

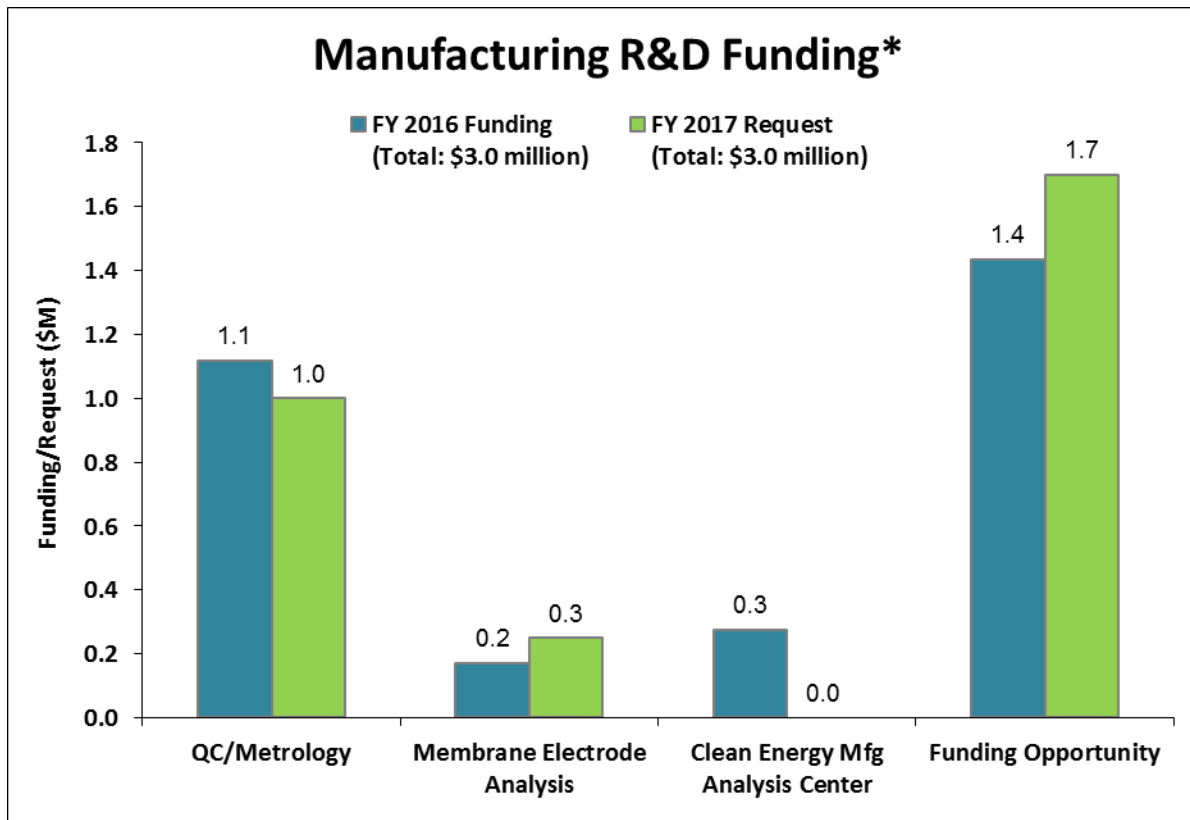
## 2016 — Manufacturing Research and Development (R&D) Summary of Annual Merit Review of the Manufacturing R&D Program

### Summary of Reviewer Comments on the Manufacturing R&D Program:

In general, the reviewers felt that there was great potential in breaking through the manufacturing R&D barriers and challenges that the U.S. Department of Energy’s Hydrogen and Fuel Cells Program faces. They commended the program for having projects that are well structured, effective, and significant in reaching goals and milestones. In particular, they recognized the Hydrogen Fuel Cell (HFC) Nexus website, which was established to provide product information on hydrogen and fuel cell components and systems to the entire community, thereby enhancing domestic supply chains and enabling further widespread commercialization of hydrogen and fuel cells. One key recommendation was further exploration of the differing assessments of manufacturing readiness by original equipment manufacturers and Tier 1 suppliers.

### Manufacturing R&D Funding:

Funding for the Manufacturing R&D program was \$3 million for fiscal year (FY) 2016, and \$3 million was requested for FY 2017. In FY 2016, funding is provided to continue existing Manufacturing R&D projects for quality control (QC)/metrology and membrane electrode analysis in addition to projects from funding opportunities. The FY 2017 request-level funding will continue existing Manufacturing R&D projects and provide funding for new projects through a competitive funding opportunity announcement, subject to appropriations.



\* Subject to appropriations, project go/no-go decisions, and competitive selections. Exact amounts will be determined based on research and development progress in each area and the relative merit and applicability of projects competitively selected through planned funding opportunity announcements.

**Majority of Reviewer Comments and Recommendations:**

This year, 5 projects funded by the Manufacturing R&D program were presented and reviewed. The reviewers' scores ranged from 2.8 to 3.5.

**QC/Metrology:** One project was reviewed in the area of QC/metrology, receiving a score of 3.5. Reviewers stated that the approach was very good and that there was little that can be improved upon. They also noted that the project was well-designed to provide quality information on various control technologies. Reviewers stated that the project team has a formidable collection of facilities and people with the highly specific skills required by the task; they see little room to improve the team's collaboration. The reviewers suggested providing a summary chart of inspection techniques, including information such as the target defect or variable, required detection limits, required scanning or detection rate, state of development, and state of adoption.

**Analysis:** Four projects were reviewed, with three projects receiving a score over 3.0 and one project receiving a score of 2.8. The reviewers were impressed by the highest-rated project for the significant progress in establishing a website that provided product information on hydrogen and fuel cell components and systems to the fuel cell community. However, the reviewers expressed concern about maintaining and updating the website once federal funding for the project ends. The reviewers felt that the lowest-scoring project provided an interesting approach to creating and supporting future regional technical exchange centers for manufacturing. However, some reviewers questioned the importance of these centers and the impact on the manufacturing and industrial needs for hydrogen and fuel cells. They noted that the project needed to improve its focus and clearly track the project's impact by further collecting and analyzing other technical exchanges.

## Project #MN-001: Fuel Cell Membrane Electrode Assembly Manufacturing Research and Development

Michael Ulsh; National Renewable Energy Laboratory

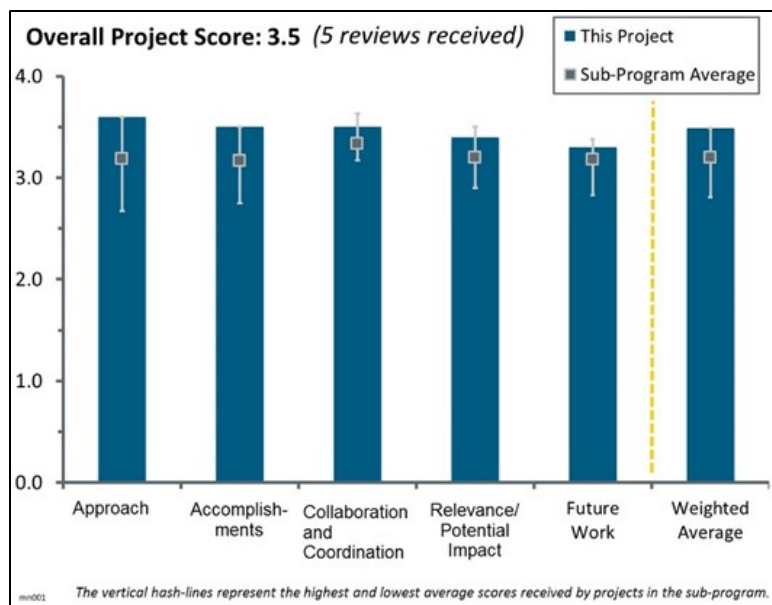
### Brief Summary of Project:

The objectives of this project are to (1) understand quality control needs from industry partners and forums, (2) develop diagnostics by using modeling to guide development and in situ testing to understand the effects of defects, (3) validate diagnostics in-line, and (4) transfer technology to industry partners.

### Question 1: Approach to performing the work

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

- The approach is very good, and there is little that can be improved upon. Convincing industry to open up and adopt project outputs on manufacturing is a difficult task. There is a consistent and concerted effort to engage industry.
- The project is well designed to evaluate various quality control technologies while working with industry, laboratories, and academia.
- Correlating defect parameters with cell/stack performance/degradation is very useful. Identification of dangerous defects would reduce inefficiency and waste related to building stacks with faulty components. Two different complementary approaches to defect detection are being pursued. A table comparing defect parameter ranges with detection capabilities would clarify the status of the project. The evolution of defects during operation needs more consideration.
- The approach slide does not offer much detail, but the first impression is that this is an excellent approach based on the diagnostics and validation. The National Renewable Energy Laboratory (NREL) should continue getting broad industry input and pushing technology transfer. NREL should also consider hosting a workshop for every interested supplier and integrator.
- The NREL work is valuable and interesting. The studies presented at the U.S. Department of Energy (DOE) Hydrogen and Fuel Cells Program Annual Merit Review focused on one barrier—the membrane quality. There are many other barriers, and some of them are equally valuable and interesting. A funded cooperative research and development agreement (CRADA) is in place that involves that emphasis, which is good.



### Question 2: Accomplishments and progress toward overall project and U.S. Department of Energy (DOE) goals

This project was rated **3.5** for its accomplishments and progress.

- Through-plane reactive excitation efforts are showing good progress and potential utility. Technology transfer efforts are improving.
- The progress shown is good.
- Feasibility of the techniques has been demonstrated. Developing a table comparing thickness and defect parameter ranges and detection capabilities would clarify the status of the project. The go/no-go gate has been passed, but the quantitative results relative to significant defects are difficult to decipher.

- It is difficult to evaluate the accomplishments and progress. Clearly, technical results did lead to the “discovery” of polymer film defects, and that was accomplished using several different approaches. Also, it was clear that results were of interest to at least one original equipment manufacturer. Even so, the DOE goals are to enable a fuel cell system, and there are many more issues that were not mentioned that are beyond the narrow focus of this activity.

### Question 3: Collaboration and coordination with other institutions

This project was rated **3.5** for its collaboration and coordination.

- The team has responded to reviewer comments and continued to add and rotate collaborations as needed. There is little room for improvement here.
- General Motors lends reality and credibility to the project. Technology transfer to Mainstream Engineering facilitates scale-up, adoption, and commercialization of the techniques. Other team members provide modeling, fabrication, and cell testing capabilities. The team would be enhanced by the addition of cell component manufacturers.
- The project incorporates useful contributions from industry, national laboratory, and academic partners.
- This NREL activity collaborates with a national laboratory and is integrated with the NREL National Center for Photovoltaics and a few universities. This is considerable “horse power.” The project partners have excellent facilities with highly competent staff. The interactions with 3M, a company with a long history of coating plastic (e.g., Scotch Tape®), are sensible and useful. However, the exact role of the partners was not very clear.
- There is broad involvement. There may be room to identify and include custom membrane electrode assembly (MEA) suppliers.

### Question 4: Relevance/potential impact on supporting and advancing progress toward the Hydrogen and Fuel Cells Program goals and objectives delineated in the Multi-Year Research, Development, and Demonstration Plan

This project was rated **3.4** for its relevance/potential impact.

- This is a quality control activity, which is an essential part of firming up the fuel cell manufacturing base. Durability in fuel cells is a complex issue with many pathways that can lead to early failure. Robust assessment tools are essential and are especially critical in the early phases of commercialization.
- Development of in-line, real-time diagnostics for cell component quality is clearly relevant to improving performance and durability and reducing cost.
- NREL is tackling a variety of manufacturing goals.
- NREL has done excellent technical work. The pathway to industry adoption of the manufacturing tools needs more explanation. It is not clear how the resulting improvements in manufacturing bring down the costs or performance.

### Question 5: Proposed future work

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

- The future work appeared to be a continuation of the current activities. There is a “target of opportunity” approach, identifying technology target areas and then addressing the issues found there. This is a smart way to do this kind of support technology.
- The future work logically continues the approach. The correlation between relevant defects and cell behavior will be elucidated, and modeling will continue. Platinum-group-metal (PGM)-free catalysts will be explored.
- Future work has been planned appropriately; most important, the effects of defects will be included.
- Future work should also include an assessment of benefits and an approach to getting industry adoption. Also, the technology transfer should have a more detailed plan and include more than collaborators.

### Project strengths:

- The project is well run, the principal investigator clearly makes an effort to garner end user input, and the inclusion of project partners is managed well (i.e., included where needed). Technical progress is continuous, and technology transfer is moving forward.
- The formidable collection of facilities and people at NREL is the strength of this project. The tasks require highly specific skills, and few organizations in the United States could address this as well as NREL.
- This project is well designed and executed with pertinent contributions from collaborators.
- The project has great research and development and tools.

### Project weaknesses:

- The team has done a very good job. The only weakness that may exist is the potential for some level of pushing technology, rather than it being pulled from industry as a need. However, this weakness is a stretch. The project has been run very well; every effort seems to be focused on industry needs with periodic validation.
- History shows that the fuel cell stack is quite reliable. Certainly bad things happen when the stack is run under adverse conditions. Hydrogen starvation in the anode is just one example, but a telling one. Like all other “engines,” the fuel cell stack can survive only if operated within a set of appropriate operational parameters. Just like running an internal combustion engine at rotational speeds above the “red line,” a fuel cell stack cannot be expected to work through any number of untoward events.
  - History also teaches that 80% of all fuel cell system issues result from misbehavior of balance-of-plant (BOP) components. Hence, durability is more a function of the BOP than the stack, yet NREL is focusing on the stack. This focus is necessary, especially because industry is so bewildered by that complexity; however, the project would be stronger if some number of BOP and control strategies were included in its emphasis.
  - It is also obvious that the final system design of a fuel cell engine is still to be determined. What DOE has “invented” may have little in common with the future fuel cell electric vehicle power plant. NREL should be chartered to spend some time on alternative system designs. It is important that the power electronics are included in the system—this is a fuel cell–battery hybrid. Consequently, the fuel cell probably does not have to do much load following. It does not have to start up promptly or shut down immediately. It might work intermittently, similar to how photovoltaic arrays operate. It would be unwise to limit the engineering to the problems with the alleged system instead of considering what advances could be made to nullify the technical problems of the existing designs.

### Recommendations for additions/deletions to project scope:

- It would be helpful to see a summary chart of all the methods being developed and considered for development under this project. This summary could include brief information on the target defect or variable, required detection limits, required scanning or detection rate, state of development, and state of adoption. Summarizing the progress in a chart would make it easy for an end user to scan to see if NREL has developed a solution of interest. In addition, the inclusion of potential future methods and defects to be investigated may garner input from end users as to the usefulness.
- The project should conduct industry workshops to distribute this good work to a broader audience beyond the collaborators. The pathway to industry deployment, including costs and benefits, should be assessed.
- The scope should be expanded to the entire fuel cell system, inverter and all. The emphasis should be on the question of what operating parameters can be optimized to keep the fuel cell stack healthy. Also, the fuel cell stack should be considered as a heterogeneous catalytic chemical reactor, and those many, well-established tricks in chemical engineering known to enhance performance and durability need to be evaluated for the fuel cell system case. One of the several “laws” in early times (when the polymer electrolyte membrane technology was a solid polymer electrolyte) was “never put or admit air into the anode.” That could still be an appropriate design consideration.

## Project #MN-012: Clean Energy Supply Chain and Manufacturing Competitiveness Analysis for Hydrogen and Fuel Cell Technologies

Pat Valente; Ohio Fuel Cell Coalition

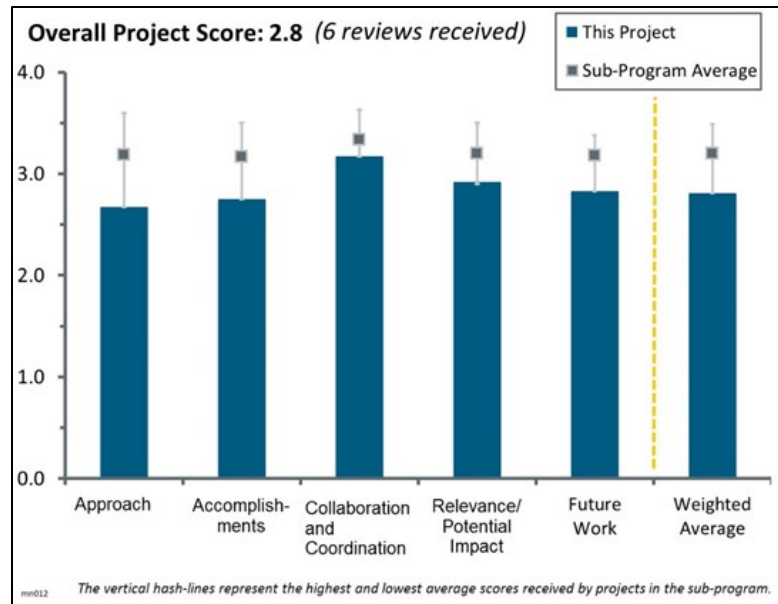
### Brief Summary of Project:

The objectives of this project include the following: (1) establishing regional Technical Exchange Centers to increase communication between original equipment manufacturers (OEMs) and hydrogen and fuel cell component and subsystem suppliers; (2) establishing a readily web-accessible database containing inputs from suppliers and OEMs along with a supplier contact list; (3) standardizing component and subsystem component specifications; and (4) developing strategies for lowering cost, increasing performance, and improving durability of components and subsystem components.

### Question 1: Approach to performing the work

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

- The approach for executing the project's efforts is generally good. A Gantt chart (or similar) would be helpful for the approach and milestones. Consideration should be given to how best to measure the effectiveness or outcomes of the efforts.
- The project stresses creation and support of a "supply chain," an interactive group of companies that produce and sell components for fuel cell systems, with an obvious bias toward those that support fuel cell electric vehicles.
  - The approach is to assemble a group of companies with that common interest and provide information to improve cooperation and coordination among the suppliers. Certainly, creation of a supply chain is an admirable objective. Even so, that task is difficult. Some of the interested companies are competitors. Some may not be prepared for the complexity of this market.
  - There is no apparent effort to match specific, quality companies with potential buyers of the hardware that those assemblers might need. Although some necessary components are not complex (e.g., electrical connectors), other essential fuel cell components may take considerable investment before marketing is possible. An example might be the Eaton Scroll Compressor.
  - The project might include publishing routes in which public money could be available for product development and product improvement.
- The "Approach" slide contained milestones. It would be better if the slide presented the high-level goals, metrics for success, and strategy to get there. The slide should include the success criteria for the regional centers. It is not clear what they will they look like.
- The approach begins with some potential, but it has failed to produce any tangible outcome to date. Holding industry collaboration workshops can produce valuable information and relationships. However, there is little to no indication that anything has been garnered and disseminated from the work to date. Perhaps the groundwork has been laid during year one and future work will yield results.
- The approach of this project was not as focused as the other projects. This project had four completely different objectives while others were far more focused with mainly one objective. The strength of this project is the establishment of technical exchange centers to improve communication. The project should use this strength and leverage other projects for the website and database tasks.





- The regional technical exchange centers are virtual entities that exist only online, so it is not clear why they have regional names; why we need regional centers rather than one online center; and how these centers contribute in developing communications between manufacturers and suppliers, which is one of the key barriers listed.

### Question 2: Accomplishments and progress toward overall project and U.S. Department of Energy (DOE) goals

This project was rated **2.8** for its accomplishments and progress.

- The project has done a good job in establishing a national database center and arranging supply chain exchange and partnership development forums. These address two key barriers: (1) the lack of a national database and (2) the lack of communication between suppliers and manufacturers. However, the importance of regional exchange centers is perhaps overstated.
- The accomplishments for the first objective are excellent, with the October 22 and May 5 events and plans for the next event in Ohio. The plans for accomplishments for the second objective are credible, with the database being designed to be compatible with MN-013, the Virginia Clean Cities project. However, there was little presented on the other two objectives. There was no discussion of the status of the working groups, who the members are, and how the project plans to identify pathways to standardization of components and subsystems. It was also unclear what is being done to lower cost and increase performance and durability of components and subsystems.
- The project has made acceptable progress toward its goals. Better correlation of the project's goals to DOE goals is needed.
- Some companies are showing interest. Even so, the largest fuel cell trade show is the Fuel Cell Expo in Tokyo, which attracts about 30,000 individuals. One has to start somewhere; however, it seems that interest is modest.
- The project has executed tasks to improve communication between OEMs and suppliers. However, there is no indication of progress measured against performance indicators. It is not clear what the performance indicators are. To date, none of the milestones listed on slide 7 has been completed, even though some were scheduled for the first and second quarters of the project. It is not clear if there were unforeseen hurdles; the presentation does not indicate so. The project has failed to even produce a brochure within the first nine months of operation.
- More time is needed to assess accomplishments and progress.

### Question 3: Collaboration and coordination with other institutions

This project was rated **3.2** for its collaboration and coordination.

- The collaboration with MN-013, Virginia Clean Cities, is excellent. The project outreach to suppliers and OEMs is great. Collaboration with MN-014, GLWN, has potential to benefit both projects. It would also be informative to see the budget distribution between the various collaborators/partners.
- The project appears to include collaborations across multiple organizations and has organized industry-wide sessions.
- Partners have appropriate breadth and depth of experience to support this project.
- There is great collaboration, at least as in regard to the project participants.
- The principal investigator (PI) seems connected with others who are doing similar activities in other sections of the United States. The lack of any interactions with universities is puzzling. It would make sense to tie in with engineering programs that emphasize manufacturing technology. The thrust seems centered on the fuel cell stack, which is fine. However, that stack involves the assembling of a large number of replicated parts, and the most likely on-ramp may be to break-in with some necessary component of the larger product.

#### Question 4: Relevance/potential impact on supporting and advancing progress toward the Hydrogen and Fuel Cells Program goals and objectives delineated in the Multi-Year Research, Development, and Demonstration Plan

This project was rated **2.9** for its relevance/potential impact.

- The project addresses key barriers required for manufacturing cost-effective fuel cells outside the technical research and development issues.
- The potential for this project to have an impact is high. However, the project needs to do a better job of tracking this impact. Having the technical exchanges is excellent. However, the project needs to identify outcomes from these exchanges that are benefiting the Hydrogen and Fuel Cells Program (the Program). The working groups could have high relevance to the Program if they have the right people in them and if they can identify ways to lower cost while improving or maintaining performance and durability.
- DOE appropriately is encouraging a build-out of the manufacturing base of clean technology, such as fuel cells, which could be a primary plank of the global 21st century economy. Getting a piece of the action involves building up a credible technical manufacturing base. Creating supply chains is one approach.
  - There seems little question that, globally, clean technology hardware is a huge business—the value of photovoltaics and wind power equipment is obvious. The real concern is market share.
- This project should be very relevant, but a set of better-defined success criteria would be helpful.
- The project intent appears to align with the Program objectives. However, it difficult to believe the project will yield any value if progress and the quality of work are not improved.
- The project needs to better express its relevance with respect to the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan’s barriers.

#### Question 5: Proposed future work

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

- The future work is apparently a continuation of the current activities. There is a plan for a brochure, which is good. In addition, the plan includes building a database (perhaps contributing to the existing database). The PI certainly understands the issues and is trying hard to address a rather tough situation.
- The project has a well-structured plan to address key challenges for the stated barriers.
- The seven tasks listed in the future work are very good and appropriate.
- Future work seems reasonably well planned. A Gantt chart (or similar) would be helpful for this.
- It would be beneficial to see more detail regarding future work.
- There is little detail provided to indicate that the future work will have substance. More detail would be helpful.

#### Project strengths:

- The project has well-qualified people, has organized and well-developed plans, and addresses key barriers in manufacturing cost-effective fuel cells.
- Setting up technical exchanges is great. Coordination with MN-013, Virginia Clean Cities, on the database website integration is good.
- Broad involvement is a project strength.
- Pat Valente is the primary individual involved with this activity. Clearly, he is the “strength.”

#### Project weaknesses:

- The funding seems adequate to support the work. However, the funding is not sufficient to be effective.
- The project may be too ambitious, particularly in the development of standards for parts and subsystem components. Also, there is no well-defined performance matrix to evaluate progress. For example, it is not clear how many people are using the database and what its impact is. For each of the tasks, a performance matrix should be defined for the future years.



- Few details were presented on the working group other than in the approach. This part of the project needs significant attention to achieve several of the project goals.
- The presentation should have provided more detail and better addressed the scoring criteria. There was no definition of success criteria.
- The project lacks detail and substance. The inability to produce a brochure within nine months of the project start is one example. It is not clear what the “creation of four regional technical exchange centers” means. It seems like these centers already existed, so it is unclear what work was actually performed. The project needs to be more effectively managed to produce value.

**Recommendations for additions/deletions to project scope:**

- The data collected from the technical exchanges need to be carefully analyzed, and coordination with MN-014, GLWN, will help achieve DOE goals better.
- The “standardizing component and subsystem specifications” scope should be revisited. It is not clear what this really means or what it involves. At the least, this scope should be much better explained and defined.
- The issue is like matchmaking. Success will come when the PI learns of an opportunity and then contacts the company that is competent and interested in that business and the economic starts. Within small companies, the real value is usually people. One task might involve assembling a “directory” of interested companies, which includes the biographies of key employees, and then shopping that around the assembler community.
- Adding to the project scope is not recommended.

## Project #MN-013: Fuel Cell and Hydrogen Opportunity Center

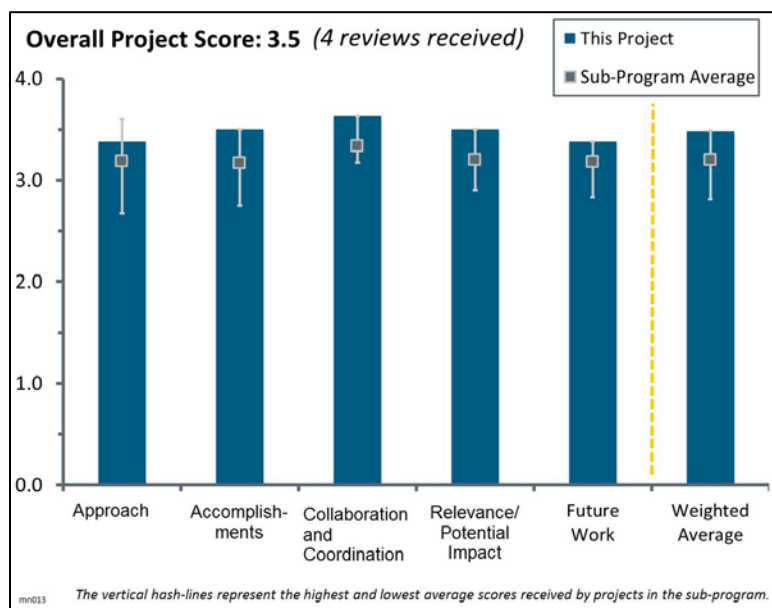
Alleyn Harned; Virginia Clean Cities at James Madison University

### Brief Summary of Project:

The project aims to facilitate the widespread commercialization of hydrogen and fuel cell technologies by expanding the domestic supply chain of hydrogen components and systems. The Fuel Cell and Hydrogen Opportunity Center is building and populating a comprehensive communications database and using an aggressive outreach campaign to drive U.S. companies to the database website.

### Question 1: Approach to performing the work

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



- The approach is very good. The team is close to launching the website and seems to have done a good job of creating a useful tool for the community.
- The plan to accomplish this work is well laid out, and significant progress has been made.
- The task focuses on building an open-source database that covers the global fuel cell industry and others “interested in alternative fuels.” Wisely, the task began by acquiring an existing database (written under the direction of Robert Rose), which is a good endowment for building a useful tool that identifies industrial players. A new website has been initiated.
  - The task intends to seek and identify “gaps” and to promote meaningful cooperation between organizations, as a step in developing competitive U.S. industrial activity.
- The project has a good approach. The team is doing the website first. However, details are lacking on the information about the database other than the number of companies. It is not clear what exact information is in this database or what value it adds to original equipment manufacturers (OEMs) and suppliers. The website and database can greatly benefit from coordination with MN-012, Ohio Fuel Cell Coalition (OFCC), and MN-014, GLWN.

### Question 2: Accomplishments and progress toward overall project and U.S. Department of Energy (DOE) goals

This project was rated **3.5** for its accomplishments and progress.

- The team has made excellent progress with the website. The team is meeting aggressive deadlines, with the website set for hard launch in July.
- The team is clearly showing progress toward objectives and completing tasks.
- The work is on track according to the work plan. The website coming online will be a major milestone.
- Many tasks are just now getting traction. This sort of activity, which is certainly an essential activity, is somewhat similar to planting seeds and hoping that important shoots will emerge and they will be apparent. However, both the appearance of the shoot and the place where the shoots appear are difficult to predict. Today it is far too early to understand exactly what has been accomplished. Certainly, the principal investigator appears keen, focused, and intelligent. His plan is formulated, and the team is on the field.

### Question 3: Collaboration and coordination with other institutions

This project was rated **3.6** for its collaboration and coordination.

- The task is housed at a university and integrated with Virginia’s statewide focus on clean cities, i.e., cities with significant technology deployed to mitigate air and water pollution. There is strength in that collaboration because it brings together a collection of many individuals and educational, governmental, and private industries.
  - A close tie to Birch Studios, which has people well versed in web-based products, is a strong asset.
  - Although there was no indication that fuel cell electric vehicles will be a primary focus, there was a clear indication that clean cars, such as fuel cell cars, need to be on the radar. However, other technologies can play equally well. It may prove difficult to break into a technology dominated by Asian automakers, companies that tend to have a well-organized and protected set of parts suppliers. Other markets might be more appropriate for initial thrusts into commercialization.
- There is cooperation between the state-funded Virginia Clean Cities, James Madison University, Birch Studio (an experienced web-based site developer), and the Breakthrough Technologies Institute. It will be necessary to incorporate industrial organizations, which should happen as the task progresses.
- The project is reaching out to the suppliers and manufacturers and seems to be connecting with the correct groups to be successful.
- Results indicate the team is effective at collaborating so far. The more important step of garnering collaboration from the broader community will be the real measure of success.
- Coordination with MN-012, OFCC, and MN-014, GLWN, needs to be improved. The presenter did excellent work in inviting the audience to help collaborate in making the website a success.

### Question 4: Relevance/potential impact on supporting and advancing progress toward the Hydrogen and Fuel Cells Program goals and objectives delineated in the Multi-Year Research, Development, and Demonstration Plan

This project was rated **3.5** for its relevance/potential impact.

- If the project is successful at garnering input from the hydrogen and fuel cell community, then this will be a successful and valuable project. To date, the team has laid the groundwork to begin receiving such input.
- The fuel cell industry needs this information, and the way it is being presented on this website should fill the void.
- The impact of the website can be high. However, care needs to be given to the type of information that goes into it and how it helps DOE meet its targets.
- DOE and others are fully cognizant that fuel cells are “happening” globally, and that they represent a transformational technology. There is keen interest in getting the United States and U.S. companies involved in these new products. This project is funded to make progress in developing a strong industrial base in fuel cell technology.
  - The potential impact could be significant. Even so, Virginia Clean Cities cannot be a primary actor, but rather a catalyst that accelerates the process.

### Question 5: Proposed future work

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

- This is the first year of the project. The plans for the website seem reasonable, and methods to improve the website each year have been presented.
- The website portion is excellent. However, details are lacking with respect to the database.
- The project is just starting. There is an acceptable plan, and the tasks are described. Some progress is apparent.

- The principal investigator should create and include metrics of success. These metrics will help guide the project to make adjustments where needed to provide value to the community and contribute to the Hydrogen and Fuel Cells Program goals.

#### Project strengths:

- Collecting this information and combining it on a single website will be very useful to the fuel cell community.
  - There is a strong design team and plan for developing the website.
  - The matchmaking interface will be very useful.
- The project has executed on first-year tasks and appears to be moving forward. The team should continue with its current approach; it seems to be working.
- The web portal launch is excellent.
- The PI seems essential for project success. Much will depend on his skill and luck. To be sure, success will involve those with access to capital and markets.

#### Project weaknesses:

- It is not clear what metrics are being used to determine project success.
- OEM and supplier interactions and database content were not clear.
- The task involves overcoming some serious competition. The electrical utilities are not keen on facing price competition from alternative energy sources. The oil companies are not keen on seeing no market for their reserves, so those on this proposed task will be challenged. This task is large, and the budget is meager.
  - There is no clear initial focus and no description of what the first commercial targets are. There is no apparent effort to identify specific products (fuel cell system components) that might be early commercial markets. There is no apparent focus on building a story about clean air/water health benefits, etc.
  - The principal investigator did not mention James Madison University involvement or ways that he might tap into the enthusiasm of students to promote and address these new technologies.

#### Recommendations for additions/deletions to project scope:

- Activities that can be done are started. A team is in place. This activity should be given some time to develop. The team should just stay on course, work hard, and seek partnerships as possible.
- The inclusion of data or charts showing the number of database entries and usage would be helpful to validate the acceptance of tools provided by the project. It would also help to ensure that information is reaching an appropriate audience and to guide the project in case adjustments are needed.
- The database needs more effort (than entering data from a questionnaire) and better coordination with MN-012, OFCC, and MN-014, GLWN.
- It is not clear how this website will be maintained after the DOE funding is complete.
  - It is not clear how the supplier information will be vetted and selected to be a part of the website.
  - It is unclear how suppliers will be monitored and removed if they are no longer supplying to the industry. These actions will all require time and effort that may be cost-prohibitive if no revenue stream is generated.

## Project #MN-014: U.S. Clean Energy Hydrogen and Fuel Cell Technologies: A Competiveness Analysis

Patrick Fullenkamp; GLWN – Westside Industrial Retention & Expansion Network

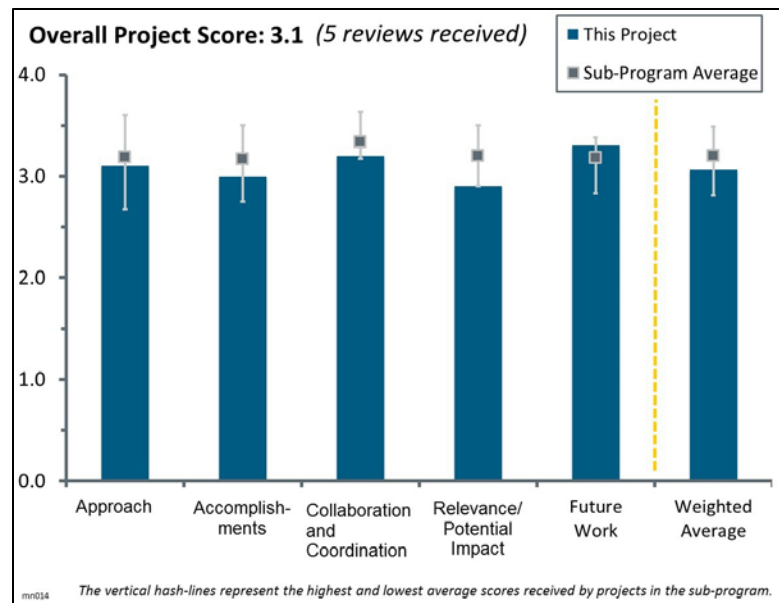
### Brief Summary of Project:

This project falls under the Clean Energy Manufacturing Initiative (CEMI) mission to increase domestic manufacture of clean energy products and increase energy productivity. Competitiveness is driven largely by cost, so this project is examining current and projected costs, supply chain evolution, and global trade flows of clean energy hydrogen and fuel cell technologies. Project results will help CEMI identify strategic investments, identify technology areas for research and development (R&D) investment, and lay out a prospective future supply chain.

### Question 1: Approach to performing the work

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

- The approach for this project is well structured and should materially help address identified barriers.
- The project is clearly well run, and the approach has been effective at moving the project toward its goals.
- Original equipment manufacturer (OEM) interviews are an excellent place to start. The assumptions in slides 9 and 10 may not be realistic. It is unclear whether OEMs have expressed interest in buying entire fuel cell systems and balance-of-plant (BOP) from Tier 1 suppliers, given the strong fuel cell research/patent portfolio and proprietary designs involved. This is akin to buying the car's engine from a Tier 1 supplier. It is not clear whether OEMs are speaking with one voice or how one would capture differing opinions and quantify them.
- This task is funded through CEMI, and the thrust is to address the supply chain necessary and appropriate for building and assembling products that flow from that emphasis on clean energy.
  - The thrust assumes competitiveness is driven largely by cost and therefore uses cost as a success metric. The task works to support the identification of high-value strategic investment, the design of a future supply chain, and technology areas for future technology investment.
  - There seems little focus on the “on-the-ground” current status. Major industrial firms in the global marketplace are delivering products, and the firms could accomplish that only if a “supply chain” exists for their manufacturing base. It seems useful to fully understand who is manufacturing what, and what current costs are.
  - The other missing step involves specifications. Certainly other manufacturers are building products to meet specifications. Because “fuel cell durability” is a serious concern, quality control of components needs to be a continued focus. Specifications are mentioned, indeed. However, the task of obtaining such information is not well described.
- The approach has not been clearly communicated in terms of generating a competitiveness analysis that is consistent in methodology with other competitiveness analyses done for the Office of Energy Efficiency and Renewable Energy (EERE). It is not clear how the tasks described by the presenter contribute to an overall methodology.
  - It seems that the project so far has replicated data or analyses from other projects (e.g., the cost analysis by Strategic Analysis, Inc., [SA] and E4tech's commercial market analysis).



- Stated outcomes are aiding DOE in identifying strategic investments and R&D investments, but it is not clear how this project will contribute to those outcomes beyond existing activities such as manufacturing cost analyses and market reports.

## Question 2: Accomplishments and progress toward overall project and U.S. Department of Energy (DOE) goals

This project was rated **3.0** for its accomplishments and progress.

- Overall progress toward goals has been good. The information gathered regarding manufacturing readiness is particularly interesting.
- The OEM surveys have gathered some insightful information, though there were some conflicts between the OEM and Tier 1 feedback that could have been explored further, e.g., the OEM “No” and Tier 1 “Yes” on membrane electrode assembly (MEA) #3.
  - There was agreement on the storage cost projections, shown on slide 12, attributed to the industry being more mature, yet on the survey, neither the OEMs nor the Tier 1 suppliers thought the technology or manufacturing was ready for production >1,000 units/year. This should be explored.
  - For the supply chain evolution, the Prius comparison seems useful, though there is no mention of the obvious difference between the Prius and fuel cell electric vehicles (FCEVs), namely infrastructure. It seems like the lack of support for infrastructure development could cause the evolution pathway for FCEVs to be significantly different.
  - The predicted evolution for MEAs, in which the OEMs will eventually have Tier 1 suppliers make the entire fuel cell power system, seems likely. It is not clear, however, how these evolution analyses contribute to the competitiveness analysis or what this means for U.S. MEA suppliers such as 3M or, potentially, Gore.
- The project is moving forward toward its goals. Progress toward DOE goals will be better known once the project reaches later milestones as data are rolled up with conclusions.
  - What the performance indicators are—how the project measures success—is not clear.
- There has been good progress on data collection. More information needs to be provided in slide 11. Just the ratio of the highest to lowest OEM estimate might be misleading. More robust statistical analysis is necessary to draw conclusions from these data.
- The principal investigator (PI) assumes that the “OEM” will build the fuel cell stack, an assignment similar to the current methodology of the internal combustion engine OEMs. This seems a questionable conclusion. The manufacturer of a flashlight is seldom the company that makes batteries. The clear example of a more likely market is the lift truck business, in which a fuel cell supplier builds a drop-in device to power lift truck vehicles. Options at this early stage need to be open.
  - Completed work focuses on projection of future fuel cell markets, with a clear bias toward the vehicular fuel cell market. Some interesting data about fuel cell stack projection were presented, along with cost projections from potential manufacturers. There were no surprises.
  - No list of actual or suspected current parts suppliers was mentioned.

## Question 3: Collaboration and coordination with other institutions

This project was rated **3.2** for its collaboration and coordination.

- Collaboration appears to be effective to date. Future tasks, including garnering detailed cost data, may be more challenging. However, the PI looks to have a very good handle on this challenge. The PI should keep up the good work.
- The project has strong collaborators from the project execution side and from industry stakeholders.
- The project has very good partners in terms of experience in the industry, technical knowledge of fuel cell systems and manufacturing, cost analysis, and market analysis. The relationship with the National Renewable Energy Laboratory, “data collaboration,” was not explained very well.
  - As much as the analysis seems to be relying on the SA cost analysis, it would be good to see, in future reviews, how the results of this competitiveness project have affected the analysis or methodology used by SA.



- Collaborations are with other organizations that are funded by this project. Although there is considerable competence in those team members, and one (SA) has built a credible bill-of-materials list, much of the actual present or future designs is not well understood. Certainly this information will flow eventually. The emphasis seems focused on FCEVs, even though the large global market today is combined heat and power (CHP). One interesting market possibility is to sell CHP systems as appliances and do the necessary market creation by working through permitting and safety evaluations that permit those systems to be deployed widely in the United States. Other potential markets need emphasis as well.
- More should be done to coordinate with the other Manufacturing R&D projects, including MN-012, Ohio Fuel Cell Coalition, and MN-013. Virginia Clean Cities.

#### **Question 4: Relevance/potential impact on supporting and advancing progress toward the Hydrogen and Fuel Cells Program goals and objectives delineated in the Multi-Year Research, Development, and Demonstration Plan**

This project was rated **2.9** for its relevance/potential impact.

- There has to be a start in building the U.S. supply chain, and this work is laying that foundation. There is no bias shown for any specific U.S. location—the place where the businesses will be built—which seems most appropriate.
- There is potential for high impact if the web portal from MN-013, Virginia Clean Cities, is integrated with the all the data collected from this project. Maybe the project can be extended to include early markets, including forklifts, cargo, and buses, in addition to the automotive application considered in this project.
- The project will help identify supply chain gaps and potentially yet unrecognized barriers.
- The presentation does not make clear how this project will assist DOE, beyond currently supported cost and market analyses. Supply chain decisions ultimately rest with OEMs, not DOE.
  - It is not clear whether the project will output new technologies that need to be developed or parts or components that need to be redesigned to assist DOE.
  - It is also not clear whether this project will be linked with jobs assessments, such as at Argonne National Laboratory, nor whether there will be coordination with the other supply chain projects supported by DOE.

#### **Question 5: Proposed future work**

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

- The work for next year includes an estimate of global shipments of fuel cell and hydrogen storage components. That document could be very interesting and valuable. It would be useful to include plans that build an early technology utilization scheme, for instance, a residential development that is built as a test bed of distributed fuel cell power. There needs to be focus on market creation, and getting interested and competent people involved could be most useful.
- The project is well run, and the PI is aware of coming challenges. The PI has experience with this type of work and has overcome similar challenges in the past. The reviewer looks forward to seeing next year's presentation.
- The proposed work for fiscal year (FY) 2017 is excellent.
- Future work is clearly identified. A Gantt chart (or something similar) would be helpful for understanding timing.
- Future work is a continuation and expansion of current work. It would be good to see more emphasis on ensuring consistency with current EERE competitiveness analyses.

#### **Project strengths:**

- The project is well run. The PI has run similar projects in other industries and has developed workable approaches to challenges.
- The PI brings decades of experience in part supplier relationships. His contacts are critical for project success.

- The project has good contributors, with long experience and understanding of fuel cell technology, industry, cost, and market.
- The project has a good foundation with the company questionnaire. The FY 2017 goals to identify specific advantages are also commendable.
- The project has the potential to yield very useful and actionable supply chain information.

#### **Project weaknesses:**

- The focus on vehicles seems critically dependent on existing OEMs, yet these organizations carry huge debts, money used to finance their existing technology manufacturing base. There should be greater emphasis on more—probably early—markets for fuel cell products.
  - There needs to be some concern for designs (including operation parameters) that result in necessary performance and durability.
  - There is no concern expressed for end-of-life considerations and the companies required to pull off those necessary tasks.
- Dissemination of results as a final report may not be adequate. It would be unfortunate if valuable results were not more readily available or accessible to the community. Perhaps there are other approaches in addition to a report that might help garner interest and highlight results.
- Overall, the methodology of the project to provide the Fuel Cell Technologies Office (FCTO) with competitiveness information regarding automotive fuel cell production has not been shown. It is not at all clear how this project will benefit DOE beyond current cost analysis and market analysis projects.
- The approach to get to FY 2017 objectives needs to be laid out better.

#### **Recommendations for additions/deletions to project scope:**

- It may be enlightening to explore further the instances of differing assessments of manufacturing readiness by OEMs and Tier 1s.
- It would be good to see a benchmarking of the project methodology against the standard EERE/CEMI methodology at the Clean Energy Manufacturing Analysis Center. It is not clear what purpose redesigning “5 key components” plays. The value of this activity is not clear.
  - Better coordination with the other FCTO supply chain projects would seem to be of value.
- Having vehicles as a focus is okay, but other markets should not be excluded.

## Project #MN-017: Manufacturing Competitiveness Analysis for Hydrogen Refueling Stations

Margaret Mann; National Renewable Energy Laboratory

### Brief Summary of Project:

This project contributes to manufacturing cost analysis for major hydrogen refueling station (HRS) systems. The project will work with the Fuel Cell Technologies Office to establish HRS manufacturing cost models and a manufacturing cost framework to study costs of HRS systems, including the compressor, storage tanks, chiller and heat exchanger, and dispenser. Investigators will assist in highlighting potential cost reductions in the manufacturing phase for future research and development projects in this field.

### Question 1: Approach to performing the work

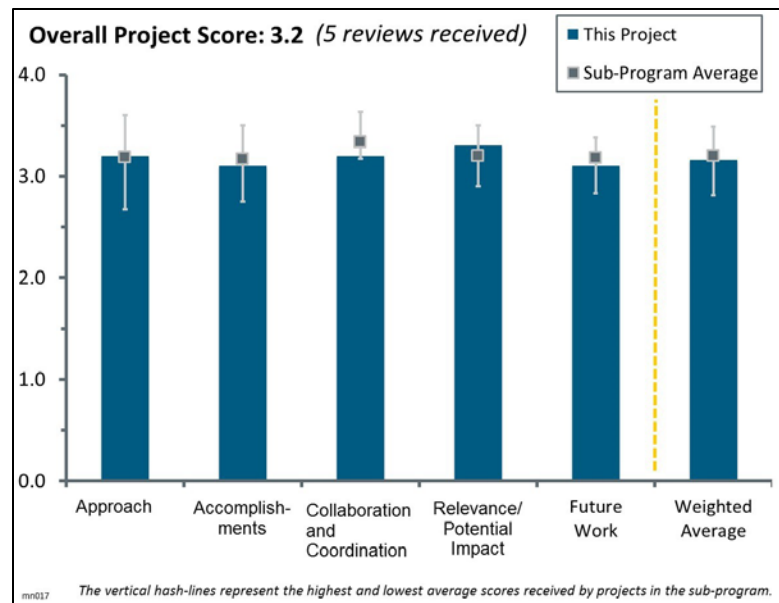
This project was rated **3.2** for its approach.

- The National Renewable Energy Laboratory (NREL) looks at capital costs necessary to install a HRS as part of the U.S. Department of Energy's (DOE's) Clean Energy Manufacturing Analysis Center. The organization and execution of the activity appears to be of the highest quality. As stressed, the data project current evaluations. Such a study requires a reference design and the results will be influenced by that design.
- Capturing the HRS cost and projections for growth is important work, and this project has made significant progress in capturing this information.
- The work to date appears to be thorough and detailed. The approach seems to be working.
- NREL should take into account new compression technologies such as electrochemical compression, which seems to be on the verge of commercialization. It is not clear whether the project is focusing on current technologies available or those that have the potential to reduce costs in the next five years.
- This project tries to study too many things in such detail and is making many assumptions that may not be justified. These details are probably best left to manufacturers and original equipment manufacturers (OEMs). The project needs to better focus on the big picture with a realistic set of assumptions, taking into account the experience gained with stations in California, Germany, and Japan.

### Question 2: Accomplishments and progress toward overall project and U.S. Department of Energy (DOE) goals

This project was rated **3.1** for its accomplishments and progress.

- Continuing the work as planned will provide useful information to help steer other programs.
- The project is 75% percent complete, with analysis completed on many of the aspects of the HRS.
- The project has made good progress for the funding. NREL reports many details on various sub-systems. However, very little is being done to use this information to identify gaps and guide DOE on future research needs, etc.



- Considerable information was presented on both the deployment of stations in the global community and costs for those existing stations. It might have been more useful to include hydrogen production costs, but that would have clouded the issue: how much money is required to build the HRS.
- It is not clear how the project addresses the current barriers.

### Question 3: Collaboration and coordination with other institutions

This project was rated **3.2** for its collaboration and coordination.

- There are good partnerships between Sandia National Laboratories, Argonne National Laboratory, Pacific Northwest National Laboratory, and a number of overseas contributors.
- The study could have been possible only with cooperation of current industrial manufacturers. However, there is no indication of other collaborations.
  - A good collection of excellent collaborators was described. Actual roles among participants were not clear.
- There are good collaborations with various relevant institutions. Maybe more can be done with the HRS operators in California.
- Perhaps collaboration with new technology developers could be helpful: solid and organic storage, electrochemical compressor, commercial dispenser, and point-of-sale suppliers.
- While data have been gathered for cost analyses, there is no indication that the results have been shared with existing manufacturers for validation.

### Question 4: Relevance/potential impact on supporting and advancing progress toward the Hydrogen and Fuel Cells Program goals and objectives delineated in the Multi-Year Research, Development, and Demonstration Plan

This project was rated **3.3** for its relevance/potential impact.

- This information is needed to further the growth of HRS installation and development. This research has dissected the HRS and broken down the costs into the components.
- The project gives a clear understanding of costs for an HRS. It assumes a hydrogen supply from either pressurized gas cylinders or from cryogenic liquid hydrogen. In many cases, it might make sense to include steam methane reforming or electrolysis in the station design. Those additional costs are understood.
  - The issue of finance was mentioned but not addressed. Certainly, some governmental and some private funding mix will usually be required.
- Results will be valuable to help guide the focus of future funding.
- It is not clear whether the models are used only for helping DOE assess status. Impact could be larger if these models are shared and used by the developers.

### Question 5: Proposed future work

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

- The project is almost complete, and the plan to complete the final tasks is logical and reasonable.
- Future work should include additional companies that produce gasoline dispensers, new heat exchangers, electrolytic compressors, and novel storage that is nearly commercialized.
- The information given was that the project would terminate in December. One suspects this team will be given an additional assignment, one that may or may not be a follow-on to this study. The presentation was lacking in big picture details.
- It is not clear how the objectives stated in the “Relevance and Goals” slide are going to be met.

### Project strengths:

- The project has been successful in meeting the goals and milestones. The cost analysis seems to be very thorough for each component.

- The engineering team is obviously first-rate. A very detailed manufacturing cost breakdown was given.
- The project represents a nice aggregation of cost data for current systems and components.
- The team has produced very detailed and comprehensive analyses to date.
- The analysis of various sub-systems is detailed.

#### **Project weaknesses:**

- The lack of choices from manufacturers limits some of the robustness of the cost calculations, but this is not the fault of the researchers.
- It would have been interesting if some effort was spent on durability and operating expenditures (OPEX). In some ways, the design was minimal. For example, there was no allowance for better utilization of the delivered hydrogen in the tube trailer. There was no mention of various compressor designs, such as the ionic liquid (Lurgi) design that operates with considerably higher efficiency. Again, that would be an OPEX consideration.
- It would be good to close the loop and garner comments from existing industry players as to the accuracy of results, i.e., “sanity check” the results and see whether they make sense.
- There is not enough focus on driving innovation and what areas would result in the largest benefits for cost reduction and reliability.
- The project is 75% complete, and it is not clear how thoroughly the objectives will be met by the end of the project.

#### **Recommendations for additions/deletions to project scope:**

- The study was done well. It seems likely that the next one will be of similar quality.
- NREL should discuss how the researchers will transfer this information to industry. It is not clear to which groups it will be disseminated and what methods will be used to transfer the information, i.e., whether it will be through the DOE website or another method. It is good information, but it needs to be disseminated.
- NREL should focus less on the details of the various sub-systems because they are already based on so many assumptions. These assumptions can be made at the sub-system level, and the model can focus on the main objectives of the project.
- The project should reach out to existing manufacturers and developers to review the results and the assumptions that drive the models.
- The project should bring in companies that are innovating away from the traditional and mature systems and components—technology readiness levels 6 and 7.