying it to a different process.

Project # PDP-08: Hydrogen Production for Fuel Cells via Reformation of Coal-Derived Methanol

Erickson, Paul Anders; University of California, Davis

Brief Summary of Project



Hydrogen can be produced from many feedstocks, including coal. The objectives of this project are to establish and prove a hydrogen production pathway from coal-derived methanol for fuel cell applications. The project has used internal and external analyses to quantify the differences in composition between coal-derived and a baseline fuel-cell-grade methanol. Degradation rates in a steam reforming system have been observed with both fuels, and enhancement methods have been studied. Both autothermal reformation and steam reformation have been proven with the coal-derived methanol. Presently, clean-up methods are being investigated and operation within a PEM fuel cell system will shortly take place with the coal-derived methanol.

Question 1: Relevance to overall DOE objectives

This project earned a score of **3.1** for its relevance to DOE objectives.

- Lowers the cost of hydrogen ($1.77/gge) via methanol reforming.
- Addresses hydrogen storage (via methanol).
- The project objectives and the work scope are partially consistent with the Hydrogen Initiative and the DOE program goals. The major objective is to compare the properties and performances of coal-derived vs. fuel cell grade methanol.
- The presentation does not address key technology issues related to production and delivery of hydrogen, does not list risks and barriers, nor pro-active approaches to overcoming key technology barriers. "Develop reforming technologies for gasification and pyrolysis processes" is more of an objective (intended result) statement, rather than a statement of barriers.
- A slide on the relevance and contribution of the work to DOE and Hydrogen Initiative program goals (i.e., why do it), is needed, but not included in the presentation (for the reviewer's understanding of the major issues and the current technology deficiencies).
- Methanol as a transportable intermediate from coal and biomass is a viable option that does not attract as much attention as ethanol. The project addresses two important factors: methanol impurities and reactor temperature inhomogeneity in leading to degradation. These are important barriers although not specifically called out in the MYPP barriers.
- The project consists on the hydrogen production through on board reforming of methanol. It is in disagreement with the recent DOE on-board fuel processing no-go decision.
- The project is well aligned with the President's Hydrogen Fuel Initiative and shows close bearing to DOE's RD&D Plan.
- If successful, it will provide a method to transport and store hydrogen using the existing infrastructure for liquid fuels.
- DOE has terminated onboard reformer program.
- Methanol has no existing infrastructure.

Question 2: Approach to performing the research and development

This project was rated **3.1** on its approach.

- Overcome non-chemical grade methanol reforming limitations.
- The major driver of the work is the three times petroleum hydrocarbon content in coal-derived methanol compared to fuel cell grade methanol.
- The approach to some extent involves innovative technical strategies and solutions to advancing knowledge base as well as routine data collection using proven techniques to achieve project goals.
- The approach will contribute to achieving the project goals.
- This is a sound academic approach to an engineering study. The reforming and autothermal should be compared on an efficiency basis as well as by conversion rates.
- The goal of the project was to evaluate the effect of the impurities of coal-derived methanol on the hydrogen production. In spite of the deactivation observed, the project did not propose solutions to overcome this problem.
- The approach is sound and logical.
- Both steam reforming and autothermal reforming were included.

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

This project was rated **3.2** based on accomplishments.

- Demonstrated geometry improved reformer operation/life.
- Tested monolith ATR catalyst.
- The findings that (1) proper flow distribution can improve reactor capacity via heat transfer enhancement and (2) reactor geometry has the most influence on catalyst performance are novel and insightful.
- The project has developed a novel static flow distributor to prevent misdistribution and significantly minimize radial thermal gradient in the catalytic reactor.
- The novel static flow distributor is potentially patentable and the PI may consider applying for a patent.
- The slides present data without sufficient data interpretation and analysis and without adequately discussing the relevance of findings.
- It is not always clear how the new info relates to program goals and contributes to solving problems in order to advance hydrogen production technology state-of-the-art.
- During the review the PI explained the work scope and results very well.
- The conclusion from a 30 hr test that reactor geometry has the profound influence on catalyst degradation has been made prematurely.
- Limited SR performance data presented; does not appear to be of significance for scale-up studies.
- The most important accomplishments, bullets 1 and 2 of the Progress Results slide, are least explained.
- Temperature profiling of reforming reactor is excellent work. The presence of hydrocarbon impurities is an important factor to be considered. The results should be consistently labeled with operating conditions, including temperature, weight hourly space velocity, and steam to carbon ratio.
- The project did not demonstrate ways to overcome one of the technical barriers (deactivation) in order to improve the performance of the process.
- The project appears to be progressing well on schedule and has identified barriers to meeting objectives together with strategies to address these barriers.
- Some interesting data on methanol reforming were presented, including the installment of flow distributors in reformer (fixed bed).

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

This project was rated **2.8** for technology transfer and collaboration.

- Collaboration with Eastman Chemical.
- Eastman and Methanax are reported as technology partners, but their contributions to achieving the project goals are not documented and therefore clear.
- Most of the work seems to have been conducted at the PI's facility.
- The PI said that Eastman has helped in the analysis and characterization of the coal-derived methanol fuel.
- Worked with Eastman and Methanex.
- The support of one the industrial partners ended recently (Nov 2004).
- The project only lists one passive collaborator (Eastman Chemical) who provides the PI with plant-produced methanol. It is unclear if Eastman's role will grow beyond this, or if Methanex will re-start its support that ended in Nov 2004.
- Needs more interactions with industries to seek R&D inputs.

Question 5: Approach to and relevance of proposed future research

This project was rated **3.2** for proposed future work.

- Need to finish ATR degradation/transient tests, review clean-up technology, integrate reformer with PEM hydrogen fuel cell, and compare performance.
- The proposed future work including quantifying fuel cell performance with two grades of methanol is consistent with project objectives.
- While completing autothermal data collection phase should perform parametric studies with mass balances and determine energy efficiencies.
- Before the integration of the reformer and cleanup to fuel cell, the project should focus on overcoming the barrier. The purchase of the complete system also does not address the problem of the impurities of the feed.
- Future plan is well focused with milestone tasks culminating on the final quantification of fuel cell performance using coal-derived methanol.
- What is the purpose of this study? Will this be answered in the future work?

Strengths and weaknesses

Strengths
- Good approach and progress.
- The project has progressed well consistent with the technical baselines listed in the Gantt chart.
- Good experimental studies of an important option for coal-derived methanol.
- The project builds on an existing commercial method of producing methanol from coal and using this methanol to produce hydrogen through steam and autothermal reforming technologies. If successful, it will produce hydrogen at around $1.77/gge (better than DOE's goal). It could potentially alleviate the need for hydrogen storage and distribution in transport applications if reforming can be conducted on-board a vehicle.
- Reforming data with coal based methanol were presented.

Weaknesses
- The PI agreed that the three times concentration of petroleum hydrocarbons in coal-derived methanol can be easily removed by using a guard bed packed with commercially available getter materials (the concentration is only in mg/liter range): therefore, a major project objective to conduct extensive work on how to use coal-derived methanol as the hydrogen carrier for fuel cells may not be that important.
- Results are not fully discussed in the presentation, e.g., why did conversion get worse at higher temperatures?
- The PI should solicit more involvement by the private sector at this stage to ensure on-going funding for a commercial demonstration.
- Discussions on the significance of catalyst deactivation data were inadequate.
- Inadequate discussions on the reasons leading to the improvement in methanol reforming with flow distributors.

Specific recommendations and additions or deletions to the work scope

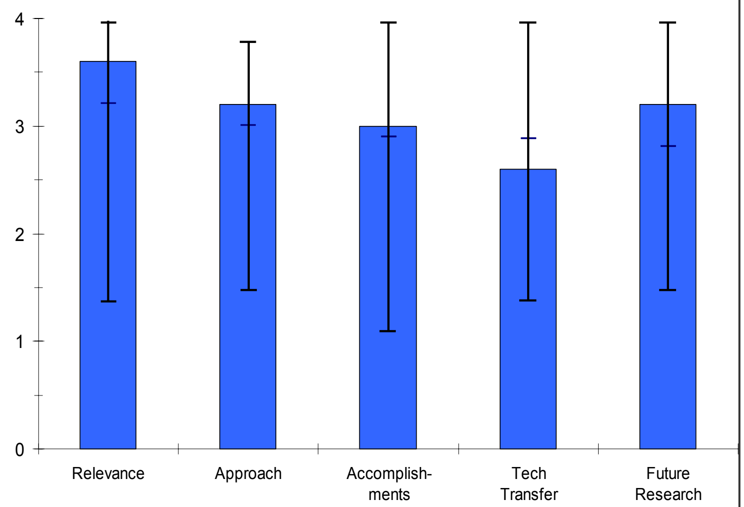
- Stationary hydrogen storage and production studies/tests are recommended.
- Expand to bio-derived alcohol feedstocks.
- The future work should include, as stated, the quantification of the coal derived vs. fuel cell grade methanol performance, and add a third test involving a guard bed with getter materials when using the coal-derived methanol.
- The project should focus on eliminating the barrier identified (deactivation due to the presence of impurities). The relevance of the project should be evaluated due to the recent decision of DOE to stop the support to studies of on-board hydrogen production.
- A rapid determination of the preferred reforming technique (steam reformation with Cu catalysts and optimized reactor geometry) versus autothermal reforming.
- Greater effort on quantifying fuel cell performance with coal-derived methanol. This approach, if successful, can radically alter DOE's R&D funding focus on hydrogen production from coal, hydrogen storage, and distribution.
- Quantify the differences in petroleum hydrocarbon composition between fuel grade methanol (from natural gas) and coal-derived methanol.
- Needs a good plan to wrap up the data in a package to show whether the coal-derived methanol is as good as or interchangeable with fuel grade methanol from natural gas.

Project # PDP-09: Hydrogen Production via a Commercially Ready Inorganic Membrane Reactor
Liu, Paul; Media & Process Technology Inc.

Brief Summary of Project

A carbon molecular sieve based hydrogen selective membrane has been developed as a reactor for water gas shift reaction. In addition to combining the reaction and separation in a single step, we will investigate field-implementation related issues, such as the development of full-scale membrane and modules, evaluation of the long term performance and material stability of the membrane, and a means to accommodate cooling requirement in a membrane reactor environment.

Overall Project Score: 3.2 (5 Reviews Received)



Question 1: Relevance to overall DOE objectives

This project earned a score of **3.6** for its relevance to DOE objectives.

- Lowers the cost of hydrogen.
- The project objectives are consistent with the Hydrogen Initiative and the work scope is consistent with the DOE hydrogen production program goals.
- The project results will expand knowledge base and advance the hydrogen production current state-of-the-art.
- The project is well aligned with the President's Hydrogen Fuel Initiative and shows close bearing to DOE's RD&D Plan.
- If successful, it will provide a method to produce hydrogen efficiently through a single stage WGS and gas clean up.
- Combining water gas shift (WGS) and hydrogen separation in one step will help program.

Question 2: Approach to performing the research and development

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

- Includes process intensification, membrane development, and pilot tests .
- The technical strategy and process development scope show potential for maturing to technical readiness for engineering scale-up and demo scale tests.
- Innovative approaches and solutions have been used to expand knowledge and develop a novel technical know-how.
- The approach is sound and logical.
- A scattered focus in the approach that seems a little too ambitious for the work effort and funding level. The work described ranges from fundamental mathematical modeling to constructing and testing a pilot-scale unit.
- A sound approach was proposed.

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

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

- High purity hydrogen and flux rate.
- Low cost ceramic membrane.
- A novel heat transfer mechanism (based on the moisture permeability of the membrane reactor material) could result in the development of a one-stage high temperature-Low temperature shift process without interstage cooling.
- The approach allows improved efficiency, process intensification, and potentially lowering hydrogen production cost.
- Developed a predictive mathematical model and verified the model with experimental data.
- The project is progressing well along established technical baselines and has achieved significant milestones.
- Many of the claims made use subjective terms, i.e., excellent, proved, verified, etc., without providing sufficient data to support these claims.
- No reference is made to potential and well-known barriers to combining WGS reactions with hydrogen separation (i.e., kinetics, catalyst poisoning by excess CO).
- Good progress made in several areas including carbon molecular sieve (CMS) membrane fabrication and membrane performance modeling.

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

This project was rated **2.6** for technology transfer and collaboration.

- Collaboration with USC (Professor Tsotsis), Pall Corp., and Dr. Kleiner.
- Pall Corp, Prof. Tsotsis of USC, and Dr. Kleiner, a consultant is involved in the project.
- No commitment from Pall Corp is included in the presentation.
- Also, Pall Accuse SS substrate may not be suitable because of low flux an higher cost compared to ceramic substrate.
- The project only lists consultants and suppliers. No clear indication of other institutions or efforts of coordination among other institutions.
- Needs more interaction with industry to seek R&D inputs.

Question 5: Approach to and relevance of proposed future research

This project was rated **3.2** for proposed future work.

- Includes simulation, pilot tests, economic analysis, and field test site identification.
- Legitimate future work, can be easily related to technology development goals, and will move the project forward to meaningful, successful outcome.
- A field test is planned, but not funded.
- Future plan is focused on the construction and testing of pilot-scale reactor and the refining of the mathematical model with pilot-scale reactor data. Based on the progress reported to date since the project's inception on 10/1/03, it is somewhat questionable whether these tasks can be completed on time without additional personal. If needed, this should be done at no additional cost to DOE.
- CMS membrane scale up plan was presented.

Strengths and weaknesses

Strengths
- Excellent development.
- The LT-WGS-MR technology is most adaptable to warm gas clean-up technology schemes and amenable to further scale-up.
- The high hydrogen serration flux at LT-WGS conditions compared to Pd-Cu membranes is very encouraging.
- The project is an effort in process intensification to develop a membrane reactor that can combine the WGS reaction and hydrogen separation simultaneously.
- Systematic approaches were used to pursue parallel approaches using ceramic and stainless steel substrates.

Weaknesses
- The PI correctly said that industry is moving away from hot gas clean up. At warm gas clean-up conditions, the HT-WGS technology is no longer applicable. PI agrees that the HTWGS-LTWGS approach is no longer applicable.
- Lacks academic approach and guidance, and has membrane sealing and defects issues.
- The terminology "Commercially Ready" used in the title is misleading -- the PI has yet to prove that his membrane reactor is ready for commercialization.
- The PI has not addressed any potential barriers or show-stoppers in his process intensification work effort that can delay or halt progress.
- Efforts on stainless steel/CMS membrane R&D were inadequate. Discussions on CMS membrane scale up issues were not adequately discussed.

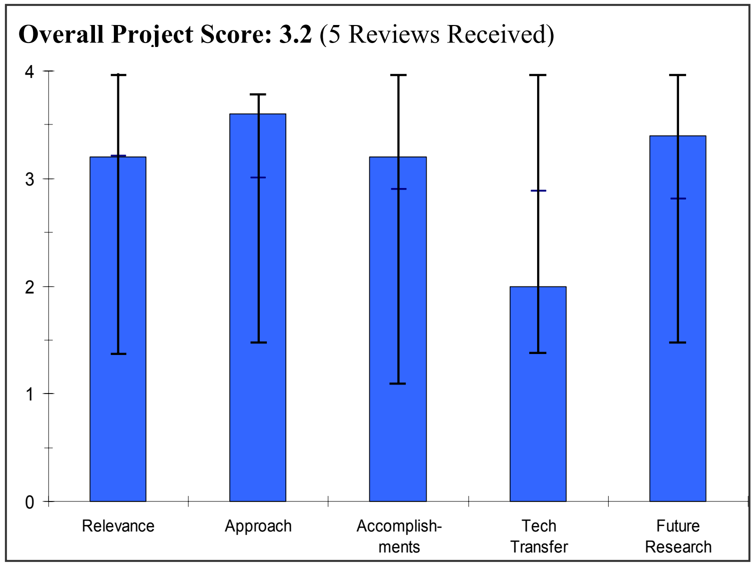
Specific recommendations and additions or deletions to the work scope

- Although the hydrogen flux at low temperature conditions is higher than achievable by Pd alloy membranes, it is not clear if the flux meets the DOE commercial target; the project needs to at this issue.
- Low flux will not achieve the process intensification claim.
- An awareness of potential barriers during process intensification (i.e., catalyst poisoning, kinetics) that might arise together with strategies to address them.
- Focus work on improving the effectiveness of stainless steel/CMS membrane development. More experimental work is needed to substantiate the modeling results. More long term life testing of membranes.

Project # PDP-10: New York State Hi-Way Initiative
Bourgeois, Richard; GE Global Research

Brief Summary of Project

Under this DOE contract, the GE Global Research hydrogen production team is researching methods to achieve considerable reduction in alkaline electrolyzer system costs compared to prevailing prices of available new equipment. They will do this through technological advances in production methods and materials of construction. Appropriate physics-based models will be used to optimize the system for practical performance at low cost.



Question 1: Relevance to overall DOE objectives

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

- Electrolysis hydrogen generation is important to DOE goals and objectives.
- Emphasis on New York State barriers or hydrogen infrastructure development is too narrow although probably translatable to some other states.
- Most aspects of the project align with the President's Hydrogen Initiative and the RD&D plan objectives.
- This project addresses lower cost electrolyzers, which is a key element in the HFCIT MYPP.
- Supports a very important task in the distributed electrolysis portion of the hydrogen production component -- the development of electrolyzers with much lower cost than today's devices.
- The work to reduce cost for electrolysis is aligned.

Question 2: Approach to performing the research and development

This project was rated **3.6** on its approach.

- The approach is logical.
- Leverages multiple aspects of GE expertise.
- Economic potential may be too tied to low cost electricity; need to benchmark using standard programmatic assumptions for electricity cost, storage, handling, etc.
- The approach is generally well thought out and effective but could be improved in a development of larger units. Most aspects of the project will contribute to progress in overcoming the barriers of high cost electrolyzers.
- Program takes approach of revisiting the components of an alkaline electrolyzer and trying to find ways to maintain their key functionalities, but with goal in mind of low cost manufacture using low cost materials and manufacturing processes.
- Would score it 4 on the electrolysis work, but 1 on other aspects of the scope.

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

This project was rated **3.2** based on accomplishments.

- A summary of 1-page overview/summary of progress would have been helpful in assessing status toward objectives. The words "accomplished", "completed", "initiated", "in progress" would have helped.
- Good progress in design and performance in a relatively short period of time.

- The project has shown significant progress toward against its objectives and to overcoming the barrier of higher cost electrolyzers.
- Impressive work in designing a modular five cell stack with plastic housing and simple connections for water, power, and products. Wire arc method for forming electrodes seems amenable to low cost manufacture. Excellent modeling (kinetic and CFD) to understand factors affecting homogeneity of reactions in working cells and stacks.
- Advanced manufacturing techniques look extremely encouraging.
- Can't see what the cost improvement is towards the $/gge target.

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

This project was rated **2.0** for technology transfer and collaboration.

- It is unclear what the role of each team member is. Therefore, it is hard to determine if all bases are adequately covered.
- Competitive interests limits collaboration.
- Third-party validation of system would benefit the project.
- Little coordination exists; full coordination would take significant time and effort to initiate.
- This project would benefit if there were commercial sites that could use the developed technology. Currently the developed technology is too small in size, but any scale up should have a demonstration site included for field verification.
- Most of the work seems to have been done in house at GE, but this does not seem to be an issue as GE has many of the requisite skills in house.
- From data presented appears to be internal to GE.

Question 5: Approach to and relevance of proposed future research

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

- Reasonable but ambitious for the remaining 6 months.
- Long-term performance testing at a practical scale will be essential.
- Further improvement in electro catalyst, membrane, etc, not discussed. Is this the best design or is further optimization planned?
- Although future funding may not exist, this project shows excellent capacity for meeting DOE cost goals in the future and addresses key technical barriers.
- Next steps durability testing and scale up appear appropriate at this stage. Durability testing is needed to find which components are vulnerable to degradation, and this will lead to further work to solve those problems.
- Consider funding additional development. It appears the program ends this year.

Strengths and weaknesses

Strengths
- Leverages multiple capabilities in molding, system design, catalysis, materials development, manufacturing, and power generation and utilization.
- Innovative new electrolyzer design that shows potential for lower costs and mass production capability.
- Good integrated team at GE that seems to have the skills to make this real. PI appears to have access to many of those in-house skills and facilities.
- Very innovative manufacturing approach.

Weaknesses

- Needs to show path to achieving HFCIT targets for stack/system cost, using standard programmatic assumptions.
- Current demonstration is too small (only 500W size).
- Economic analysis seemed very limited. This project needs to have H_2A economics applied, especially with respect to electricity cost in order to get a more realistic view of the net hydrogen production costs. Those costs will have to include sitting, maintenance, labor, etc. A cold-eyes look at the estimated manufacturing cost would also be helpful in order to add credibility to the overall economics.
- Could improve with more collaboration outside.

Specific recommendations and additions or deletions to the work scope

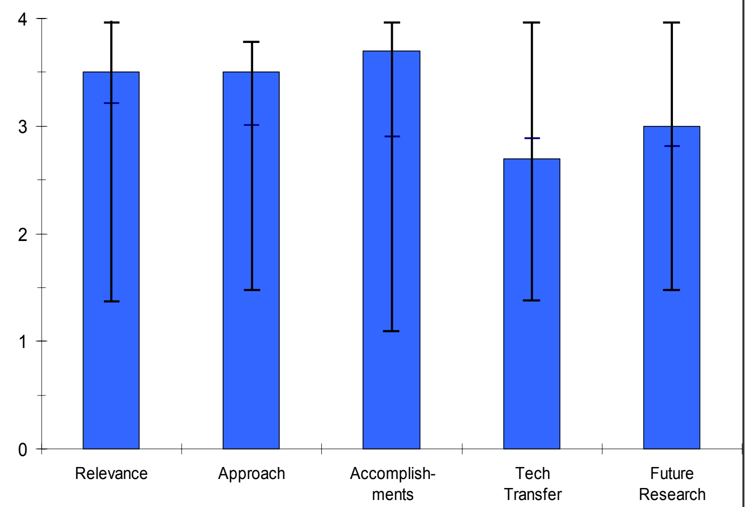
- Scale up to larger size -- 50kW minimum.

Project # PDP-14: Development of Dense Ceramic Membranes for Hydrogen Separation
Balachandran, Balu; Argonne National Laboratory

Brief Summary of Project

Argonne National Laboratory is developing dense membranes for separating hydrogen from mixed gases, particularly product streams generated during coal gasification and methane reforming, at commercially significant fluxes under industrial operating conditions without using electrodes or electrical circuitry. These membranes are to be ceramic-based, highly selective for hydrogen, chemically stable in corrosive environments at operating temperatures up to ≈900 C, and possess the physical integrity to withstand high operating pressures. Single-phase mixed proton-electron conductor and dual-phase cermet (ceramic/metal composite) membranes are being investigated in this project.

Overall Project Score: 3.4 (6 Reviews Received)



Question 1: Relevance to overall DOE objectives

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

- This project provides outstanding support of the goals of DOE Fossil Energy draft "Hydrogen from Coal RD&D Plan" in that Dr. Balachandran's objective in performing the research is to develop dense ceramic membranes for separating hydrogen from mixed gases at commercially significant fluxes under industrially relevant operating conditions. However, the project provides only a fair amount of overall support to the Department's Hydrogen program since the product streams of interest are exclusively coal gasification and (large-scale) methane reforming, limiting the overall relevance to the DOE Hydrogen Program.
- Lowers cost of hydrogen.
- Addresses six barriers under "Separations and Other Cross-Cutting H_2 Production" in the Multi-Year Research, Development and Demonstration Plan.
- Addresses barriers in FE's hydrogen from Coal RD&D Plan. This work is funded by DOE FE.
- Extremely relevant to the Hydrogen Initiative.
- The project is well aligned with the President's Hydrogen Fuel Initiative and shows close bearing to DOE's RD&D Plan in the development of hydrogen transport membranes.
- Consistent with generation of pure hydrogen from fossil fuel gasification streams.

Question 2: Approach to performing the research and development

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

- The approach is focused on achieving a flux rate of 100 at a low cost while. This is better than the 2010 goal for microporous membranes stated in FE's RD&D plan.
- ANL's focus on reproducibility and stability is critical
- The poster demonstrates a very good understanding of safety considerations.
- Systematic approach to select/fabricate, test, optimize and commercialize dense ceramic membranes.
- Approaches are right on target to meet the goals of the DOE Hydrogen Fuel Initiative and hydrogen from coal R&D plan.
- Perform high pressure flux measurements at Argonne.

- The three-pronged approach to develop the membranes is very good. All options are explored/covered by this approach.
- Sealing, defect issues major stumbling block for industrial application.
- The approach is technically sound and logical.
- Excellent approach of developing mixed proton, electron conducting membranes which permit a total selectivity for hydrogen separation.

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

This project was rated **3.7** based on accomplishments.

- The Hydrogen from Coal RD&D Plan, however, expects to identify advanced hydrogen separations technology including membranes tolerant to trace contaminants by 2006 before the project concludes. Since 1998, high temperature membrane development at ANL has shown steady progress and should be a candidate for downselection.
- Developed dual-phase dense membranes that nongalvanically separate hydrogen.
- Steady progress since 1999 in H_2 flux improvement (2 to 66 scfh/ft^2) (400 scfh/ft^2 potential).
- Short-term measurements show stable flux in CO, CO_2, CH4, H_2O, and H_2S feed streams.
- Recognized as one of 2004's 100 most significant technological developments in R&D 100.
- Outstanding progress has been achieved in all areas of research related to several barriers.
- Hydrogen flux numbers obtained here are higher than DOE target numbers.
- Outstanding progress is seen from their slide #21.
- The project has overcome many of the past reviewers comments to increase flux, enhance performance, improve chemical stability, and reduce operating temperature.
- Outstanding membrane material development work from a PI with a substantial record of accomplishments in this field of high temperature membranes.

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

This project was rated **2.7** for technology transfer and collaboration.

- The potential for technology transfer is not well established. Poster indicates that under guidance from NETL program managers, membrane technology transfer will occur through industrial collaborations.
- Collaboration with NETL.
- Potential collaboration with Eltron, Praxair, and Air Products.
- Collaborates with NETL in the high pressure permeation measurements.
- Have CRADA with Eltron Research Inc., but that project was not reviewed here.
- This project is funded under the National Lab base research program.
- The project only lists the P.I.'s organization (a national lab) and one other national lab as its partner.
- Private organizations should be marketed to recognize and commercialize this development effort of hydrogen separation membranes.
- It appears that more 'pull' from technology developers is needed to render it industrially practical.

Question 5: Approach to and relevance of proposed future research

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

- Proposed future work such as testing the long-term chemical stability of selected HTMs in atmospheres typical of coal gasifiers builds on past progress.
- Acquire analytical equipment (i.e., GC-MS) for additional testing.
- Continue developing new high temperature membranes to reduce cost, increase flux, and improve mechanical/chemical stability.
- Technology transfer through industrial collaborations.
- Excellent future plan.

- Include high pressure hydrogen permeation measurement.
- Can ANL do long-term permeation experiments (say 6-12 months)?
- Future work is focused on the further validation of past findings and the eventual transfer of the hydrogen separation membrane technology through industrial collaborations.
- The future research should be more guided by an engineering and scale-up model for its implementation. A development path should have been delineated.

Strengths and weaknesses

Strengths
- The dense ceramic membrane meets FE's flux goals for 2010 that were established specifically for microporous membranes, which may have lower material costs than dense ceramic membranes but lower flux rates.
- Systematic approach.
- Good progress.
- Research team with considerable experience in the area of gas transport membranes.
- Detailed approach of research.
- Experimental safety analysis, risk mitigation, and structural and procedural controls.
- Research recognized by peers -- R&D-100 Award in 2004. Experience/expertise in ceramic science and engineering.
- The project has developed dual-phase dense membranes that show potential of meeting DOE goals for hydrogen separation flux, stability, and operating conditions.
- Very impressive high temperature membrane synthesis and discovery capabilities. Excellent results of hydrogen selective permeation from acid gas containing source streams.

Weaknesses
- While the chosen material reduces membrane cost, the cost of development is very high and it is unclear how much if any cost sharing is provided.
- Long-term tests needed (future).
- Catalysis/catalyst area.
- Membrane sealing, defect issue. Stumbling block for industrial application.
- Private sector collaboration should be aggressively sought out to ensure that the PI's useful findings are moved toward commercialization.
- An apparent lack of a total system model where this membrane technology would be incorporated.

Specific recommendations and additions or deletions to the work scope

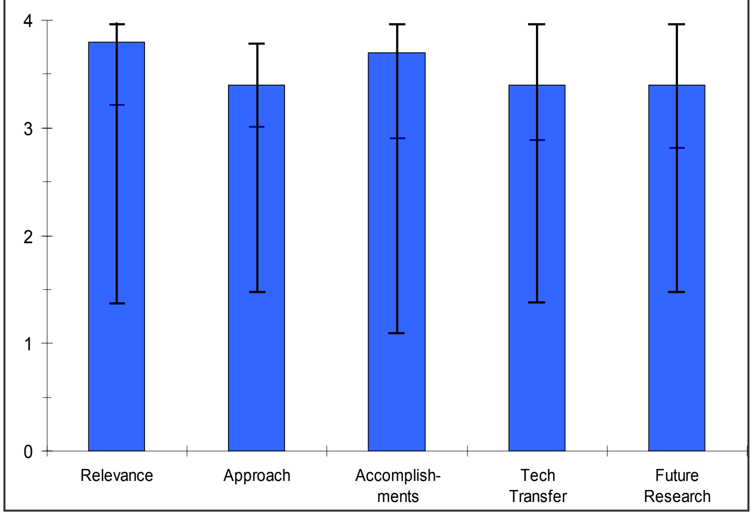
- ANL and FE might consider partnering with the renewable fuels and coal companies to test both biomass and coal feedstocks using the prototype dense ceramic membrane.
- Letters of support from industrial partners should be solicited rather than including the technology transfer aspects under "future work."
- Field testing in conditions of actual use.
- Additions:
    - High-pressure & high-temperature permeation test set-up at Argonne National Laboratory.
    - Study effect of catalysts on membrane surface.
    - Perform detailed microstructural analysis of the membranes & interfaces.
- Include the construction of a membrane reactor utilizing the ANL-3 (or improved) membranes to evaluate optimum membrane configuration, seals, and fabrication challenges (if any).
- Proceed with work but in a closer context with the requirements on the implementation development next stage.

Project # PDP-15: Ceramic Membrane Reactor Systems for Converting Natural Gas to Hydrogen and Synthesis Gas (ITM Syngas)
Chen, Christopher; Air Products and Chemicals, Inc.

Brief Summary of Project

Since 1998, Air Products and Chemicals, Inc. directed this research team comprised of industry and university participants to research develop and demonstrate an Ion Transport Membrane reactor system for the low-cost conversion of natural gas to hydrogen and synthesis gas. Technical, engineering, operational and economic data necessary for full commercialization is being collected and analyzed.

Overall Project Score: 3.6 (5 Reviews Received)



Question 1: Relevance to overall DOE objectives

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

- Low cost ceramic membrane reactor is relevant to the success of the hydrogen program.
- The project is well aligned with the President's Hydrogen Fuel Initiative and shows close bearing to DOE's RD&D Plan in the development of hydrogen production methods from natural gas.
- Proposed work offers advantages in improving the economics of hydrogen production from natural gas, with a CO_2 stream ready for sequestration.

Question 2: Approach to performing the research and development

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

- Development of potential material with unique composition and properties to ensure thermodynamics stability, mechanically reliable and ensure oxygen ion transport to enhance conversion of national gas to syngas is great.
- The approach is technically sound and logical.
- A good step-by-step approach was proposed to advance the development from bench unit to current process development unit PDU scale demonstration.

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

This project was rated **3.7** based on accomplishments.

- Needs to address long term durability issues regarding the seal technology.
- Is there an issue with flux aging (degradation) with time?
- Great accomplishments to date on material development and the method of stacking planar membranes are novel accomplishments.
- The project has addressed many of the challenges associated with ion transport membranes (ITM) for this application.
- Clear cut results have been shown that directly impact barriers that are being addressed.
- Good progress made in all key aspects including membrane flux improvement and module assembling.

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

This project was rated **3.4** for technology transfer and collaboration.

- Strong team with broad expertise
- Air Products as an engineering and chemical company has good track record in commercializing technologies.
- The project only lists its 9 partners. Their role is not clear, i.e., financial sponsors, in-kind providers of goods and services, or fee-based service or equipment providers.
- The industrial participants were well represented from researchers to end user.

Question 5: Approach to and relevance of proposed future research

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

- Scale up and testing is now appropriate for this technology.
- Future work builds on past progress and is focused on the testing of full size planar membranes at a 1 million scfd subscale engineering prototype.
- Future advancement from PDU to large scale units should help further advance this technology.

Strengths and weaknesses

Strengths
- Their innovative ideas and how they are being implemented is their strength.
- The project has made extensive progress in the development of planar membranes to meet the physical and material demands for producing syngas from natural gas.
- Great strides made in the areas of seals and module assembling. Plan was made in the water gas shift (WGS) catalyst accommodation in the membranes reactor.

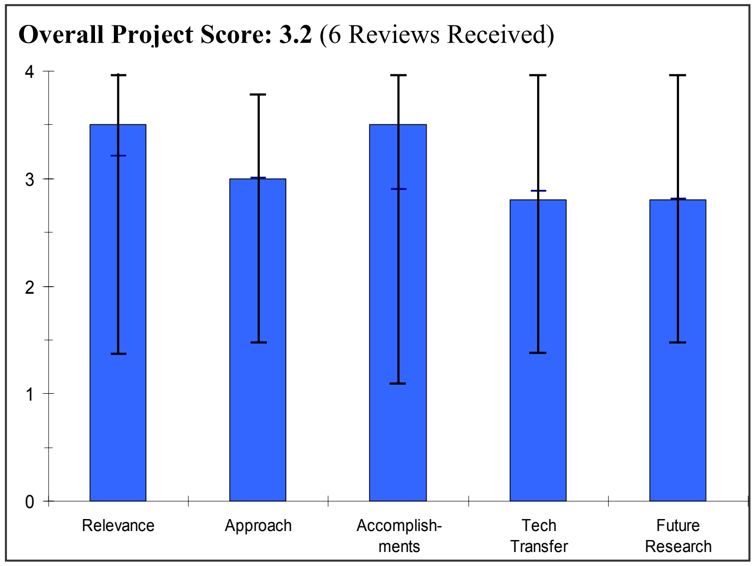
Weaknesses
- The outcome of the project may remain commercially unattractive until carbon emission taxes and other similar constraints favor the economics for the conversion of natural gas to hydrogen.
- The lack of a clearly articulated set of implications concerning the impact of hydrogen production.
- Inadequate quantitative experimental data were presented on membrane performance. No descriptions of WGS catalyst development.

Specific recommendations and additions or deletions to the work scope

- Expand work on WGS catalyst development, which needs to be incorporated into the membranes with high activity and long life. Continue to increase the through put per membrane module. Obtain operating data of membrane performance with natural gas feed and reforming catalysts incorporation into the membrane.

Project # PDP-16: Cost-Effective Method for Producing Self-Supporting Pd Alloy Membrane for Use in the Efficient Production of Coal-derived Hydrogen

Lanning, Bruce; Southwest Research Institute



Brief Summary of Project

The overall goal of this project at Southwest Research Laboratory (SwRI) is to develop technologies that effectively and economically separate hydrogen from mixed gas streams that would be produced by coal gasification. SwRI will develop a process methodology for the cost-effective manufacturing of thin, dense, self-supporting palladium (Pd) membranes; reduce Pd membrane thickness by >50% over current state-of-the-art; demonstrate viability of using ion-assisted vacuum processing to engineer a membrane microstructure and surface that optimizes hydrogen permeability, separation efficiency, and lifetime; demonstrate efficacy of continuous roll-to-roll manufacturing of membrane material with performance and yields within pre-defined tolerance limits; and establish scale-independent correlations between membrane properties and processing parameters.

Question 1: Relevance to overall DOE objectives

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

- It is relevant to DOE Coal to Hydrogen Effort, however the degree of relevance to the overall DOE hydrogen program may be limited.
- Lowers the cost of producing hydrogen.
- Success should lead to reduced cost of production for coal, natural gas, and biomass.
- The project is well aligned with the President's Hydrogen Fuel Initiative and shows close bearing to DOE's RD&D Plan in the development of hydrogen production methods.
- Has offered to develop a self supported Pd membrane for hydrogen separation.

Question 2: Approach to performing the research and development

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

- It is relevant to DOE Coal to Hydrogen Effort, however the degree of relevance to the overall DOE hydrogen program may be limited.
- Formation of dense Pd alloy films on supporting substrates using ion/plasma-based vacuum processing.
- Optimization of release processes, characterization/testing, demonstrate membrane optimization.
- Approach shown on slide 4 was nicely described in results slides.
- Should perform matrix-designed experiments to characterize materials and manufacturing methods. From what is presented, only a few isolated approaches are researched.
- Good that PI is studying flux as well as hydrogen purity.
- The approach is technically sound and logical to develop a process to deposit a substrate on a thin-film metallic membrane.
- Has proposed a good work plan.

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

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

- Best performance data @ 400 C shown for a 5 μm Pd-Cu alloy foil, area = 2.6 cm^2:
    - pure hydrogen permeability = 2 •10-4 cm^3•cm/cm^2•s•cmHg0.5
    - hydrogen flux = 124 cm^3/cm^2•min = 242 SCF/ft^2•h;
    - feed pressure =20 psig
    - Exceeds DOE Hydrogen Program and 2010 DOE Fossil Energy Technical Targets.
- Developed innovative fabrication methods.
- Demonstrated high purity hydrogen (> 99.95%).
- Increased hydrogen permeation (thin film, surface pre-treatment) exceeded DOE targets demonstrating hydrogen @ flux of 242 scfh/ft^2.
- Nice results.
- Need more matrix studies to draw generalized conclusions.
- The project has made significant progress in developing methods for membrane fabrication, using flexible and rigid substrates.
- Results include exploratory study and membrane fabrication.

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

This project was rated **2.8** for technology transfer and collaboration.

- Low cost sharing. Not enough information on how technology transfer is to occur, however excellent partners are at least identified.
- Collaboration with Colorado School of Mines and IdaTech.
- No mention of what partners are responsible for.
- CSM and IdaTech are good partners, but what do they do?
- The project lists 2 partners, of which only one (Ida Tech)has provided some financial cost-share for the project along with DOE funding.
- Discussions on technology transfer needs to be expanded.

Question 5: Approach to and relevance of proposed future research

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

- Future RD&D in enhanced permeation seems reasonable, however demonstrating at 99.95% pure hydrogen has limited application in terms of direct use in hydrogen fuel cell vehicles.
- Enhance hydrogen permeation (alloys, defect minimization).
- Module demonstration (performance and characterization @ 75 sqin).
- Prototype module to industrial partner IdaTech for testing at targeted ~100 scfh/sqft.
- With better matrix experiment design, approach should lead to significant results.
- Future work builds on past progress and is focused on improving hydrogen permeation, alloy compositions, and minimizing defects.
- Future work should include some lifetime tests to evaluate the stability of the membrane over time.
- No tests planned with gas mixtures to evaluate selectivity.
- Proposed work scope is broad. Priority of work order was discussed adequately.

Strengths and weaknesses

Strengths
- Low temperature membrane to complement existing high temperature ceramic membranes is reasonable way to diversity the FE portfolio.
- Fabrication development.
- Innovative.
- The project has made extensive progress in the development of Pd-alloy membranes that can be fabricated with substrates, providing control over hydrogen permeability.
- Good advances in membrane fabrication technique. Preliminary exploratory study conducted to improve membrane performance was presented.

Weaknesses
- Hydrogen purity levels derived in recent tests (99.95%) would be insufficient for direct use in fuel cell vehicles.
- Need full-scale development and long-term testing (future).
- PI was not available at poster on three separate visits. Couldn't answer questions that might have allayed concerns.
- Inherent limitations of planar design. Sealing and packing density limited.
- No tests conducted to determine membrane and substrate robustness or to test selectivity in gas mixtures.
- Inadequate discussions on the pros and cons using rigid substrate backing for Pd membranes compared to other alternatives. No conclusions. No milestones.

Specific recommendations and additions or deletions to the work scope

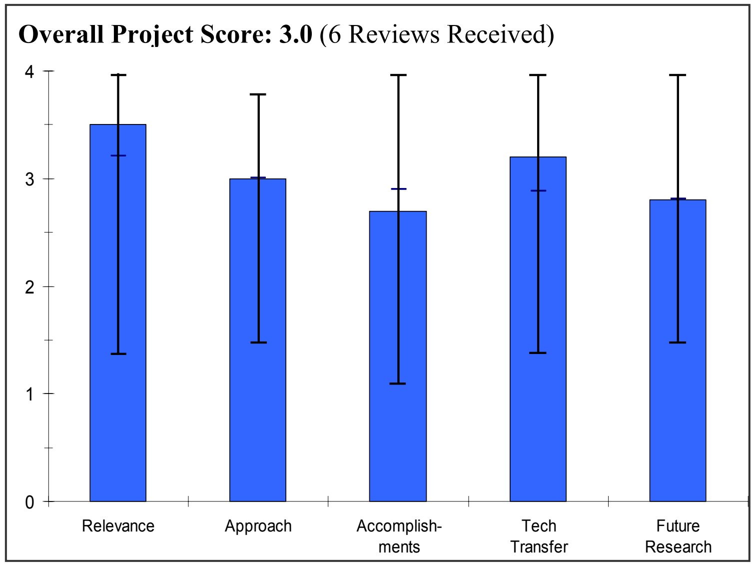
- Include testing of renewable feedstocks as well as coal.
- Full-scale development.
- Need more matrix experiments.
- Broaden test program to include membrane and substrate lifetime tests as well as tests with gas mixtures.
- The term "Cost-Effective" used in the title implies some cost information and economic analyses was or will be performed to support this claim. No such information has been provided in the work performed so far.
- Expand work to address issues which must be overcome to advance the membranes for testing by IdaTech. Prove out the reproductability of thin-film Pd membrane fabrication and its performance. Fine tune the membrane preparation technique. Needs long term life testing of membranes.

Project # PDP-17: Defect-Free Thin Film Membranes for H_2 Separation and Isolation

Nenoff, Tina; Sandia National Laboratories

Brief Summary of Project

In this project, Sandia National Laboratories (SNL) is working towards synthesizing defect-free thin film membranes for hydrogen separation and isolation which can replace existing expensive and fragile Pt catalysts. This work includes demonstrating effective light gas separations and commercialization potential of zeolite membranes. SNL will model the permeation of light gases through various frameworks/pores for optimized performance and validate them with actual permeation data obtained through testing on pure and mixed gases, including industrially relevant reforming streams. Collaborations for modeling and gas stream testing include New Mexico State University and New Mexico Tech University.



Question 1: Relevance to overall DOE objectives

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

- Good topic. PI is very knowledgeable on subject. Good use of zeolines with thin film base.
- Project is fully relevant to RD&D plan objectives-- lower cost hydrogen separation technologies have been identified as a critical need
- Relevant for low cost hydrogen production.
- The project is well aligned with the President's Hydrogen Fuel Initiative and shows close bearing to DOE's RD&D Plan in the development of hydrogen production and separation methods.
- Proposed work offers potential for improved H_2 separation if key issues can be overcome.

Question 2: Approach to performing the research and development

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

- Appears good. Good list of accomplishments and seems to be on track.
- Are effects of constituents besides H_2O and H_2S being evaluated?
- Limited solution provided by double-sided membrane for basic defect and sealing problems.
- Synthesis, testing and optimization of the performance of silicalite membranes.
- The approach is technically sound and logical.
- Unclear how "Defect-free" membranes are obtained through the proposed approach.
- Approach is research rather than development oriented.

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

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

- The team has made a lot of progress and has incorporated lessons learned in their work.
- Need to show progress against stated DOE targets.
- Little progress toward real world environment.
- Experimental results do not collaborate modeling results.
- The project has made significant progress in developing 1- and 2-sided membranes, testing these membranes, and determining that 1-sided membranes provide superior performance.
- Good progress made on thin film zeolite fabrication.

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

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

- Good activity with partners.
- Modest cost sharing contributions from industry.
- Encourage more collaboration for testing in "real world" conditions.
- No sure what the commercialization plan is.
- The project lists three industrial partners who have provided in-kind funding toward the project.
- More interactions are needed with industry to seek inputs to R&D work.

Question 5: Approach to and relevance of proposed future research

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

- Funding has been cut. Future work looks reasonable.
- What are the plans/prospects for integrating this membrane into a module that would/could be tested in an operating environment?
- Project appears not to have any future since funding has been cut.
- The applicant has identified several areas of interest that appear worthy of further investigation, including the deleterious effects of steam and CO2 as well as the increase in hydrogen selectivity with temperature.
- Proposed future work is broad in scope. Needs a priority order.

Strengths and weaknesses

Strengths
- Team seems to have found several other issues of interest while conducting work. Good to follow up with if funding is available.
- The project has made extensive progress in the development of zeolite membranes that have been tested with pure gas mixtures at temperatures up to 300ºC.
- Thin zeolite film (1-7 micron thickness) was successfully fabricated.
- Inadverse effects of steam on zeolite membrane performance were studied.

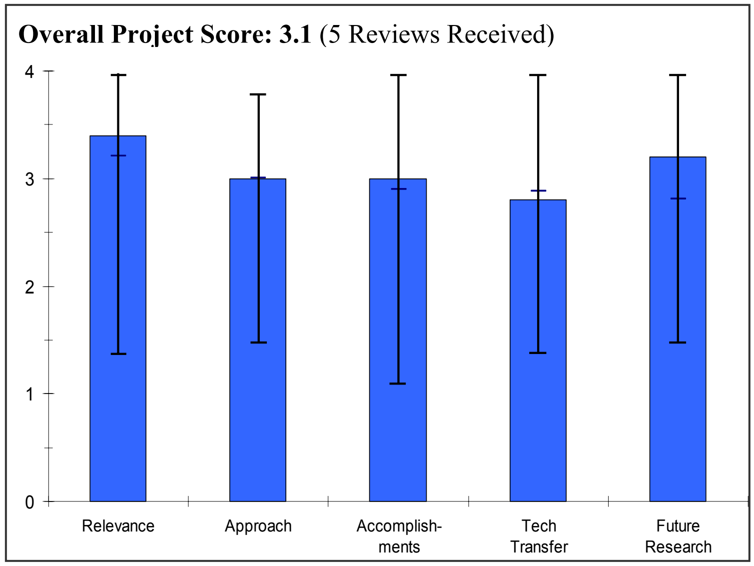
Weaknesses
- Little progress toward real world environment.
- The membrane manufacturing process described is unclear on how a "defect-free" membrane is obtained, other than by trial and error.
- Lifetime tests should be conducted to determine the performance of the zeolite membranes after an extended period of time.
- Inadequate discussions on the membrane performance data
- Did not list the target separation factors.

Specific recommendations and additions or deletions to the work scope

- With additional funding, the project should investigate the effect of H_2S on the membrane; i.e., if H_2S "plates out" at higher temperatures.
- Broaden test program to include lifetime tests.
- Additional tests with increasing levels of H_2S in the feed to confirm the absence of H_2S in the product as well as no damaging effect on the membrane.
- Highlight the pros and cons of zeolite membranes for H_2 separation when compared to competing technologies.
- Long term life testing is needed with promising membranes.
- Needs to test membranes at temperatures beyond 300C (note simulation data at 500C).

Project # PDP-19: Membrane Applications for Nuclear Hydrogen Production Processes
Bischoff, Brian; Oak Ridge National Laboratory

Brief Summary of Project



This Oak Ridge National Laboratory (ORNL) project will investigate the applicability of inorganic membranes for the production of hydrogen via the sulfur-iodine thermochemical cycle using nuclear energy as the source of heat to drive the relevant reactions. Inorganic membranes are candidates for facilitating the shift of the equilibrium in the decomposition of sulfuric acid, which is a critical step in this cycle. ORNL's inorganic membranes are being evaluated for the separation of hydrogen from steam and oxygen in high temperature electrolysis systems. The dramatically different separations in the sulfur-iodine cycle and in high temperature electrolysis dictate the need for a versatile and flexible fabrication process using materials compatible with the environments of interest.

Question 1: Relevance to overall DOE objectives

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

- It is relevant to DOE Nuclear-to-Hydrogen effort, however the degree of relevance to the overall DOE hydrogen program may be limited unless the scope is expanded to include separations applicable to renewable electrolysis applications for PEM fuel cells.
- Membranes for the S-I process support the President's Hydrogen Fuel Initiative.
- It is not clear how the membranes will lower the temperature of S-I process.
- Membranes for high temperature electrolysis only partially support the Initiative. Why do you need a membrane here?
- The project is well aligned with the President's Hydrogen Fuel Initiative.

Question 2: Approach to performing the research and development

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

- Tests involving sulfur cycles and high temperature electrolysis seem reasonable.
- Why do we need a membrane to separate hydrogen from steam (high temperature electrolysis)? Water can be easily condensed.
- ORNL claims that their membrane fabrication is already versatile -- then why to put too much emphasis on fabrication of membranes and support tubes?
- Sulfur provides harsh environment for membrane.
- The approach is technically sound and integrates well with work conducted earlier by the applicant (on another project) to modify the outcome from these prior efforts into a new application.

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

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

- Preliminary work is encouraging where first-generation membranes show low-temperature separation of oxygen and sulfur dioxide from sulfur trioxide allowing high conversion at lower reaction temperatures.
- Data relevant to this project is not given.
- Separation factors are not high enough for practical applications.
- Almost identical accomplishments were presented in another presentation at this review meeting.
- The project has made significant progress in modifying its membrane design and materials of construction to adapt it for higher temperature operation for the sulfur cycle and high temperature electrolysis.

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

This project was rated **2.8** for technology transfer and collaboration.

- Zero cost sharing. Not enough information on how technology transfer is to occur; however, excellent partners are at least identified.
- Collaborators (GA & INL) role is not defined. Are they real collaborators?
- The project lists one industrial partner and one national laboratory. It is unclear whether their involvement will continue in the absence of DOE (or other government agency) funding.

Question 5: Approach to and relevance of proposed future research

This project was rated **3.2** for proposed future work.

- Short-term plans for the remaining fiscal year seem plausible where samples will be exposed at high temperatures and characterized to determine the effect on support materials.
- Too much emphasis on the support tubes and too little on actual active membranes.
- No future plans for the high temperature electrolysis membranes and it is a good thing because there is no need for such a membrane.
- The PI has identified several areas of interest that appear worthy of further investigation, based on the work conducted to date.

Strengths and weaknesses

Strengths
- Inorganic membranes (if proven to work in high temperature conditions) may cost less to manufacture than microporous membranes used for S-I processes.
- Versatile process for fabrication of membranes.
- Safe operation procedure.
- Good experience in the area of porous membranes.
- Potential high payoff.
- The project has made extensive progress in the modification of the applicant's inorganic membranes in adapting them to thermochemical cycles requiring high temperature (850ºC) operation.

Weaknesses
- It doesn't appear as though ultra-pure hydrogen will result even after a second process step.
- Results that are relevant to this particular project were not given. The results presented here are old data and were presented in another oral presentation at this review meeting.
- Why should permeance increase with temperature in the porous membranes?
- Water molecules are smaller than hydrogen molecules -- how will the hydrogen be removed from water?
- Future plan lacks detail-- very vague. Be very specific.
- Sulfur provides harsh environment for membrane.

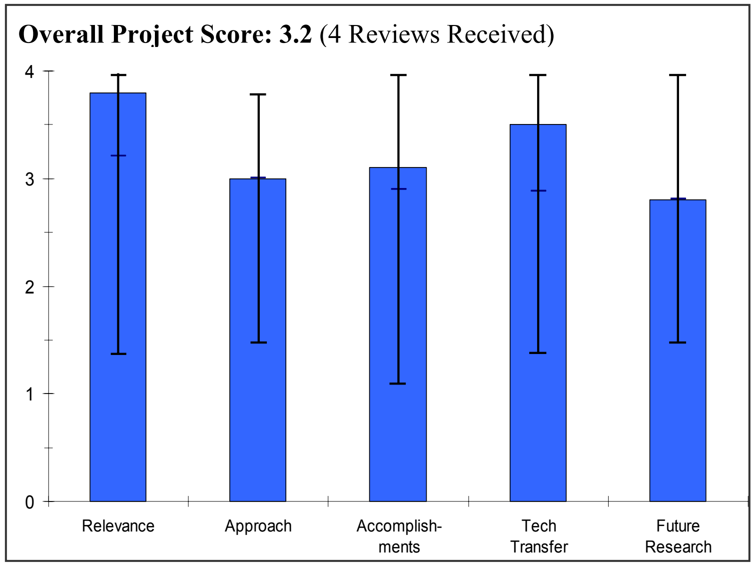
- The challenge in this effort is finding suitable materials to perform as membranes with the ability to withstand the rigorous conditions of high temperatures and acid gas environments.

Specific recommendations and additions or deletions to the work scope

- Delete the membranes development work for high temperature electrolysis.
- Add tasks to investigate the active membrane materials for the S-I process instead of concentrating just on the support tubes.
- Delete the tasks on fabrication of membrane modules; it is already claimed that they have a very versatile fabrication process.
- Add tasks to increase the separation factors for the S-I process.
- Some modeling studies may help reduce the vast number of options available for the selection of suitable membrane materials for this harsh environment application. This should precede the selection of materials as coupon samples for tests.

Project # PDP-20: Materials for High-Temperature Thermochemical Processes
Wilson, Dane; Oak Ridge National Laboratory

Brief Summary of Project



High temperature thermochemical processes are one of the promising approaches being investigated in the DOE Nuclear Hydrogen Initiative (NHI) for the production of hydrogen using nuclear energy. The thermochemical cycles currently being investigated include the sulfur-based cycles (sulfur-iodine and hybrid-sulfur) and calcium-bromine. These cycles generally involve very corrosive environments at elevated temperatures, up to 900ºC, which pose significant materials challenges. Identifying and demonstrating suitable materials of construction are critical viability issues for these cycles. The NHI is developing a long-term materials testing program to identify materials options and requirements. The ongoing reviews allow for an understanding of the material challenges of these processes, development of an "evolving" research and develop path forward, and identification of prioritized materials issues.

Question 1: Relevance to overall DOE objectives

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

- Project is 10% complete and appears to be a good project relevant to NE.
- Promote the development of processes, materials, and test methods for thermochemical hydrogen production at very high-temperatures up to 900ºC.
- Reduce costs of hydrogen production by using high temperature heat to accelerate reactions.
- Enable the use of waste heat from existing and/or future nuclear sources.
- Successful operation at 900ºC promising for use in new nuclear plants.
- Addresses volume and cost objectives for hydrogen production.
- This program can have a big impact on large-scale hydrogen production.
- The project is extremely relevant and the PI did an excellent job of demonstrating this relevance.

Question 2: Approach to performing the research and development

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

- Good characterization of project. Appears to be well thought out. Good partners are identified.
- Provide coordination and developing alternatives and testing to: (1) understand chemistry and temperature of various heat exchange mechanisms and production processes; (2) identify candidate materials; (3) establish test program to evaluate the materials and processes for operation at 900ºC or 600ºC; and (4) should focus on one temperature range rather than another.
- The approach to separate the S-I thermochemical cycle is a good step. However, material selection seems to be taking place in an empirical way and only through a literature search. It ought to happen more systematically on the basis of failure mechanisms, such as creep, creep-related damage, stress corrosion cracking, stress design requirements, microstructure stability, reliability, etc.

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

This project was rated **3.1** based on accomplishments.

- Good progress so far. Identified two sets of materials for S-I/Ca-Br.
- 2004 start, 10% complete.
- Assessment of NHI thermochemical cycle service conditions and candidate materials.
- Reported on materials requirements for nuclear hydrogen generation.
- Isolated chemicals and temperatures for H_2SO_4, HI and CaBr reactions.
- Materials testing for NHI cycles initiated; refractory metals showing best corrosion performance, so far.
- Good progress was made including several publications.
- PI knows the area well, so expect significant accomplishments as the project matures.

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

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

- Good collaboration with GA, French, UNLV and other partners.
- Project enables transfer and collaborations among partners in industry, university, and labs.
- Cooperation and benchmarking with similar efforts internationally like Japan's pilot process.
- Very long timeline for commercialization at scale benefits greatly from coordination function as well as transfers and collaborations.
- The project has a good coordinated team.
- Even though the project is well thought out and its relevance well documented, coordination with other project was not that transparent.

Question 5: Approach to and relevance of proposed future research

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

- Good proposed research. PI will continue to work with partners.
- Revise and update material selection document.
- Develop a prioritized, integrated, materials evaluation program.
- Clear project plan with decision points in lab scale stage.
- Might benefit from separate tracks for high and medium temperature environments.
- Future plan is sound but not much detail identified.
- Extremely vague.

Strengths and weaknesses

Strengths
- Addresses a promising path for high volume, climate neutral, inexpensive, centrally-produced hydrogen.
- Could address either high temperature (900ºC), or medium temperature (600ºC). Project work is heat source independent -- higher temperatures targeting new nuclear plant waste heat.
- Medium temperatures have potential for, or are capable of, retrofitting to existing nuclear plants.
- Provides coordination and direction for the first stage of a long term multi-player project
- Work applicable to other heat sources.
- Good experienced team facing a large and difficult problem.
- The strength of the project is the PI. He is extremely knowledgeable of the overall engineering aspects of the project, but he needs to take charge and address issues of mechanism-based approach versus empirical approach on issues such as material selection, etc.

Weaknesses
- Numerous safety issues need to be addressed
- A very broad range of materials will need to be evaluated which will be a challenge for this project.
- Pressure differentials are important as far as the mechanical response of components is concerned, and need to be reported in the process of material selection.
- The project needs to go beyond the empirical selection of materials through a literature search. It is difficult to believe that SiC composites are materials suitable for heat exchangers.

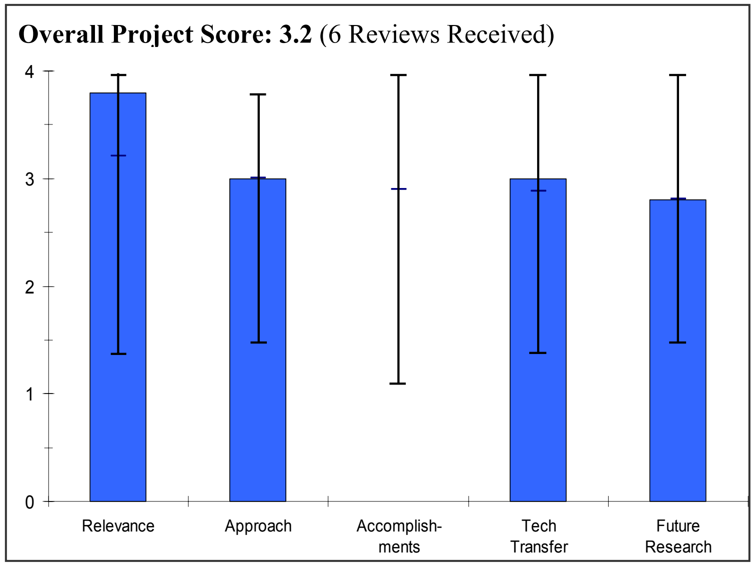
Specific recommendations and additions or deletions to the work scope

- Continue with research to narrow down potential materials.
- Project should make middle temperatures the priority to allow more heat sources, including existing nuclear heat exchange systems
- Depending on Japanese pilot experience, glass should be considered as a possible vessel material.
- Safety must consider interactions with nuclear or other plant components.
- List of selected materials re-written on the basis of operation requirements. For instance, classify materials based on their creep resistance, corrosion resistance, etc. Then weigh the importance of creep resistance versus corrosion resistance and look for optimized solutions. In other words, the project needs a systematic plan of stated material requirements, failure mechanisms, reliable operation condition requirements, and then an optimization of all these parameters based on appropriate and well thought out weight factors.

Project # PDP-24: A Novel Membrane Reactor for Hydrogen Production from Coal
Lau, Francis; Gas Technology Institute

Brief Summary of Project

In partnership with the National Energy Technology Laboratory, Illinois Clean Coal Institute and American Electric Power, Gas Technology Institute is conducting research on the technical and economic feasibility of a membrane reactor coupled with a coal gasifier for clean, efficient, and low cost production of hydrogen from coal. The project will screen, test, and identify potential candidate membranes under high temperature and high pressure coal gasification conditions. The best performing membranes will be selected for preliminary reactor design and cost estimates.



Question 1: Relevance to overall DOE objectives

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

- Lowers cost of hydrogen.
- Relevant to hydrogen-from-coal program.
- Aims to reduce the cost of hydrogen production.
- Success should lead to reduced cost of production from coal, natural gas, and biomass.
- The project is well aligned with the President's Hydrogen Fuel Initiative.
- The proposal work, if successful, should lead to significant improvement of the current coal to hydrogen production technologies.

Question 2: Approach to performing the research and development

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

- Permeation apparatus design and construction.
- Membrane materials development, screening and testing at high temperatures and pressures.
- Conceptual modeling and design of membrane reactor.
- Process evaluation and economic evaluation.
- Putting the membranes inside the gasifier is not a good approach -- extremely difficult for the membranes to survive.
- Feasibility studies an excellent way to start research project. Provided a more focused effort.
- Studying several good candidate membranes.
- Partners being able to provide membranes lets PI focus on areas of institutional strength.
- Testing apparatus makes research go more smoothly.
- Excellent series of experiments on temperature dependency and stability.
- Should also study purity as a function of temperature and stability.
- Planning on conducting studies of flux as a function of material area. Excellent that this was first modeled.
- Improvements critically related to availability of robust membranes.
- The approach is technically sound and adequate for this level of effort.
- Approach has included both experimental and modeling work.

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

This project is just starting and therefore was not scored on technical accomplishments, although reviewers provided the following preliminary observations:

- Constructed and commissioned high temperature/high pressure (1100ºC /1000 psi) membrane permeation unit.
- Developed membrane fabrication techniques.
- Demonstrated reasonable hydrogen flux for proton-conducting parasite membranes.
- Began chemical stability evaluation (stable in 250 hr pure H_2 feed, Zr doping shows good CO_2 stability, Zr doped BCN disk shows short term H_2S stability).
- Developed reactor model.
- Project is not kicked off yet.
- Work done using their internal funds was presented.
- Very low flux numbers obtained.
- Modeling work has been done for this concept.
- Set of very informative results.
- No data on purity.
- Very informative modeling results.
- Modeling provided good data to guide experiments.
- The project has made significant progress in developing suitable membranes and testing them in a high pressure and temperature device.
- Developed a model to evaluate the process.
- Results on experimental and modeling work were obtained.

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

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

- Partners with Arizona State University, University of Florida, and NETL.
- Collaborations with two universities.
- The two professors are well-known for their work in the development of membranes.
- Good coordination and role assignments between collaborators.
- In speaking to PI, learned that they will also work with Wah Chang.
- The project lists two partners from academia. It is unclear whether these partners can continue the project in the absence of DOE funding.
- There are no industrial partners for this project.
- More interactions are needed to seek inputs from industry (e.g. in areas of coal gasification and syngas cleanup and conversion to hydrogen).

Question 5: Approach to and relevance of proposed future research

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

- Flow sheet simulation.
- Chemical stability improvement.
- Hydrogen flux improvement (reduce thickness from 200 to 20 micron, dual-phase membranes, from 1 to 100 scfh/sqft).
- Reforming catalyst development.
- Simulated syngas testing scale-up.
- Mixed-conducting ceramic membranes show very low flux values -- why continue work in this area?
- Preliminary data shows the flux actually decrease with pressure over 4-5 atm.
- A timeline for achieving plans should be included.
- Which syngas will be tested?
- PI should make plans to test membrane with contaminants (S, alkali, ash, etc.).

- The only portion remaining under future work within this project is the completion of the technical and economic assessment of the membrane gasifier. All other items described will require new funding.
- Much more work is needed to prove out the feasibility of this challenging technology.

Strengths and weaknesses

Strengths
- Steady progress.
- Modeling work.
- Membrane test facility.
- Good team of researchers.
- A novel technical concept of accomplishing hydrogen separation within the gasifier itself, thus reducing the number of processing steps.
- Developed parasite membranes that can withstand high temperatures and pressures while producing sufficient flux.
- Has prepared ITM membranes and conducted hydrogen flux measurement at high hydrogen pressures at high temperature. Conceptual coal gasification configuration was presented to include the membranes. Preliminary membrane thermal stability data were obtained under simulated conditions.

Weaknesses
- Need long-term flux, chemical and mechanical stability testing in gasifier conditions (future).
- Working with mixed-conducting ceramic membranes with very low flux values.
- Trying to put the membranes inside the gasifier? Difficult for the membranes to survive.
- One of the project objectives to determine the technical and economic feasibility of a membrane reactor coupled with a coal gasifier was accomplished through theoretical modeling. The conclusions drawn from this modeling effort were already known in the literature (Hydrogen from Coal, David Gray, Mitretek, 2002), so it is unclear why a similar effort was undertaken by the PI.
- Mechanistic details of the model and assumptions made should be provided to understand the algorithms used in the model.
- It is also unclear whether kinetics can become rate limiting due to catalyst poisoning in the WGS reaction by the build up of non-permeates.
- Plot of hydrogen flux dependence vs. hydrogen pressure showed a peak in the mid- hydrogen pressure range. Inadequate discussions in the importance of these data , if any.

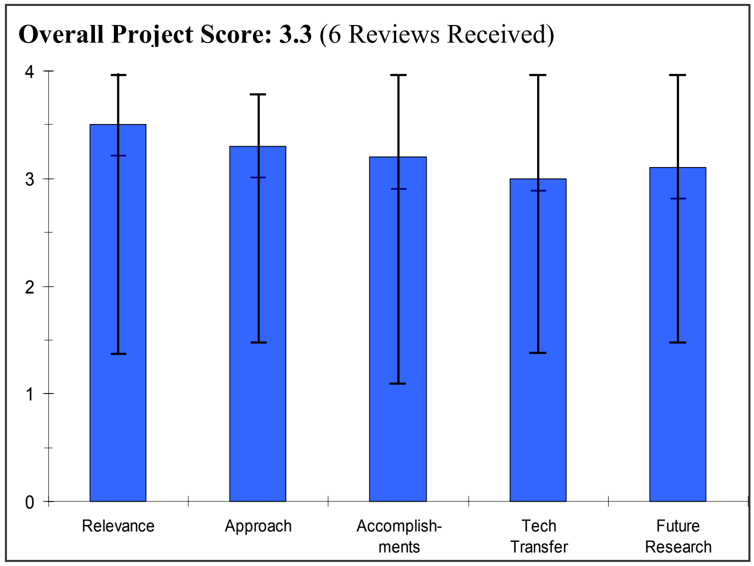
Specific recommendations and additions or deletions to the work scope

- Investigate fluid dynamics of conceptual membrane gasifier.
- Delete the effort on developing mixed-conducting ceramic membranes.
- Add efforts on dual-phase membranes that show promising flux numbers.
- An experimental verification of the model's findings, i.e., does the process intensification concept proposed here matches the theoretical findings of improving hydrogen production by 30-50%? Or are there unknown factors not included in the theoretical model that can negate this finding?
- Need to define the target hydrogen flux for membrane based on PI's know-how on local gasification. Need to prove out that membrane performance is not affected by the presence of particulates present in coal-based syngas.

Project # PDP-25: Hydrogen Separation
Killmeyer, Richard; National Energy Technology Laboratory

Brief Summary of Project

The overall goal of this project is to investigate, develop, and evaluate separation membranes to enhance hydrogen production from fossil fuels. Of interest are robust membranes suitable for the rapid, selective removal of hydrogen or carbon dioxide from various gas streams, while remaining resistant to impurities.



Question 1: Relevance to overall DOE objectives

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

- Lowers cost of hydrogen.
- Addresses barriers in Fossil Energy's Hydrogen from Coal RD&D Plan.
- A cost-effective coal gas derived hydrogen production technology, such as the project R&D aims to develop, responds to the Hydrogen Fuel Initiative mission, and the work scope of the project is consistent with DOE Hydrogen Program goals.
- The work scope is adequately planned and successful results for scale-up and technology demo is likely.
- The barrier issues are listed and the research efforts are focused on overcoming key technology barriers.
- Some definition of a success criterion such as, the cost of hydrogen production or meeting the DOE target, and how the R&D team plans to accomplish this milestone, would have been appropriate.
- Relevance critically related to availability of robust membrane.
- The project is well aligned with the President's Hydrogen Fuel Initiative and has identified the barriers that it is striving to overcome.
- Work proposed should help advance the hydrogen separation technologies.

Question 2: Approach to performing the research and development

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

- Water Gas Shift (WGS) membrane reactor development.
- Pd-Cu membrane testing of sulfur resistance.
- Novel hydrogen production and separation membrane development.
- Experimental approach is geared toward achieving the project milestones.
- NETL is focusing on developing Pd-based membranes.
- The researchers are using innovative approaches to provide solutions, explains advantages and differences from the current knowledge base, and generating a data base en route to a novel technical know-how for hydrogen production.
- The PIs recognize the technology R&D needs and has proposed work to overcome the technology barriers for scale-up leading to commercial maturity of the Pd alloy membrane system for hydrogen production.
- The approach is technically sound for a preliminary evaluation of the concept of incorporating a Pd-Cu based membrane reactor to perform the WGS reaction and hydrogen separation.
- Has proposed an approach including fundamental studies.

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

This project was rated **3.2** based on accomplishments.

- Demonstrated steam and CO effects with temperature on Pd-Cu permeability and morphology.
- Demonstrated high permeability area (bcc) of Pd-Cu alloy phase diagram is subject to H_2S poisoning but the fact phase is resistant.
- Pd-based ternary alloy tested.
- Completed performance tests for ANL, ORNL, Eltron, and Synkera collaboration partners.
- Recent publication in *Science*.
- Steam was shown to have negligible effect on hydrogen permeation.
- Membrane surfaces were pitted after exposure to steam and CO; reasons not known.
- Good number of publications.
- CO slightly reduces the hydrogen permeation.
- Planned tasks and current accomplishments are conducive to achieving project goals.
- The schedule is consistent with DOE Hydrogen Program requirements.
- The project is progressing successfully along technical baselines towards a meaningful outcome.
- The project has made stepwise progress in the determination of the feasibility of membrane reactors in gasifiers and has preformed studies addressing key questions (e.g. effects of trace impurities on pd member separation efficiency)..

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

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

- Collaboration with ANL, ORNL, Eltron, and Synkera (performance testing).
- Collaborates with ANL, ORNL, GTI, and REB, Inc. (Muxbaum).
- The project is collaborating with other National Labs, research institutes, and a consultant.
- Most of the work is done at the project site.
- The project lists three National laboratories and one industrial company as partners. While technical input is provided by these partners, it is uncertain if these partners can financially sustain the project in the absence of DOE funding.
- More interactions with industries are needed to seek inputs to R&D work.

Question 5: Approach to and relevance of proposed future research

This project was rated **3.1** for proposed future work.

- Membrane pitting tests
- Test CO_2, NH_3, and HCl contaminant effects on Pd-Cu membranes.
- Conduct WGS membrane reactor tests in fabricated Pd-Cu helical coils.
- Conduct WGS experiments in presence of H_2S.
- Determine mechanism of S poisoning and resistance of Pd-Cu alloys.
- Continuing to do what they have done already (for most part).
- Trying ternary alloy is new work for the future.
- Legitimate future work has been proposed and can be related to the original objectives and intended outcomes of the work.
- Performance improvements using different membrane reactor configuration will be studied.
- Effects of other contaminants present in coal gas will be studied.
- Insightful mechanistic studies on why Pd-Cu alloys are sulfur tolerant will be conducted.
- Find and test other (better) membranes.
- The future work is a logical extension of past findings and focuses on further investigation of observations such as the influence of contaminants, time dependence of membrane pitting, and reactor configurations.

- Future work should investigate hydrogen production with and without the integrated WGS membrane reactor to experimentally verify theoretical projections of hydrogen production cost savings.
- Has proposed future research to assist industries to evaluate membrane effectiveness for hydrogen separation.

Strengths and weaknesses

Strengths
- Developing excellent membrane testing capabilities.
- Membrane test facility.
- Experience with fossil resources.
- Excellent team and& collaboration with top-notch institutions.
- Good number of publications.
- The researchers have recognized that pitting is a failure mode and will investigate further.
- The development of the Pd-Cu phase diagram will add value to membrane science information base.
- This R&D has made very interesting observations and reported new findings.
- The researchers have developed an fcc phase with sulfur resistance.
- A novel technical concept of accomplishing the WGS reaction and hydrogen separation within the gasifier itself, thus reducing the number of processing steps.
- Membrane permeation tests show sufficient flux at gasification temperatures. Other useful findings regarding the effect of factors such as steam and H_2S have also been obtained.
- Quantitative data were presented to show the effects of CO, H_2S and steam on H_2 separation using Pd-Cu alloys. Efforts have begun to study membrane morphology before and after hydrogen separation study.

Weaknesses
- Look at additional membrane thicknesses and types.
- Why not look into other alloys? Why just Pd-Cu?
- Membrane fabrication.
- The PIs are conducting experiments outside the desired or anticipated commercial operating ranges.
- The PIs recognize the barriers and may wish to refocus their efforts more towards technical maturity issues en route engineering scale-up and technology demonstration.
- Some of the project results, although obtained by advanced characterization techniques and approaches, do not necessarily advance the status of science; instead re-confirms known info.
- The PIs seem to be conducting experiments outside the desired or anticipated commercial operating range targets.
- Flux data at lower temperatures (~ compatible with warm gas clean up temperature) in the presence of CO and H_2O (or the sulfur-tolerant fcc phase) does not appear to be commercially significant, but the researchers have not adequately analyzed this observations or address this performance issue.
- Figure titles would make the information in the figures more readily comprehensible to the reader.
- One of the project objectives to determine the technical and economic feasibility of a membrane reactor coupled with the investigation of different Pd-Cu alloy compositions (0-100% Pd) at three different temperatures to determine their sulfur tolerance may take up an extended period of time due to the infinite number of binary and ternary alloy combinations.
- It is also unclear whether kinetics can become rate limiting due to catalyst poisoning in the WGS reaction by the build up of non-permeates.
- Pd membranes used were thick and gave low hydrogen permeability. No separation factor data were reported. Duration of membrane testing was not discussed.

Specific recommendations and additions or deletions to the work scope

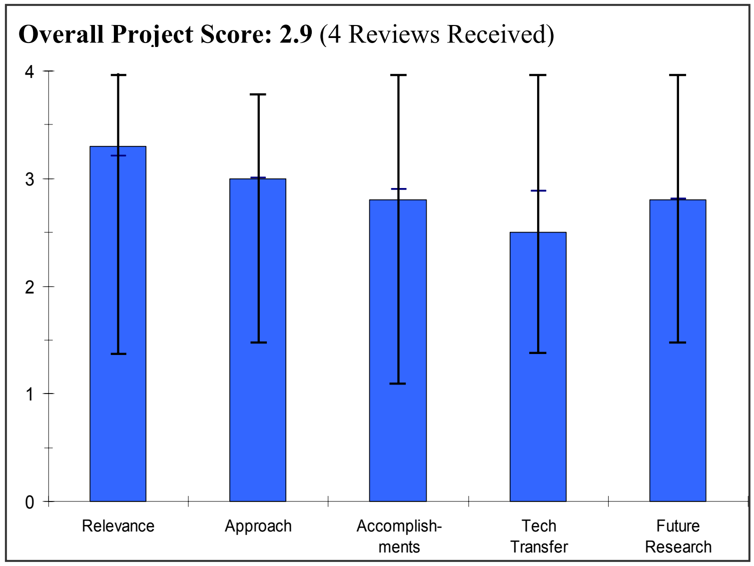
- Potential to expand membrane types and partners.
- Search for other alloys.
- Understand the reasons for pitting.
- Computational analysis to develop new membranes.

- Utilize mathematical modeling to predict potential alloy combinations that can be subsequently investigated in the laboratory.
- Perform experiments to verify if the process intensification concept of combining the WGS reaction and hydrogen separation reduces cost by 30%.
- Work with Pd membranes which yield higher hydrogen permeability and become competitive with competing technologies. Conduct long-term life testing with Pd membranes exposed to impurities. Prioritize future work which is broad in scope. Expand capabilities to serve as a site to test hydrogen separation membranes submitted by industries and to meet the testing needs of industries.

Project # PDP-27: Startech Hydrogen Production
Lynch, David; Startech Environmental Corp.

Brief Summary of Project

Startech Environmental Corp. will field test integrated hydrogen production on a pilot scale using plasma gasification and ceramic membrane hydrogen separation, and evaluate commercial viability and scalability through extended operation under representative conditions.



Question 1: Relevance to overall DOE objectives

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

- The project involves plasma processing of municipal solid waste (MSW) streams into a hydrogen-containing stream which is then passed through a separator vessel to purify the hydrogen. The process could be applied to other renewable streams.
- The project does support a limited but important portion of the hydrogen RD&D plan.
- MSW is cheap feedstock for hydrogen.
- Innovative. Could be part of a novel pathway.

Question 2: Approach to performing the research and development

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

- The plasma equipment was previously developed. This project integrates a hydrogen separation membrane to produce high-quality hydrogen.
- It is not clear that compatibility of the membrane with expected process streams is being sufficiently established.
- Some concern due to complexity of the project and multiple new technologies (membrane, plasma, etc.)
- Good approach for MSW since no waste sorting required and high destruction rate.
- Good progress.

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

This project was rated **2.8** based on accomplishments.

- The first attempt at making the separation unit failed because of materials issues. It seems that insufficient design and materials analysis was performed to choose an appropriate material.
- Problems with membranes has caused a delay in the overall programs objectives
- Reasonable progress. Need clear timeline.

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

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

- Startech makes plasma equipment. Their partner makes ceramic hydrogen separation equipment.
- This project could benefit from additional university and national lab coordination.
- Good with membrane manufacturer. May need more interaction with other entities.
- Not overly broad yet. Perhaps due to the early proprietary work?

Question 5: Approach to and relevance of proposed future research

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

- More materials and design analysis should be performed.
- Having a backup membrane provider might have kept the project on track
- Should include process economics & energy balances very early. Need to compare with other hydrogen technologies. Electricity cost should be included.
- Need to address materials handling and solid by products as well.

Strengths and weaknesses

Strengths
- The system hardware appears to be completed now and ready for testing.
- Unique idea that may have applications to other areas such as medical waste treatment.
- Interesting approach. Low cost of MSW makes it a good potential feedstock.
- Novel approach.

Weaknesses
- Very little progress was made on the project.
- No experimental results to date.
- Electrical energy input carries generation inefficiency with it.
- Need heat and material balances to understand how process will work, i.e., efficiency of waste heat recovery & full utilization of process heat.
- Still early in the program, so hard to judge

Specific recommendations and additions or deletions to the work scope

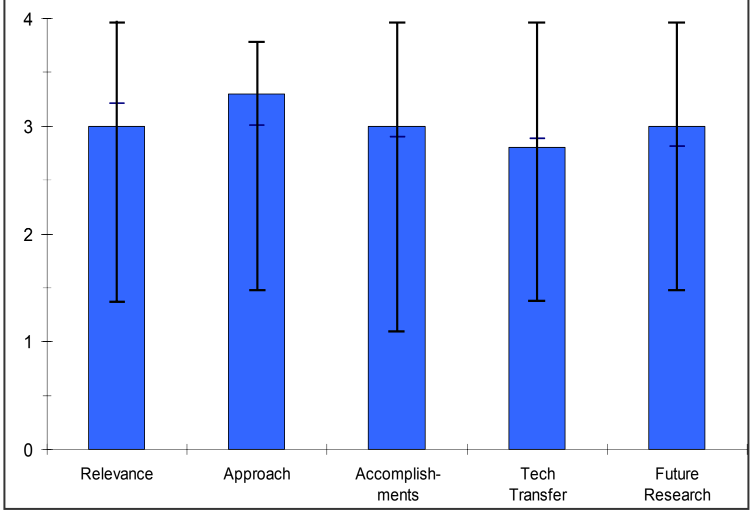
- The project needs to demonstrate results soon to show if this overall approach has any merit.
- Economics and energy balance need to be done ASAP.

Project # PDP-28: EVermont Renewable Hydrogen Fueling System
Maloney, Tom; Northern Power Systems

Brief Summary of Project

Northern Power Systems is assisting DOE in the development of hydrogen production technologies by building and testing a validation system. Objectives of the project are to: develop an advanced PEM electrolysis fueling station that utilizes renewable electricity sources; reduce cost of hydrogen production; improve electrolyzer efficiency; improve fueling station integration and controls; utilize hydrogen fueled vehicles for testing and validation; and show viability of distributed production pathway.

Overall Project Score: 3.0 (4 Reviews Received)



Question 1: Relevance to overall DOE objectives

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

- Most aspects of the project align with the President's hydrogen vision and program objectives.
- This project addresses improved electrolyzer efficiencies and reduced cost for power electronics, which area key elements in the HFCIT MYPP.
- Project is fairly well aligned with overall program goals

Question 2: Approach to performing the research and development

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

- Addressing the renewable integration and the power electronics design/cost is a significant step towards making these systems practical.
- The approach is generally well thought out and effective but could be improved by integration with other renewable electrolyzer projects. Most aspects of the project will contribute to progress in reducing the capital costs of electrolyzers.
- Process configuration options have been considered

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

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

- Project is making significant progress on cost and efficiency of cell and power electronics.
- The project has shown significant progress toward against its objectives and to overcoming the barrier of higher cost electrolyzers. Further research and funding is needed in the area of reducing electrolyzer capital costs.
- Potential for using different operating configurations is interesting and may provide some of the most interesting results.

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

This project was rated **2.8** for technology transfer and collaboration.

- Collaborations appear to be compartmentalized around system components with little technology transfer between organizations.
- A little coordination exists; full and needed coordination would take significant time and effort to initiate. This project should collaborate with other renewable-electrolyzer projects.
- Should further develop a strong public relations and education component.

Question 5: Approach to and relevance of proposed future research

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

- Demonstration of cell design and power electronics in fueling station application to prove technology is significant next step.
- Development of power electronics has potential for further cost and efficiency improvements.
- Although future funding may not exist, this project shows excellent capacity for meeting DOE cost goals in the future and addresses key technical barriers.
- Should continue to pursue additional vehicles to increase the hydrogen use.
- This is a one-year earmark, and they appear to have very little planning for future development.

Strengths and weaknesses

Strengths
- Development of cell and power electronics to improve cost and efficiency.
- Demonstration in fueling application.
- Excellent improvement in electrolyzer efficiency.
- Good improvements in reducing power electronics costs.
- This company should examine the power requirements for specific applications and integrate designs for the power electronics to those markets.

Weaknesses
- Look at opportunities to lessen the dependency on the grid for power when wind is unavailable.
- This project should focus more on the improvements of the electrolyzers and not demonstrating the technology until ready.

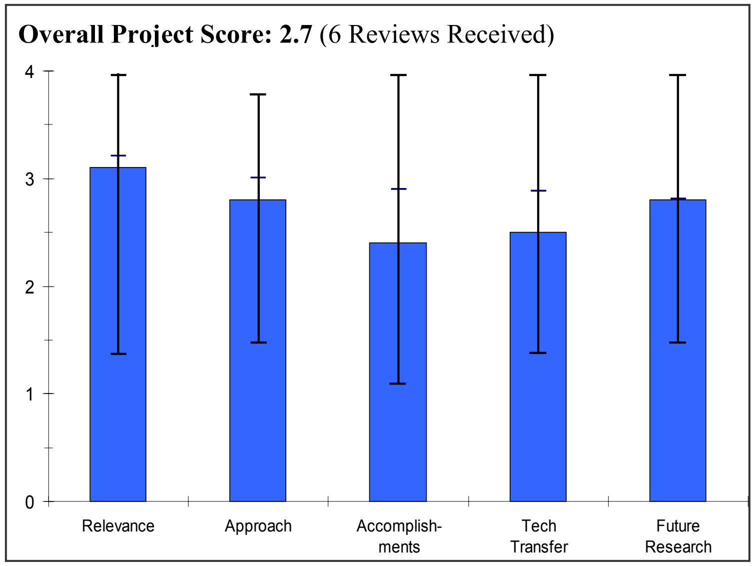
Specific recommendations and additions or deletions to the work scope

- Document progress against the DOE targets as the project proceeds.

Project # PDP-33: Discovery of Photocatalysts for Hydrogen Production
MacQueen, Brent; SRI International

Brief Summary of Project

This SRI International and NanoGram Corporation project addresses efficiency, durability and cost of photocatalyst materials for use in direct water-splitting systems for the production of hydrogen. The materials discovery required to meet the technical targets will be expedited by the use of high throughput screening tools being developed in this project. The inclusion of a partner with the means to produce commercially relevant amounts of materials will hasten the development required to make photoelectrochemical hydrogen viable.



Question 1: Relevance to overall DOE objectives

This project earned a score of **3.1** for its relevance to DOE objectives.

- Materials discovery is at the core of this research area. High throughput screening of bulk materials is an important area and should compliment the combinatorial and directed research approaches.
- The approach of using photocatalysts for the production of hydrogen is based on well established concept of 70's. The PI's proposal to improve the efficiency of water splitting reaction by the discovery of low cost materials with improved efficiency is relevant to the program
- Semiconductor nanorods are an innovative approach to single bandgap photoelectrochemical converters. The approach makes clever use of the novel quantum properties of nanostructure inorganic structures. In principle, this approach has the potential for high STH conversion efficiency. These devices will display low current -- a trait shared by triple junction III-V photovoltaic cells. However, an advantage with respect to triple junction cells is the much lower cost of materials. The project is highly focused on the DOE goals.
- Goal for discovering materials enabling high efficiency photoelectrolysis of water is fully aligned with DOE goal of finding efficient, cost effective paths to hydrogen using renewable energy sources. However, the development of high volume synthesis approaches is premature until promising classes of effective materials can be identified.

Question 2: Approach to performing the research and development

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

- It is unclear if this project is employing a sufficiently targeted approach to yield any kind of progress towards the technical targets.
- High-throughput screening can be useful. However, this project seems to be driven solely by industrial partner's area of interest, rather than on screening a wide array of materials to yield valuable information on the chemistry and bulk properties that could help guide future research.
- The approach of large volume nanoparticle synthesis and high though put screening has good scientific merit and this approach has helped researchers to identify useful photocatalysts. However, failure to implement additional characterization and analysis (see comments from past reviews) has limited the progress of this investigation.

- The approach is a good mixture of experiment and theory. The research is both high risk and high payoff in nature. However, present results appear to be quite limited. The project does not appear to be sufficiently thought out with respect to a logical train of experimental results.
- The approach is effective for identifying materials for testing.
- Somewhat hampered by partner's ability to produce samples.
- The approach employed involves the attempt to tune electronic properties of solids by creating nanoparticles, doping oxides with nitrogen, and investigating new candidate materials such as AgInZnSe. Theory is nicely used to justify the new materials approaches, and high throughput methods are effectively used to improve efficiency of screening many materials at the same time.

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

This project was rated **2.4** based on accomplishments.

- Does not appear to be benchmarking materials selection against what others in the field are doing or reporting. Still not making a strong effort to understand the properties that lead to success/failure.
- The project has shown modest progress with no major outcome in tackling low photoconversion efficiency.
- TiOxNy and TiOxSy materials developed in this study exhibit improved efficiency relative to TiO_2; however, the efficiency of these catalysts remains low. It is still a factor of ~10 lower than 2008 target.
- Demonstrated the ability to tune the bandgap of GaxIn1-xP.
- Photostability issues as well as the development of a reactor for water splitting reactions have not been addressed fully.
- The team has made good progress in characterizing the nanorods and determining the relationship between the geometry of the rods and their performance. Technical barriers are identified and there are well-defined approaches to their solution.
- Project has identified some interesting materials
- The researchers did a lot of work in studying many materials, but the results with the classes of materials tested proved that significant improvements in efficiency are needed to begin to approach efficiency targets. Near term stability improvements are promising, with longer term tests in progress on TiOS.

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

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

- PI needs to coordinate much more closely with others working in this field. Seems to be more focused on marketing the capability rather than leveraging the technical success of the project.
- The researcher has cited Nanogram as their partner.
- Academic collaboration would have helped these researchers to further understand the problems associated with the improving photocatalytic efficiencies.
- The researchers represent the industrial community. There is accordingly good transfer of technology.
- Project would benefit from additional collaboration or communication with other related projects
- Better coordination and sharing with groups at Santa Barbara, Hawaii, NREL possible.

Question 5: Approach to and relevance of proposed future research

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

- Again, materials selection should be guided by known properties and insight into possible success. Future work seems to be guided more by the next funding opportunity than on achieving the goals of the project.
- No effort has been made to make use of the catalysts developed in the current phase of work.
- The core shell structures involving metal chalcogenides suffer from long-term stability issues. (Lack of oxygen production in such systems has been demonstrated in earlier work. The PIs should refer to literature published on the water-splitting reaction using metal chalcogenides)

- Future research is focused on development and characterization of mixed phase materials. This clearly builds on past progress.
- Proposed work is an important next step
- Promising lead (mixed phase nanorods) identified as new class of materials for future investigations. Need to better illustrate how these materials will be characterized.

Strengths and weaknesses

Strengths
- Good materials development and screening capabilities.
- Developed a high through put screening procedure for photocatalyst evaluation.
- Identified N- and S-doped TiO_2 as the possible photocatalysts with improved performance.
- Reasonably focused approach, with a good mixture of modeling and laboratory data.
- Good mix of modeling and experimental work in the overall efforts.

Weaknesses
- Project focus seems to be more on developing capabilities than on materials discovery. Little progress has been made on advancing the science. In many aspects, the project appears to be duplicative of what others are doing, without contributing to any unique understanding on its own.
- Limited success to achieve the set goal of achieving higher photocatalytic efficiency and failure to understand the problems associated with S- and N-doped TiO_2 photocatalysts.
- The proposed core-shell structures involving chalcogenide semiconductors are susceptible to photocorrosion and needs better understanding of the photoinduced processes in such core-shell semiconductor systems.
- The quantum mechanical basis for the high potential conversion efficiency of the nanorods does not appear in the slides. Such development would add to the cogency of the approach. Additionally, the slides do not indicate a clear definition of problems that need to be solved.
- This area is in need of additional materials concepts to test for photoelectrochemical water splitting. This is a comment that applies to all the projects in this area.

Specific recommendations and additions or deletions to the work scope

- The researchers should not abandon the efforts of previous investigation. They need to continue to build composite structures based on such oxides. Switching over to chalcogenide based core-shell structure may look scientifically sound, but is likely to suffer from photostability issues and lack of oxygen production. Fundamental understanding of the differences between oxide and chalcogenide photocatalysts in water splitting reaction is important in pursuing the research goals.
- It would be interesting if the research team developed a discussion of how the nanorod approach compares with that of quantum dot sensitized TiO_2 photoelectrochemical systems?
- It does not appear reasonable that SRI will come close to meeting their target efficiency based on progress to date and the short amount of time left before project completion.

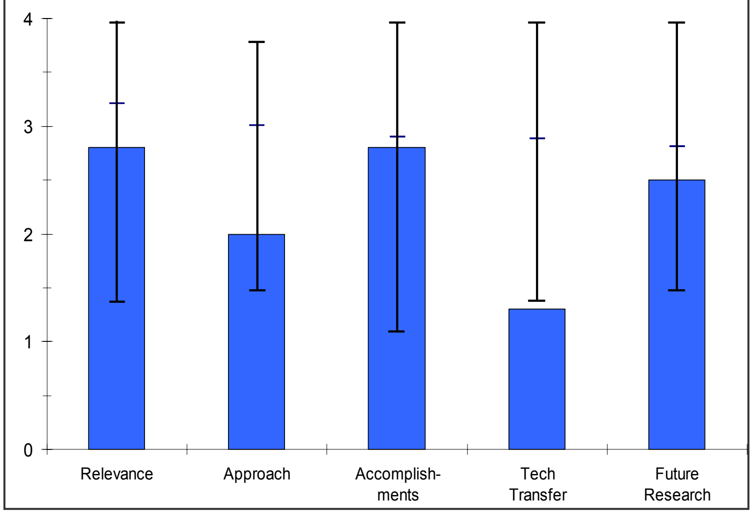
Project # PDP-39: Hydrogen Production - Increasing the Efficiency of Water Electrolysis

Pile, Donald; Sandia National Laboratories

Brief Summary of Project

Sandia National Laboratories intends to improve the efficiency and consequently lower the cost of the electrolytic production of hydrogen through higher activity catalysts and more conductive membranes. Specific objectives of the project are to prepare polymer thin films as low resistance, hydroxyl ion conducting membranes and evaluate their electrochemical performance as electrolyte/separator in alkaline-based water electrolysis cells; and prepare and electrochemically evaluate transition metal (e.g., Mo) macrocycle complex-based electrocatalysts as low-cost, high catalytic materials for hydrogen evolution.

Overall Project Score: 2.4 (4 Reviews Received)



Question 1: Relevance to overall DOE objectives

This project earned a score of **2.8** for its relevance to DOE objectives.

- The project is relevant but not critical.
- Lower cost materials are needed to achieve the stack cost targets for electrolysis.
- The project does support a limited but important portion of the hydrogen RD&D plan. This program supports alkaline electrolysis material development.
- Program proposed replaces low cost electrolyte (KOH) and asbestos diaphragm with higher cost membrane.
- Benefits of membrane over KOH not identified.
- Cost analysis not reported.
- Catalyst not tested at operating temperature of electrolysis.

Question 2: Approach to performing the research and development

This project was rated **2.0** on its approach.

- Uses alkaline electrolyte -- a different approach.
- Technical feasibility is uncertain because of the novelty of the approach and the proposed materials.
- Would benefit from a strong experimental design for the materials synthesis and characterization activities.
- The PI has a good background in polymer membrane chemistry and has identified some possible new membrane materials.
- The methodology or selection process for determining new candidate membrane materials has not been clearly demonstrated.
- Not clear how stability of membrane will be improved using amine linkage. Does not address C-H bonds
- Did not compare conductivity to KOH. Majority of commercial electrolysis systems use KOH.
- Cost benefit for developing a membrane was not identified in presentation. Approach should identify the benefits of developing the membrane.
- Program should conduct testing at true operating temperatures of electrolysis

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

This project was rated **2.8** based on accomplishments.

- Progress has been made but results are disappointing and the possibility of future success is not encouraging.
- Given the limited funding there are some interesting results in the membrane development task.
- Need to improve materials synthesis to lead to more reproducible results.
- The future work for this project should concentrate on membrane material development.
- Work on macrocycle catalyst should be discontinued in favor of membrane material development.
- Progress on catalyst was good. Researchers recognized the limitation of the catalyst and changed direction of program.
- New membrane offers promise but needs to have conductivity improved.

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

This project was rated **1.3** for technology transfer and collaboration.

- The poster did not contain any information about collaborations
- The team would benefit strongly from industrial partners, particularly in the membrane development area.
- Need to publish results and submit to a robust peer review.
- The PI discussed some collaboration but more is needed for this project to be successful.
- None identified.

Question 5: Approach to and relevance of proposed future research

This project was rated **2.5** for proposed future work.

- The membrane future work is logical and fairly specific.
- The catalyst future work involves changing both the materials and synthesis routes. This is an indication that the initial idea was not well-conceived and that the proposed changes are not ensured of success.
- There does not seem to be any go/no-go decision point or criteria.
- Need to develop a detailed plan for membrane synthesis and set targets for performance and durability testing.
- Future plan for membrane material development appear to be adequate.
- Future program does not address replacement of KOH but compares to commercial membranes. Need to compare to commercial competition which has liquid KOH.
- Future program should address the solubility of transition metal catalyst at high temperatures when in contact with hydroxyl membrane

Strengths and weaknesses

Strengths
- PI has a good electrochemical background
- The PI has shown some progress in creating materials with high ionic conductivity.

Weaknesses
- The project could benefit from additional collaborations with others in this field.
- The program does not identify the cost benefit of developing a membrane compared to KOH/asbestos diaphragm technology that is the real competitor in commercial electrolysis.
- Program does not identify industrial partners

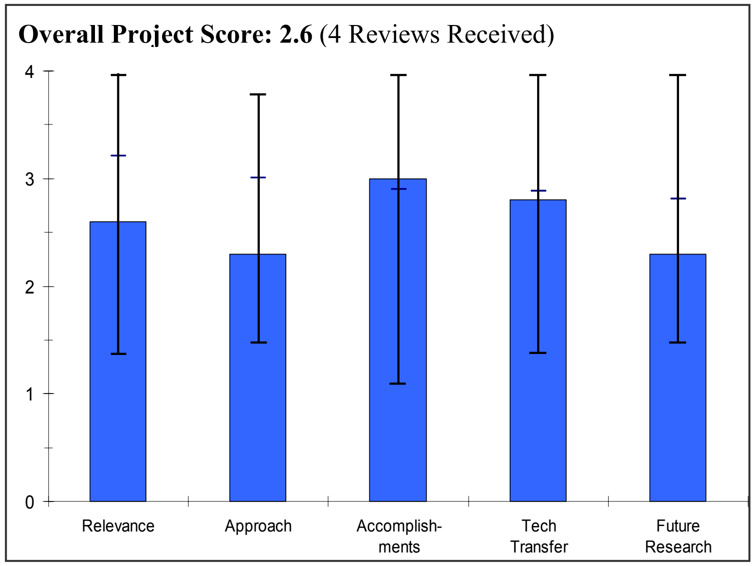
Specific recommendations and additions or deletions to the work scope

- Need to conduct a technoeconomic comparison sooner rather than later to determine the potential impact on hydrogen production cost; benchmark against current membrane and catalyst cost and performance.
- Stop catalyst development portion of project.
- Conduct solubility test of proposed catalyst prior to testing with membrane.
- Conduct cost analysis to determine if membrane replacement improves the overall cost of electrolysis equipment.
- Cost to manufacture macrocycle materials should be evaluated as they may be expensive.

Project # PDP-41: Hydrogen Generation from Electrolysis
Porter, Stephen; Proton Energy Systems

Brief Summary of Project

Proton Energy Systems and its team will determine pathways to optimum electrolysis-based hydrogen fueling through conceptual system design and component/system development. They will develop the requirements for the fueling system, optimize fueling system designs through systems analyses, and conduct R&D to improve component performance, cost, and/or durability.



Question 1: Relevance to overall DOE objectives

This project earned a score of **2.6** for its relevance to DOE objectives.

- Focus of work is clearly tied to the programmatic goals; however, need to do a better job of benchmarking against RD&D technical targets.
- Will the potential improvements identified achieve the HFCIT technical targets for electrolysis?
- This project is a straightforward attempt to improve the efficiency, durability, and cost of a membrane-based water electrolysis cell that delivers hydrogen at high pressure.
- It is not deep science or leap frog technology, but it does align with some near term visions for hydrogen utilization.
- The project does support a limited but important portion of the hydrogen RD&D plan.
- Researchers did not identify the original catalyst loading they were replacing.
- Report relative performance improvements but do not report absolute improvement values
- Not clear if they are truly approaching beneficial cost reduction.

Question 2: Approach to performing the research and development

This project was rated **2.3** on its approach.

- Appear to be targeting the improvements that will make the biggest difference in cost and efficiency.
- Need to focus more on improving the electrolyzer, rather than vehicle fueling.
- Need to ensure that a strong experimental design is used for studying durability and performance as a function of the multiple parameters being tested (temperature, catalyst loading, MEA).
- Need to define what the targets should be for meeting and exceeding conventional compression. Can a separate stack for electrochemical compression ever compete on a cost and performance basis?
- The project seeks to make improvements in overall MEA performance through optimization of core operating parameters, e.g., temperature, pressure, catalyst loading, MEA fabrication approach, etc.
- The approach is sensible and intuitive but not overly creative.
- The overall scope of the project is too broad.
- The project should emphasize electrolyzer efficiency improvements and electrochemical compressor development..
- Concept of using hydrogen pump to purify and pressurize the hydrogen needs to be experimentally proven.
- Research needs to include energy cost of drying the hydrogen. Comparison with diaphragm pump compares dry hydrogen to wet hydrogen; numbers not valid.
- Program needs to have cost analysis to demonstrate the benefits of hydrogen pumping compared to other pressurization/ purification methods.

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

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

- Considering the limited funding to this project, an impressive amount of revealing test data has been gathered since the start of the project.
- It is hard to appreciate the progress in terms of the pressing advances required to advance hydrogen utilization; however, from an incremental viewpoint, it seems that the project staff is doing a respectable job.
- Good progress was made during the past year on improving the efficiency of PEM electrolyzers on several different fronts.
- The project also made a good start on examining electrochemical compression.
- Comparison and test results offer promise that hydrogen pump concept will lead to purification process that can also pressurize the hydrogen.
- Data showing increase voltage with pressure confirms thermodynamic predictions.

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

This project was rated **2.8** for technology transfer and collaboration.

- Good partnership development efforts.
- Two collaborating organizations are mentioned in the slides; it's not obvious how they contribute to the project just from looking at the slides of the poster.
- This project could benefit from additional university and national lab coordination.
- Program is operated by industry and transfer would appear automatic.
- Program could benefit from independent cost analysis.

Question 5: Approach to and relevance of proposed future research

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

- Need to focus more on improving the electrolyzer system and on achieving the cost and performance targets.
- More R&D needs to be done to optimize operating conditions, catalyst type/loading, and membrane performance. Durability needs to be demonstrated over a wide range of conditions.
- Attention needs to be paid to balance of plant and the impact that will have on system cost and efficiency.
- Considering the scope and the goals of this project, the proposed future plans seem appropriate
- Future work should concentrate on electrochemical and electrolyzer portions of the project.
- Program needs to set hard targets for benefits obtained from this approach and set future programs to reach those targets.

Strengths and weaknesses

Strengths
- Strong team and a reasonable approach. Lots of operational experience that should benefit the project.
- The PI/presenter is clearly very knowledgeable about the technical details of the project; the presentation at the poster was very well done.
- The project organization has the means to do all that needs to be done to meet the project goals.
- The PI has a good background and experience in this field.
- Good progress was made on electrochemical portions of the project.

Weaknesses

- Need to benchmark cost reductions to achieving the technical targets. More work needs to be done on understanding the various trade-offs on cost, performance, and lifetime.
- It wasn't clear what the listed collaborations with Air Products or UC Irvine bring to the project.
- The most positive of outcomes for this project won't move hydrogen production capability forward by enough of an increment to make the most demanding production issues go away.
- Very little progress was made on the other portions of the project.
- Program reports no "hard" targets and only speaks of optimization. No measuring stick available to determine if program is really making progress toward its goals.

Specific recommendations and additions or deletions to the work scope

- Others are looking at fueling station designs. This project should focus on improving the electrolyzer system only.
- Give serious consideration to finding additional collaborators that can help move the potential positive benefits of electrolysis-based hydrogen production to a new level.
- For future reviews prepare a prior year to current year progress comparison to help gauge performance in the budget year.
- The project should concentrate on electrochemical compressor development, evaluation and testing.
- Add cost analysis and cost comparison to justify that hydrogen pumping for pressurization and purifications offers promise to meet DOE goals.
- Program should define limits to pressurization by electrochemical means. Can pressurization as high as 5,000 psi be reached using this method?

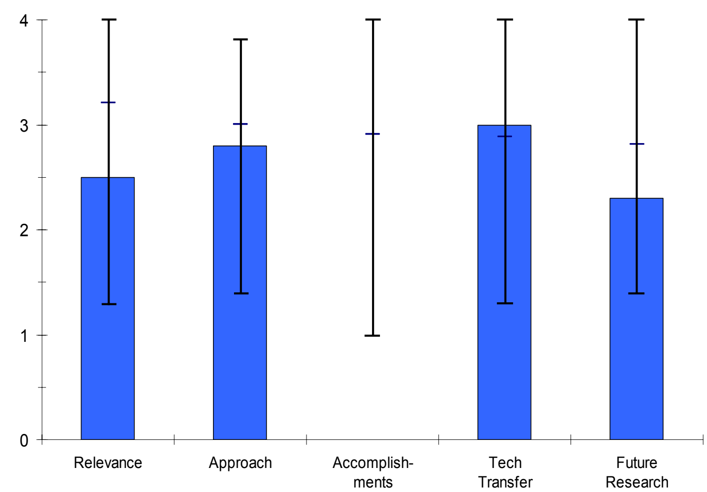
Project # PDP-42: System Design and New Materials for Reversible Solid-Oxide, High-Temperature Steam Electrolysis

Ruud, James; GE Global Research

Brief Summary of Project

GE Global Research, Northwestern University, and Functional Coating Technology, LLC will develop a pilot-scale, reversible SOEC system design capable of 1,000 kg/day hydrogen production at $2/kg based on new, low-cost, reversible solid-oxide electrodes. A system model detailed at the component level will define the plant configuration and operating parameters required to meet the cost targets. The materials will be developed and demonstrated in a multi-generational approach. The most promising materials system will be down-selected for extensive performance and durability mapping through the pilot-plant design operating space, and system performance will be predicted.

Overall Project Score: 2.6 (4 Reviews Received)



Question 1: Relevance to overall DOE objectives

This project earned a score of **2.5** for its relevance to DOE objectives.

- Production of low cost hydrogen is a major DOE program goal.
- Elements of the scope of this project may overlap with other SOFC/SOEC work.
- The program is a start up effort without any experimental data yet.
- The operating temperature proposed will be as high as 800ºC and oxidation of nickel catalyst (at the electrolysis cathode) could result and should be avoided since this would result in a mole volume change every time the system is reversed (fuel cell to electrolysis to fuel cell) degradation of the catalyst would result.
- Program does not appear to address some fundamental properties of the electrodes

Question 2: Approach to performing the research and development

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

- Project approach involves modeling and system design focused on materials selection and electrode configuration for reversible SO operation.
- Demonstration and verification of design concepts should be included as a part of the technical approach.
- The approach builds on the SOFC anode support of the electrolyte concept. This may be a flawed approach because recent results from the SECA program indicate difficulties with this design.
- The program does not address sealing of the SOEC and depends on seals being developed in a separate SOFC program. This a weakness in the program.
- At high operating temperatures, migration of interconnect materials, such as chromium, can poison the cell. The program does not address this fundamental issue and appears to depend on the SECA SOFC program to solve all of the issues.

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

This project is just starting and therefore was not scored on technical accomplishments.

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

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

- Broad team strengths unknown.
- Good team proposed with university and industrial coating partners.
- University and industry collaboration has been proposed.
- Program presentation identified collaborators.

Question 5: Approach to and relevance of proposed future research

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

- Future plans for design and modeling efforts are adequate, but inclusion of experimental program to verify design concepts and materials selection is needed.
- Project has not begun, and therefore cannot build on past progress.
- A schedule with milestones should be established for the future research.
- A go/no-go decision after the cost analysis should be in place.

Strengths and weaknesses

Strengths
- Strong, complimentary team.
- The program appears to be able to build on the activities in SOFC of the U.S. DOE SECA program and a synergistic benefit should be obtained.
- The cost analysis needs to be very rigorous so that direct comparison can be made to other methods of generating hydrogen.

Weaknesses
- Experimental verification component needed to demonstrate design concept and materials selection.
- The program has not established a clear timeline with staged/gate decision points to mark its progress. The program has a heavy dependence on the SECA SOFC program. If the SOFC program does not resolve the issue of seals, should this program be put on hold until resolution? What types of stabilities are anticipated for the interconnect materials used in the SOEC and does this problem depend upon the SOFC program?

Specific recommendations and additions or deletions to the work scope

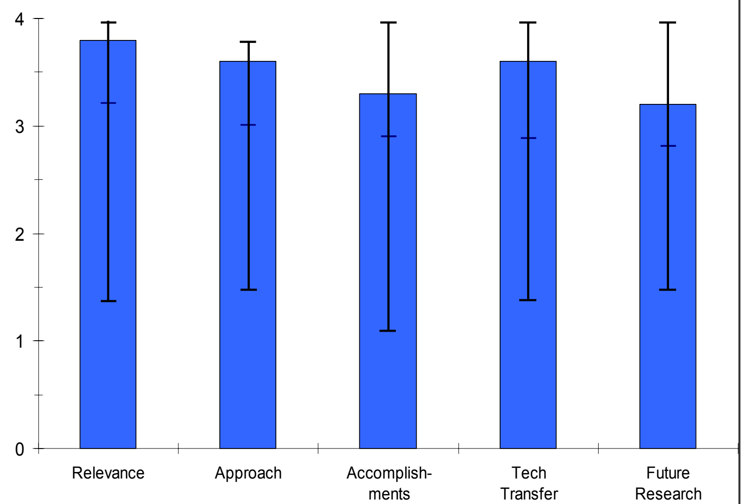
- Respond to weaknesses describe above.

Project # PDP-45: Hybrid Sulfur Thermochemical Process Development
Summers, Bill; Savannah River National Laboratory

Brief Summary of Project

This Savannah River National Laboratory project will address the key technology issues involved in the development of the hybrid sulfur (HyS) hydrogen production process. The HyS process is a highly efficient thermochemical water-splitting cycle that utilizes high temperature heat from advanced nuclear reactors or solar receivers to drive a two-step cycle involving only H-O-S chemistries. The key component, an SO_2-depolarized electrolyzer, will be designed and tested. The theoretical voltage to electrolyze water is reduced by 85% versus conventional electrolysis through the use of SO_2 depolarization. The electrolyzer development will focus on the adaptation of PEM technology for this new application.

Overall Project Score: 3.5 (5 Reviews Received)



Question 1: Relevance to overall DOE objectives

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

- Determining practicality/feasibility of thermochemical cycle hydrogen production at nuclear plants is an important initiative.
- Preliminary economic analysis indicates that the appropriate cost goals can be met.
- Fully supports the program goals of finding efficient ways to produce hydrogen from non-fossil fuel energy sources.
- This project has excellent alignment. In the end, hydrogen from water is the only option.

Question 2: Approach to performing the research and development

This project was rated **3.6** on its approach.

- Solid plan for the project, utilizing baseline flowsheets, AspenPlus software, advanced electrolyzer and PEM technologies, and small-scale testing.
- The project incorporates both past work and parallel on-going efforts, resulting in a high value-added for a relatively small investment.
- Process design flowsheeting and optimization is a key early in moving this technology option forward. Next natural step is to experimentally determine performance parameters of electrolyzer, as is planned.
- Focus includes experimental aspects of electrolysis applied to this process -- this is good and borrows from PEM development.
- Focus also includes modification of flowsheet to improve process efficiency.
- A key aspect is the decomposition of H_2SO_4 and the amount of SO_3 produced vs. SO_2. Even at 950ºC, 5 to 8 % SO_3 is formed based on thermodynamics. More emphasis should be placed on developing an understanding of this unit operation.

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

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

- DOE/NE getting excellent value for relatively small project investment.
- To overcome barriers, this work will have to be followed by more expensive testing and development work.
- Preliminary analysis indicates that the hybrid process has significant economic advantages.
- Process optimization is largely complete, and electrolyzer testing is just getting ready to start. Technical progress seems in line with project funding to date.
- Simulations completed for process, including various process options.
- Experiments started for electrolysis unit.
- Updated calculations made for efficiency and cost.

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

This project was rated **3.6** for technology transfer and collaboration.

- System in place to share/exchange information with other projects using PEM technology.
- Collaborating with University of South Carolina, which is funded from sources outside the project?
- There are multiple collaborators that are helping to accelerate progress.
- Well-integrated with related work
- PI has appropriate expertise and experience to integrate past work and related on-going efforts into this project.
- Good mix of University, Industrial, and National Lab collaborators. Major collaboration with Proton Energy Systems on electrolyzer design and construction. Not clear what role of University of South Carolina has (but reviewer did not probe this area).
- Appeared to have good collaboration with partners, e.g. interacted with GA on S-I base and with partner to incorporate PEM knowledge with electrolyzer.

Question 5: Approach to and relevance of proposed future research

This project was rated **3.2** for proposed future work.

- Next step will require $2.5 million from industry and $1 million from DOE.
- Will be at least a brief break between completion of this work and beginning of follow-on phase.
- The proposed plan is appropriate.
- The suggested budget (increase of a factor of >10) seems optimistic.
- Path forward in electrolyzer testing is clear and relevant to program goals. Would be nice to see more detail on how researchers plan to characterize electrolyzer degradation modes in testing program.
- Future research is to experiment with the electrolyzer which is the right thing to do.
- Knowledge on efficiency and cost needs updated as progress is made.

Strengths and weaknesses

Strengths

- Effectively using models, experiments to perform sensitivity analyses and trade-offs.
- Economic analyses have benefited from involvement of multiple organizations -- General Atomics, Entergy, Bechtel, PEM cell manufacturers.
- Experimental setup for electrolysis using latest from PEM knowledge.
- Updated flow sheets with improved efficiency and economics.

Weaknesses

- Project utilizing a large number of contributors from Savannah River, each contributing a portion of his or her time. Increases the management challenge.
- Need to pay more attention to the H_2SO_4 dissociation and developments being made in the catalysis area. This aspect of the process seems to be neglected, or at least assumed solved or a non-issue.

Specific recommendations and additions or deletions to the work scope

- Consider partnering with someone doing work with the catalytic H_2SO_4 decomposition step.

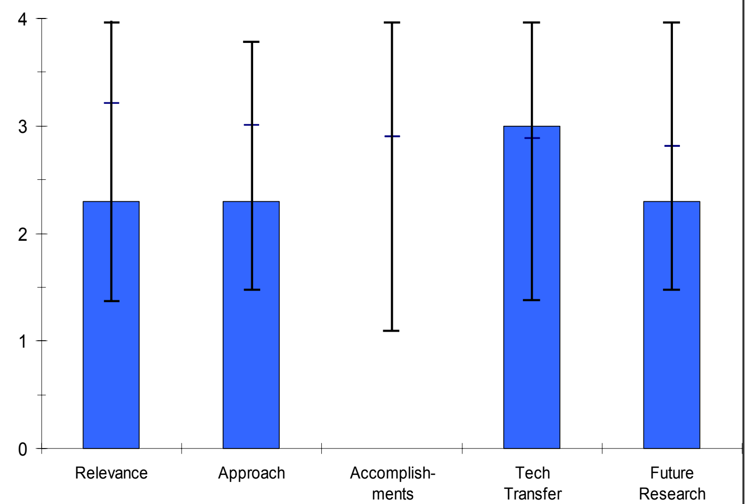
Project # PDP-46: Combined Reverse-Brayton Joule-Thompson Hydrogen Liquefaction Cycle

Shimko, Martin; Gas Equipment Engineering Corporation

Brief Summary of Project

In this project, Gas Equipment Engineering Corporation will design and demonstrate a novel hydrogen liquefaction cycle using multiple turbo-expander stages that combine the reverse brayton and joule Thompson cycles in a unique configuration. A small-scale pilot plant (several hundred kg/day) will be built that will be both a hardware demonstration and a model for scaling to larger plant sizes (>50,000 kg/day). A key component that will be developed in this project is a custom-designed foil-bearing turbo-expander.

Overall Project Score: 2.4 (4 Reviews Received)



Question 1: Relevance to overall DOE objectives

This project earned a score of **2.3** for its relevance to DOE objectives.

- Reducing cost of distributed hydrogen liquefaction.
- Pilot for medium sized fuel station, with scalability.
- No cost target, only minimization, and no reference costs with existing technology.
- This project is directed toward overcoming barriers to economic hydrogen liquefaction.
- The poster did not clearly address relevance to DOE program goals, although more efficient liquefaction technology would clearly be advantageous.
- Technology to increase liquefaction efficiencies important to delivery.

Question 2: Approach to performing the research and development

This project was rated **2.3** on its approach.

- Twin turbo expander-compressors.
- Build small scale pilot plant at 200-500kg/day of hydrogen.
- Scalable to >50,000kg/day of hydrogen.
- Targeting for capital and operating cost and power requirement reductions.
- The approach was not adequately defined, but this is likely because the project is not yet funded. The advantages of this approach are not clear.
- The project proposes starting with a small scale to match initial forecourt refueling station size but this presents cost and scale down efficiency challenges. It is not clear that small scale is the correct application.

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

This project has not started and therefore was not scored on technical accomplishments.

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

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

- Good transfer of technology from existing air separation technology.
- Would benefit with a hydrogen production collaborator, to match characteristic for effective operation at a pilot scale.
- Collaborations are appropriate.
- The existing partners are complementary.

Question 5: Approach to and relevance of proposed future research

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

- Simple project schedule provided is adequate, but could provide more detail.
- Pressure of input stream not specified.
- Unclear on how the decision points will work shown with an asterisk on the project schedule.
- All work is future research. Work plan is reasonable.
- A more complete description of expected outcomes and future plans needs to be put in place to judge progress.

Strengths and weaknesses

Strengths
- Addresses costs of liquefaction with an existing technology.
- Could provide storage alternative for storing distributively produced hydrogen at fuel stations.
- Team appears to have adequate experience in this area.

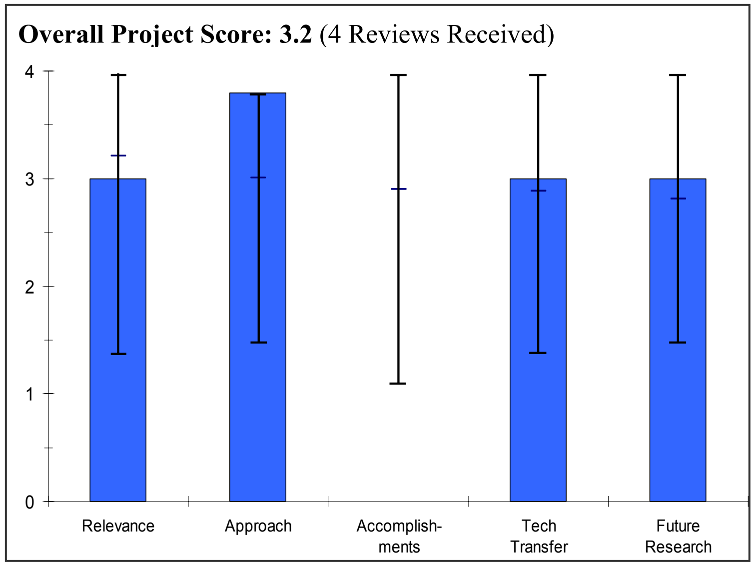
Weaknesses
- Poster does provide enough project detail to evaluate.
- Logic for large scale liquefaction not well understood.
- No cost targets or quantification of cost reduction.
- It is not clear that this project will result in any liquefaction breakthroughs.

Specific recommendations and additions or deletions to the work scope

- Provide additional justification with quantification of targets and detailing of plans.
- Add a hydrogen consumer as a project partner.
- Specify target pressure for hydrogen input stream.
- Need well defined criteria for decision points and go/no-go milestones.
- Given that turbo-expanders are not new, it is not clear that this is a 'research' project, more of a development/new application for an existing technology.
- It would be helpful to have included a technology/literature survey for existing uses and applications of turbo expanders (especially) to ensure no duplication of effort and a good knowledge of existing technology.
- It was not clear how long this program is expected to last and there was no indication of likely economics.

Project # PDP-47: Active Magnetic Regenerative Liquefier (AMRL) Development
Thompson, Robert; New Concepts Research Corp.

Brief Summary of Project



This project uses a novel liquefier that has the potential to simultaneously increase thermodynamic efficiency and reduce capital costs. The active magnetic regenerative liquefier uses an array of discrete magnetic refrigerants in a periodic heat exchanger to accomplish extremely efficient liquefaction of hydrogen. When such an array of solid refrigerants is combined into a highly effective regenerator with excellent heat transfer, low-pressure drop, and low longitudinal conduction, the potential for an extremely efficient regenerative refrigerator and/or liquefier is created. The capability to directly couple the magnetization of a working magnetic material within a regenerator unit with the simultaneous demagnetization of a working magnetic material within the same active magnetic regenerative refrigerator allows distributed work input and recovery from near-ambient temperature to cryogenic temperatures as low as ~20ºK. By using these coupled magnetization-demagnetization refrigerants, the net of work input is reduced substantially to that required for a very efficient refrigeration cycle, regardless of the temperature span of the liquefier.

Question 1: Relevance to overall DOE objectives

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

- Addressing technology, efficiency and capital.
- Needs to address capital and operating costs.
- Volume target 30 MT of hydrogen/day scale up not discussed.
- 25-35% improvement in electrical efficiency.
- A cost target for the liquefaction alone should have been included.
- Addresses liquefaction for distributed hydrogen system.
- Focused on reducing cost and increasing efficiency.
- The project addresses one component of the DOE Hydrogen Program delivery objectives.
- Liquefaction critical technology for delivery.

Question 2: Approach to performing the research and development

This project was rated **3.8** on its approach.

- Analyze design lab scale prototype (10-20 kg/day).
- Build and test first stage.
- Complete prototype.
- Use oscillating magnetic field to alternately stimulate molecules and remove heat; multiple stages to achieve liquefaction.
- Approach is radically different from the other liquefaction project.
- Barriers are understood.
- Project is designed to address the critical-path barriers first.

- The program delineates the tasks to be completed in a thorough manner.
- Status of the work and activities completed to date are listed and suggest a good start.
- Novel, high risk approach.
- Potentially breakthrough technology.

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

This project has not started and therefore was not scored on technical accomplishments.

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

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

- Predominantly technology companies.
- Canadian and American Involvement.
- Partnership with a liquid hydrogen distributor or consumer would be useful.
- Project could explore the possibility of partnering with a university with complementary (magnetic or liquefaction) experience.
- The project partners appear to be sufficient for the work proposed.
- Some industrial. Might benefit from some academic partners.

Question 5: Approach to and relevance of proposed future research

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

- Project is well thought out.
- Stop point after validation of single stage.
- A Gantt summary of the referenced MS Project plan would have been a useful addition.
- Specific discussion of price and scale-up progress evaluation should be included in the plan.
- Future work is appropriate.
- Milestones were not presented -- go/no-go decision points and criteria for making these decisions should be part of the planning.
- It is too early to say whether the proposed work will be appropriate.
- First stage in year one is a good goal. Ambitious schedule to complete liquefaction system within project scope.

Strengths and weaknesses

Strengths
- Key technology regarding liquid hydrogen.
- Focused approach and project plan.
- Off to a good start.
- Unique approach.
- Investigators seem to have a solid understanding of what is needed for the project to be successful.
- The application of magnetic refrigeration builds off existing natural gas liquefaction work.
- Novel approach. Good team.

Weaknesses
- Poster did not address breakdown of costs.
- Volume target unclear and no discussion of scale-up.
- The future work presented did not contain adequate detail.
- The project should prepare some early economics to guide decision making.

Specific recommendations and additions or deletions to the work scope

- Run project through H2A to verify target hydrogen price.
- Verify volume target volume: 30 MT hydrogen /day
- Since magnetic liquefaction is already a proven technology for liquid natural gas production, it might be asked why this project is being supported as it is essentially a development project to extend the technology to another related application.
- On the other hand a cheaper and more efficient liquefaction technology could be very valuable to the hydrogen economy.

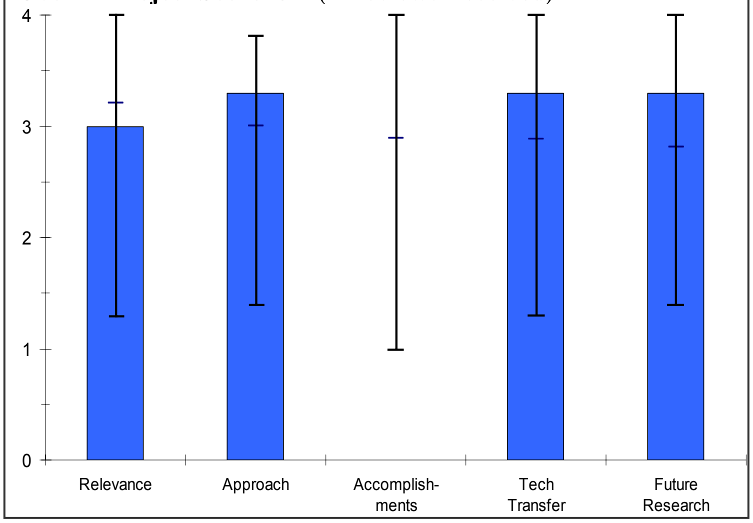
Project # PDP-48: Hydrogen Embrittlement of Pipeline Steels: Causes & Remediation

Sofronis, Petros; University of Illinois

Brief Summary of Project

Hydrogen is a ubiquitous element that enters materials from many different sources. It almost always has a deleterious effect on material properties. The goal of the proposed program is to develop and verify a lifetime prediction methodology for failure of materials used in pipeline systems and welds exposed to high-pressure gaseous environments. Our approach integrates mechanical property testing at microscale, microstructural analyses, and transmission electron microscopy observations of the deformation processes of materials at the micro- and nano-scale, first principle calculations of interfacial cohesion at the atomic scale, and finite element modeling and simulation at the micro- and macro-level.

Overall Project Score: 3.2 (4 Reviews Received)



Question 1: Relevance to overall DOE objectives

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

- This project is aligned with the President's vision for a hydrogen economy.
- Supports an aspect of the delivery program -- metal issues and potential for use of steel pipelines for hydrogen duty.
- Pipelines critical to delivery effort.
- Embitterment problem needs to be understood.
- Critical for delivery using pipelines.
- Developing necessary understanding for hydrogen embrittlement in pipelines along with the potential to develop methods for mitigation through the future planned coatings work.

Question 2: Approach to performing the research and development

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

- The approach is well-thought out and addresses a key barrier in the use of the existing natural gas infrastructure for hydrogen delivery.
- The project objectives are thorough although many must be well understood already through prior work.
- Great expertise in fundamentals of hydrogen in steel. Project will build on researcher's expertise.
- Inclusion of fundamental simulations will aide project.
- The bulk of the work focused on microscopic investigations of embrittlement.
- A mechanistic model has been formulated.
- Includes finite element modeling.

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

This project is just starting and therefore was not scored on technical accomplishments.

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

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

- Have a good team assembled including end users.
- The participants bring a good mix of skills and knowledge.
- Good relations with steel/coating companies.
- The partner base appears to be strong and should facilitate technology transfer.
- Because this project just started, there was little objective evidence for extensive collaboration to date.
- The future work appears to involve significant collaboration.

Question 5: Approach to and relevance of proposed future research

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

- Proposed research is on target.
- The proposed plan appears to be a logical extension of the program tasks.
- Good plans for extending knowledge to pipeline steels and broadening knowledge base for hydrogen steel interactions.
- Future work to include permeability studies on coatings.

Strengths and weaknesses

Strengths
- Collaborative team.
- Technical expertise.
- Fundamental experimental capability.
- Understanding embrittlement in pipelines is critical for hydrogen delivery and infrastructure. This work is a new start (4/30/05). Excellent progress has already been made. A mechanistic model has been formulated. The PI is well qualified for the work and a strong team that should lead to excellent collaborations has been established. Future work plans include studies to identify coatings with low/minimal hydrogen permeability.

Weaknesses
- None identified. Project is a new start.

Specific recommendations and additions or deletions to the work scope

- There are many similarities to two other projects reviewed, PD-33 and PD-35, and the projects should be coordinated.
- Much of this knowledge must exist already in the steel and pipeline industries since hydrogen pipelines already exist without apparent problems. Use should be made of that knowledge in this program.
- Coatings seem to have a fundamental practical problem inasmuch as they have to be applied at the mill and retain their integrity during field installation. An assessment should be made of the value of this work through quantification of the size of the problem in the field to see if anything beyond current technology is needed.
- Needs to stay close to applied researchers and make sure that learning's are applied
- None identified. This project just started in 4/30/05

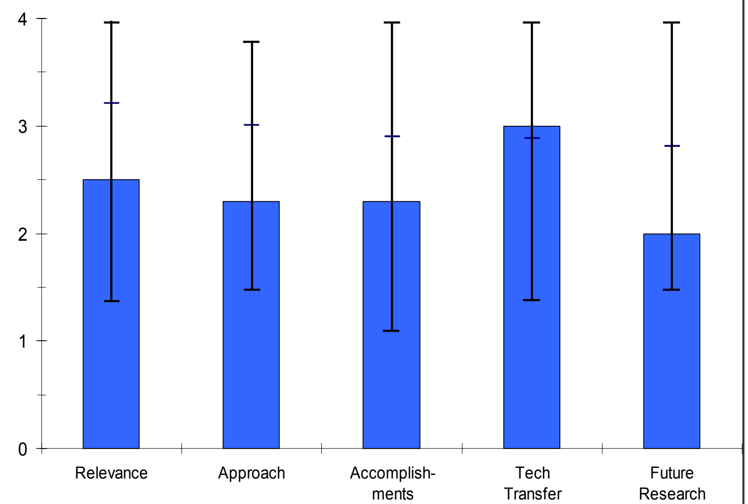
Project # PDP-49: Hydrogen Regional Infrastructure Program in Pennsylvania

Schumer , Eileen; Concurrent Technology Corp.

Brief Summary of Project

This Concurrent Technology Corporation program will undertake R&D in hydrogen delivery, hydrogen storage, and hydrogen sensing. Specifically, these R&D areas include: new and advanced materials for use in hydrogen pipelines and off-board compressed gas storage tanks, including testing and modeling of their lifetime performance; modeling of flow stratification in pipelines; gas separation technologies to separate hydrogen from its mixtures with natural gas; and hydrogen sensor development for leak and bulk concentration determination. Additionally, a hydrogen delivery tradeoff study will be conducted to determine the most attractive approach(es) for delivering hydrogen fuel, using Pennsylvania as a case study.

Overall Project Score: 2.4 (4 Reviews Received)



Question 1: Relevance to overall DOE objectives

This project earned a score of **2.5** for its relevance to DOE objectives.

- Hydrogen delivery and transport are important aspects of the hydrogen infrastructure.
- The project appears to be trying to meet too many objectives -- pipelines, storage tanks, demand forecasting - yet focuses on Pennsylvania, which may not be a realistic proxy for a U.S. rollout such that findings may not be transferable.
- Understanding the potential of the current infrastructure and materials issues associated with hydrogen delivery important.

Question 2: Approach to performing the research and development

This project was rated **2.3** on its approach.

- Mixing hydrogen/natural gas in a pipelines will add costs of separation to the hydrogen costs which are too high already.
- Advantages relative to distributed reforming from natural gas are not apparent.
- Hydrogen sensors for hydrogen-in-air and hydrogen-in-methane are already available.
- Again, the project has too many activities that do not appear to have clear relevance to achieving the program objectives, e.g., regulatory/utility issues, demand scenarios, hydrogen recovery from mixed natural gas/hydrogen pipelines, and operational effects of mixed gases for customer use in appliances is not addressed at all.

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

This project was rated **2.3** based on accomplishments.

- Have made progress identifying current pipeline materials and leak sources.
- Results seem to suggest that 50% hydrogen losses could still be cost effective; this is improbable since it would double the cost of delivered hydrogen above that for pure hydrogen delivered by pipeline.

- Program has only been in place a short time
- Considerable work has been accomplished, but it is difficult to see that much is of specific use toward addressing the stated objectives.
- Started in November 2004. Only 10% complete
- Work to date on data gathering and assessment.

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

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

- Involvement of Air Products brings a lot of hydrogen experience to the table.
- An extensive array of stakeholders/collaborators are shown but it is hard to understand what input they have provided, leading one to suspect that most are there in name only.
- Team has incorporated good partners.
- The key collaboration is with Air Products which has a large R&D (and presumably assessment) portfolio for hydrogen science and technology.

Question 5: Approach to and relevance of proposed future research

This project was rated **2.0** for proposed future work.

- Addressing issues such as hydrogen-in-air sensors which have already been developed.
- The project should focus on a smaller set of achievable deliverables, e.g., hydrogen/natural gas mixtures and effects in existing systems, not steels and storage tanks.
- Few details of the proposed future experimental work were provided.

Strengths and weaknesses

Strengths
- Collaboration with Air Products.
- Understanding the potential and limitations of current pipeline infrastructure for hydrogen delivery along with methods to improve it are important. The collaboration with Air Products which has a large R&D portfolio in hydrogen science and technology could be a strength to this program as the experimental program evolves.

Weaknesses
- Hydrogen costs should increase substantially due to additional separations costs.
- The project seems to be trying to be all things to all people without clear focus on a more manageable set of deliverables.
- The exact experimental program to be established was not presented in sufficient detail to fully assess. The project funding is considerable, so it will be important that this program is focused on specific critical barriers to delivery.

Specific recommendations and additions or deletions to the work scope

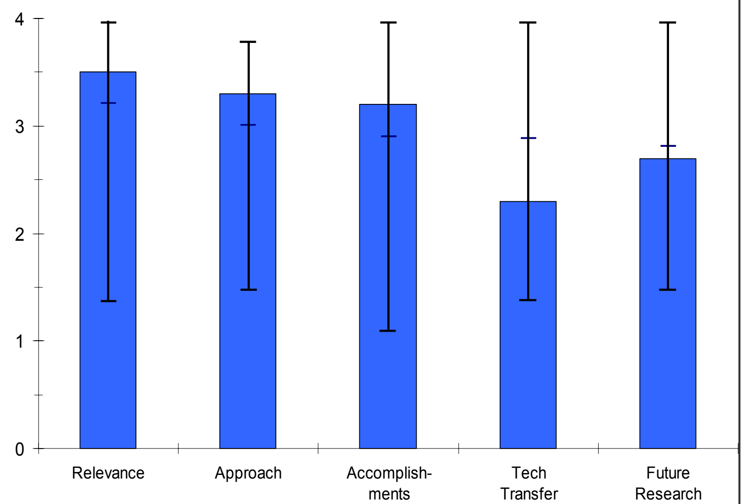
- Look at potential for using pipelines for pure hydrogen and time separated flows (with "pigs" in between), these would be preferable to mixing natural gas and hydrogen. (This is possible with gasoline, may not be possible in gas pipelines). May get some mixing, but should be more cost effective than total mixing.
- The presenter was not able to explain a direct path of transferability of the findings from this project to the rest of the USA; in fact, indicating that there are quirks to the Pennsylvania situation that make it less transferable than might be thought.
- In answer to a question as to why the utility companies were apparently not interested in having hydrogen in their natural gas pipes, the response was that they are interested, but the distribution system cannot take the higher pressures needed to maintain the energy flow with the lower density hydrogen in the system without expensive system modifications to update facilities and continue to meet applicable codes. Even so, the project seems to be ignoring this information and carrying on assessing hydrogen/natural gas mixtures regardless!

Project # PDP-55: Distributed Bio-Oil Reforming
Evans, Bob; National Renewable Energy Laboratory

Brief Summary of Project

In this project, the National Renewable Energy Laboratory is developing the necessary understanding of the process chemistry, feedstock compositional effects, reactor configuration, catalyst chemistry and deactivation and regeneration strategy as a basis for process definition and assessment for automated distributed reforming of whole bio-oil.

Overall Project Score: 3.1 (6 Reviews Received)



Question 1: Relevance to overall DOE objectives

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

- Fuel Processor improvements: capital, manufacturing, operation.
- Addresses feedstock and catalyst issues.
- Target $3.60/gge.
- Target volumes not addressed.
- What range of bio-oils is addressed?
- Project aligns with President's hydrogen fuel initiative and offers a renewable hydrogen source.
- Project applies to the distributed reforming of renewable liquids goals in the RD&D plan.
- The project objectives are clearly stated and fit with program goals.
- Enabling the fueling of 300 cars per day is a great means to support the President's initiative.
- Plausible pathway for renewable hydrogen generation.

Question 2: Approach to performing the research and development

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

- Add methanol to pyrolysis generated bio-oil and steam reform resulting vapor.
- Identify candidate bio-oils.
- Identify candidate catalysts.
- Fluidized bed reactor adds complexity and cost to the system which may not be needed.
- Autothermal reforming in a fixed bed should address coking problems with proper conditions now that the feed is bio-oil rather than bio-solids.
- Apparently competitive with other renewable liquids that can be reformed, such as ethanol. Distributed reforming barriers are addressed.
- The approach is concise and focused and includes taking note of existing work already compiled.
- Future plans through volatilization, etc. seem to be in the right direction toward a successful project extension.
- Logical.

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

This project was rated **3.2** based on accomplishments.

- Recently started.
- Initial work completed.
- Past work reviewed.
- Successful short (6 hour) runs with NREL catalysts.
- Preliminary statistical analysis of short runs provides guide to sensitivity. Sensitivity chart on the poster was very confusing needed more labeling, and better alignment of data with the tornado chart.
- Statistical method does not correlate factors affecting performance need to include interactions.
- Catalysts selectivity to hydrogen is low, with very high methane production after short periods on-line, indicating catalyst deactivation.
- New project with new concept, but it draws on prior work done on bio-oil reforming for central production.
- Catalyst characterization appears effective in identifying important variables.
- Catalyst behavior needs to be studied for a longer period of time than the period of the order of 10 hours addressed.
- Sensitivity analysis on system parameters was very convincing.
- Getting biomass into a transportable friendly state such as a liquid seems a key to any large scale use of bio-derived hydrogen.

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

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

- Adequate collaboration.
- Would benefit from a commercial partner.
- Would benefit from university collaboration.
- Does not appear to be any collaboration at this point.
- Could coordinate with projects doing biomass feedstock analysis to address any potential feedstock issues.
- A number of pyrolysis, biomass processing companies/technologies exist. The project does not appear to have made any effort to collaborate with other knowledge sources.
- Coordination of activities needs to be spelled out more specifically.
- Look for industry participants.

Question 5: Approach to and relevance of proposed future research

This project was rated **2.7** for proposed future work.

- Develop low-temperature system and improve catalysts.
- Study factors affecting costs, volumes, and by-products.
- New configuration with reaction engineering.
- Long term bench testing.
- Good project plan.
- Pilot will need to improve catalyst regeneration strategy. Bench process uses discrete manual swaps of the catalyst, not supportive of long runs.
- Homogeneous catalytic partial oxidation of these oils should be more difficult than heterogeneous. Suggest focus on heterogeneous catalysis and optimizing conditions of temperature, H_2O:C and O_2:C to minimize carbon formation.
- Builds on prior work. Need a go/no-go upon determination of ability of technology to meet DOE goals.
- The FY05 budget is only $100K and there is no mention of succeeding years, yet the forward plan goes out to 2010 -- is there a mismatch here?
- The plan is good, but specific details need to be discussed.
- Logical path.

Strengths and weaknesses

Strengths

- Establishes a process for combined gasification and reforming of bio-oil.
- Initial short run work encouraging.
- Methanol can be biomass sourced for an all bio, emissions neutral system.
- Provides an alternative renewable liquids option besides ethanol reforming.
- Factor analysis comparison for catalyst operation.
- New approach through volatilization and oxidative cracking seems to be promising.
- Pragmatic.

Weaknesses

- Uses a narrow range of feedstock sensitivity to boil-oil variety issues such as feed source, hydrocarbon composition, and contaminants.
- Need to develop catalyst regeneration strategy.
- Lack of collaborations is a major weakness.
- Effect of bio-oil composition and characteristics on catalyst behavior needs further investigation.
- A more detailed plan is needed on issues such as oxidative cracking kinetics, catalytic oxidation mechanisms, etc.
- Needs funding support to continue the pace.

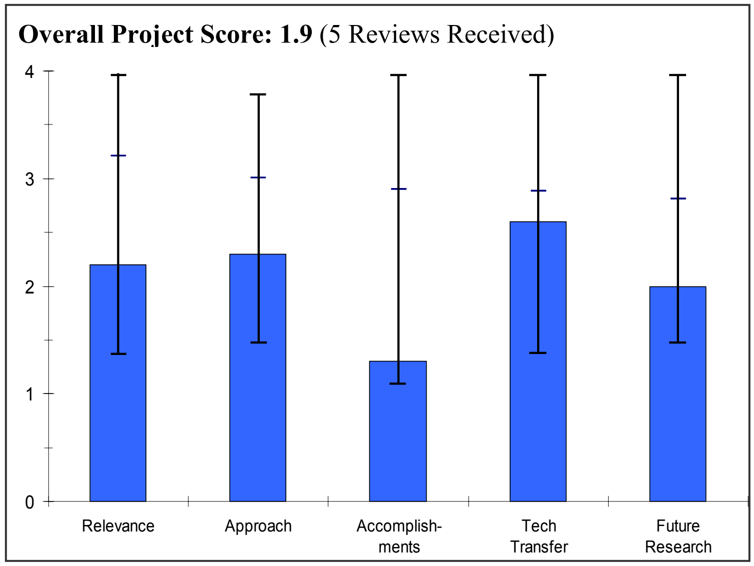
Specific recommendations and additions or deletions to the work scope

- Add a project stage to determine sensitivity of bench unit to variations in bio-feed.
- Improve the statistical analysis by including interactions between factors.
- Collaboration with a catalyst company dealing with reforming catalysts such as Sud Chemie, Johnson Mathey, etc. would help catalyst development work. Development with model compounds may help improve understanding.
- Would like to see discussion of how bio-oil would be delivered for hydrogen production on a distributed basis, and the associated cost.
- The project does not seem to have any unique elements that make it specific to NREL. Catalyst/reformer companies are already out there that could do this work.
- Address the weaknesses mentioned above and design the collaborative research plan (e.g. university involvement) toward addressing these weaknesses.

Project # PDP-57: Developing Improved Materials to Support the Hydrogen Economy
Martin, Michael; Edison Materials Technology Center

Brief Summary of Project

The Edison Materials Technology Center will solicit and fund hydrogen infrastructure related projects that have a near term potential for commercialization. The subject technology must be related to the DOE hydrogen economy goals as outlined in the multi-year plan titled, "Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan." Preference will be given to cross cutting materials development projects that lead to the establishment of manufacturing capability and job creation.



Question 1: Relevance to overall DOE objectives

This project earned a score of **2.2** for its relevance to DOE objectives.

- The project proposes to identify and initiate a series of small projects addressing hydrogen and fuel cells technical needs.
- Earmark to Ohio based non-profit Energy Materials Technology Center.
- Orientation is too near-term and for commercialization and job creation.
- Only a part of activity need be hydrogen related.
- While this process has its merits, it does not align with DOE goals, which are longer range and more likely to result in a significant improvement to energy system.
- Materials progress might be supportive of DOE objectives.
- Most of the projects funded via EMTEC do not appear focused on significant challenges to the industry, but rather near-commercial technology.
- Project marginally relevant. Subprojects funded within it seem of little importance to the overall DOE Hydrogen Initiative.

Question 2: Approach to performing the research and development

This project was rated **2.3** on its approach.

- Solicit and evaluate projects, then manage technology projects – this duplicates process already accomplished by a number for federal agencies.
- Project puts out its own solicitations, does own reviews, has awarded five projects so far, and will do another RFP soon.
- Awards are made on the basis of near term commercialization and job creation potential.
- EMTC is strictly a managing function with no major assets.
- Access to facilities through diverse membership.
- The collection of projects makes little impact on the DOE barriers.
- Appears to be duplicating DOE functions.

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

This project was rated **1.3** based on accomplishments.

- Slow progress toward identifying and selecting progress. Only seven projects funded after over a year.
- Five project awards to-date: nanocatalyst development, spiral stackable reactor, hydrogen sensor, integrated photovoltaic/electrolysis, solid state welding with hydrogen storage potential.
- This is not really a technical accomplishment. Is hard to rate versus DOE goals, as DOE metrics are not included in the poster.
- Need to identify how the project is moving towards meeting DOE targets.
- Technical achievements interesting by themselves but not clear how they fit into the overall hydrogen program.

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

This project was rated **2.6** for technology transfer and collaboration.

- Interactions/coordination primarily with in-state (Ohio) support organizations. Seven projects negotiated and funded.
- Potential for collaboration is impressive, based on the poster, including State of Ohio, USAF, AFRL and a membership with over 100 industry, university, and government members.
- These provide access to $2B in state-of-the-art facilities.
- Collaboration experience in ceramics, metals, polymers, and many material processes.
- There needs to be more focus on transferring technology from the EMTEC projects into other DOE projects.
- Edison Materials Technology Center is doing a good job of driving projects to results. This is something lacking in academic and national lab environments where the trend is so much research for research sake.
- Not much technology collaboration can be noted. It appears that different parties are working on totally unrelated subprojects within this project.

Question 5: Approach to and relevance of proposed future research

This project was rated **2.0** for proposed future work.

- Continuation of identification and project selection process, primarily of projects as they are funded.
- Specific research is not being proposed here. Rather, RFPs call for projects meeting the general criteria and a review process to award contracts.
- Difficult to evaluate the RFP/award process, though projects may ultimately be supportive of the Program.
- Unclear directions for future research. There seems to be no strategic research direction. Subprojects are not connected to each other. Despite proclaimed focus on biomass and coal, no subprojects actually address these areas.

Strengths and weaknesses

Strengths
- Orientation toward near term goals and job creation.
- Organization has a track record of energy and materials related projects.
- A different approach toward awards may provide lessons for all.
- Variety of technologies funded.
- The strength of the center is in collaborating with different groups to focus their research efforts on results.

Weaknesses
- Is potentially another layer through which researchers and developers must navigate.
- Little focus on DOE barriers and targets.
- No guiding logic behind project choices.
- Disjointed effort.

Specific recommendations and additions or deletions to the work scope

- Consider funding fewer projects at higher funding levels. Present funding levels may be too low to expect meaningful technical results capable of commercialization with marketable products.
- Alignment of the DOE goals of the awarded projects should be required.
- EMTC should coordinate awards with DOE to avoid duplication and conflict.
- Align funded projects to solve problems which are encountered in other hydrogen programs and transfer technology to those programs.
- More work on biofuels and coal-to-hydrogen.