2013 — Market Transformation
Summary of Annual Merit Review of the Market Transformation Program

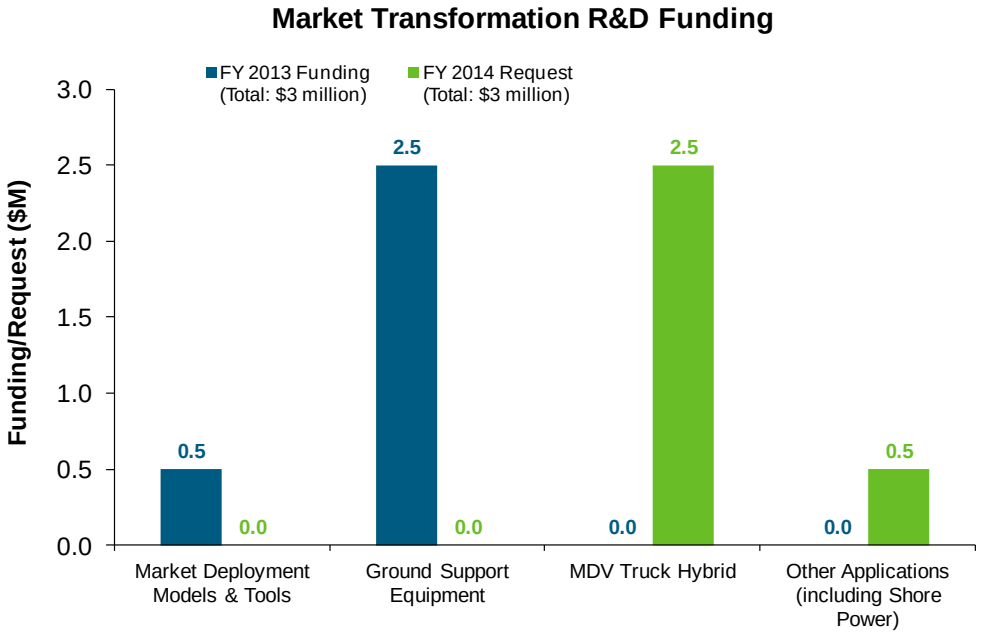
Summary of Reviewer Comments on the Market Transformation Program:

The purpose of the Market Transformation program is to spur market growth for domestically produced hydrogen and fuel cell systems. By supporting increased sales in key early markets, this program helps to identify and overcome non-technical barriers to commercial deployment and to reduce the life cycle costs of fuel cell power by helping to achieve economies of scale. The current focus of the Market Transformation program is to build on past successes in lift truck and emergency backup power applications (part of the U.S. Department of Energy's [DOE's] American Recovery and Reinvestment Act of 2009 [Recovery Act] efforts) by exploring the market viability of other potential and emerging applications. Six projects were reviewed this year, and these projects are highly leveraged, with more than half of the funds provided by DOE's partners. This substantial commitment of external resources shows the high level of interest in exploring applications and markets where the hydrogen and fuel cell industry can expand and the technologies can play a valuable role.

Generally, reviewer comments on the program were positive, noting that activities were considered to be important to enabling the commercialization of hydrogen and fuel cells. Reviewers considered the program to be well managed and noted the extensive collaboration present in the projects and the substantial leveraging of federal funds by cost-sharing. However, a number of reviewers felt that the program lacks an overall cohesive market transformation strategy and that the current projects do not seem to be part of an integrated plan.

Market Transformation Funding:

With the market successesthat have been achieved by fuel cells in lift trucks and backup power applications as a result of fiscal year (FY) 2009 and Recovery Act funding, the focus of FY 2013 funds was on a new application: airport ground support and specialty vehicles. As shown in the chart below, other applications (including shore power) will be a new focus that will achieve leverage by partnering with other federal agencies and stakeholders to deploy fuel cell systems in their operations. Another focus will be battery/fuel cell medium-duty hybrid tucks (MDV) that will demostrate a value proposition for parcel delivery fleets. Although not reflected in the FY 2013 budget, DOE invested $42 million under the Recovery Act to enable the deployment of more than 1,000 fuel cells for early market applications such as forklifts and backup power. The Market Transformation program budget for FY 2013 was $3 million.



Majority of Reviewer Comments and Recommendations:

The Market Transformation program's projects were rated average to high, and overall ratings ranged from 2.8 to 3.6, with an average score of 3.2. The projects were judged to be relevant to the DOE Hydrogen and Fuel Cells Program's activities, with good or adequate technical approaches used. Reviewers recommended that future data collected and analyzed from all deployment activities be used to develop business case reports that can be used to support further market expansion.

Stationary Applications (Micro Combined Heat and Power): One project was reviewed, with an overall score of 3.6. Reviewers commented that this project was clearly relevant and could help build significant market share for hydrogen and fuel cells in the near term. They also observed that this project was well designed for collecting and analyzing data. However, reviewers expressed concern that too much effort is being spent on modeling and more attention is needed on understanding the results of the fuel cells in the real world.

Airport Ground Support Vehicles: One project was reviewed, with an overall score of 3.2. Comments were supportive of the project's approach in that it was modeled after successful lift truck or material handling equipment (MHE) deployment projects. More than one reviewer was concerned that the schedule was very aggressive but also noted that concrete go/no-go decision milestones will minimize risks. One commenter stated that the market size may be too small and that other applications should be brought in. It was stated that, if this project is successful, the associated hydrogen infrastructure is expected to be the model for other airports to begin similar projects, which is needed to help commercialize fuel cell road vehicles. Expansive team and stakeholder involvement was positively noted. Also noted was that the project aligns well with the Market Transformation program objectives.

Direct Methanol Fuel Cell Material Handling Equipment: This project, which was focused on deploying and testing fuel-cell-powered MHE and compiling operational data for validation, received an overall score of 3.2. Reviewers noted the value of exploring technologies that offer effective alternatives to hydrogen fuel cells, particularly the usefulness in developing a business case and making technology improvements. Reviewers also commented on the significant operating data and experience being obtained from the 75 units deployed (as of June 2011). While some issues have been identified, illustrative data from "good" and "failed" stacks were reported and issues have been corrected. One reviewer recommended maintaining more information on costs, life, and customer experiences, and reporting more information on the details of the fuel cells.

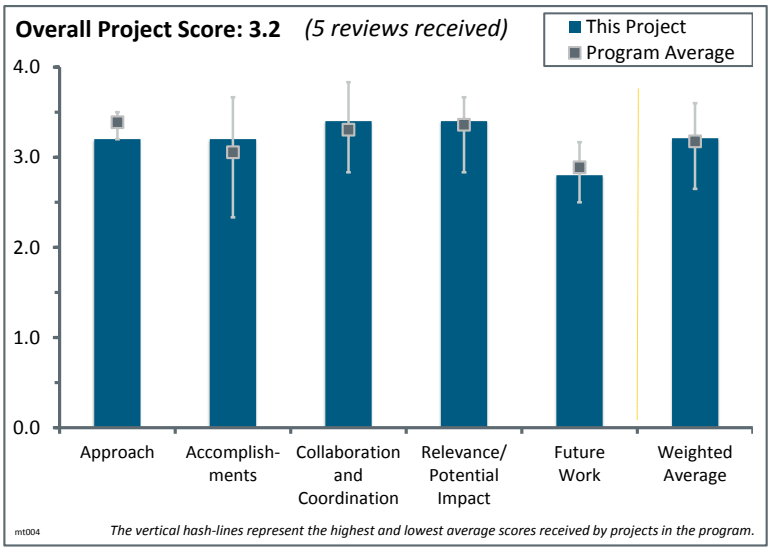
Landfill Gas-to-Hydrogen: This project achieved an overall score of 2.8 for its efforts to validate the business case and technical feasibility of using landfill gas (LFG) for hydrogen production and sharing lessons learned that may be applicable for other candidate waste streams. Reviewers recognized that the project is well focused on market transformation for fuel cell technology instead of proving the science of LFG-to-hydrogen. The project team was also commended by reviewers for showing foresight and flexibility to adapt to changes beyond the control of the project team.

Hydrogen Energy Systems as a Grid Management Tool: This project received an overall score of 3.2 for its efforts in modeling, testing, and validating potential applications for hydrogen energy systems to address grid stability issues. One reviewer commented that this project has significant potential to demonstrate a solution for larger-scale applications. Reviewers also praised the Hawai'i Natural Energy Institute for leading a well-coordinated team effort alongside its partners and recognized the high degree of collaboration among federal, state, and private entities.

Project # MT-004: Direct Methanol Fuel Cell Material Handling Equipment Deployment

Todd Ramsden; National Renewable Energy Laboratory

Brief Summary of Project:



The National Renewable Energy Laboratory (NREL), in collaboration with Oorja Protonics, built and maintained direct methanol fuel cell (DMFC) Class III material handling equipment (MHE) systems for commercial food distribution warehouses. Oorja Protonics deployed and operated DMFC-powered MHE and methanol infrastructure and compiled operational and maintenance data. Performance of the infrastructure was validated by NREL under real-world conditions. An independent technology assessment evaluated the reliability and durability of the fuel cell systems, performance of the infrastructure, and overall value proposition. This project also provided support to the market for fuel cells in material handling applications by providing relevant results for key stakeholders.

Question 1: Approach to performing the work

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

- The approach is sound. This is a pilot demonstration with limited imposed restraints. These real-world data should be useful.
- This is a well-designed experiment, but the failure of the initial 75 units had a significant impact on the project. There should, perhaps, have been some initial testing of a few units to shake out any issues before the decision to produce and purchase 75 was made.
- Fuel cell-powered MHE is being evaluated in this project. The battery is recharged by an onboard DMFC. NREL is collecting the data on its operations.
- The project approach was sound given the constraints that existed. It would have been preferable to have multiple DMFC vendors, but that may have been constrained by the market or resources. The use of the NREL Hydrogen Secure Data Center (HSDC) is well understood and prevents duplication of already existing analysis capabilities; it also potentially leverages data across platforms, uses, and technologies. This allows for some comparative analysis (for example, hydrogen-powered MHE versus DMFC-powered MHE versus battery-powered MHE). It is not clear what the non-technical barriers were and how they were addressed. This hopefully will be contained in the final report.
- The approach is focused on data collection and not on implementation barriers in the real world. There is very little discussion of the value proposition and the advantages over incumbent technologies. It is unclear if there will be enough data and lessons learned in the end to develop a recommendation on next steps. Additionally, the project focuses on one manufacturer, whereas multiple DMFC products would possibly present additional challenges not considered or presented. Overall, improvements to the effort and approach might be possible by focusing on the value proposition in addition to data collection.

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

This project was rated **3.2** for its accomplishments and progress.

- The accomplishments are interesting. The references to safety issues are important.
- Valuable information has been collected showing the hours operated, the power generated, and degradation data. The fuel cell system did not perform that well with a high degradation rate. The data collected are valuable, although more data on performance and cost should be sought. The data suggest that more stack development work is needed.
- Despite the failure of 75 units and the lack of sufficient data to do value analyses, the project showed the possible utility of a methanol fuel cell as an onboard battery charger with easy refueling.
- It is hard to adequately evaluate given current data status. This was only rated as fair because it seems to have missed several project goals for performance (units not operational, operating hours not achieved, MW/hr generated, fuel cell degradation, etc.).
- One key barrier will be the cost compared to incumbent technologies, which is the key to analyzing the value proposition. Insufficient data have been cited in providing this analysis. Technical barriers are addressed, but without cost and value data, this project is lacking overall value in terms of moving forward with a business case for commercialization of this technology.

Question 3: Collaboration and coordination with other institutions

This project was rated **3.4** for its collaboration and coordination.

- This project has good collaboration between the sites, the MHE provider, and NREL.
- While it would have been valuable to integrate multiple DMFC manufacturers into this project, the team did an outstanding job leveraging their partners. Getting multiple sites and 131 units deployed is impressive.
- This project should verify good cooperation between Oorja and the "grocery" sites. This project needs better cooperation and data exchange between Oorja and NREL.
- The collaboration should have included one other reference, the local authority having jurisdiction (AHJ). The AHJs speak with each other. If the AHJ is included in the project, it makes the next project easier to site because the AHJ of the new project can chat with the AHJ of the previous project. This word of mouth ends up being an endorsement and eases the next AHJ's reluctance to allow a project.
- This project is limited with only one manufacturer. That may be a feature of the current development base, or resource constrained, but it makes data sharing more difficult. The collaboration with users was good, and multiple users and sites helped this. For market transformation, the reviewer is hopeful that the actual forklift manufacturers start pushing out these types of options for consideration or become primes in the demonstrations.

Question 4: Relevance/potential impact on advancing progress toward DOE research, development, and demonstration (RD&D) goals

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

- The relevance/impact is as should be expected.
- The use of methanol in a real-life application is excellent; it eliminates all the perceived issues with hydrogen.
- One of the goals of the Fuel Cell Technologies Office's Market Transformation program is to conduct deployment projects "to enable life cycle cost and performance of fuel cell power lift trucks." This project enabled the deployment and subsequent collection of data on 131follow-on commercial deployments. Data collected should inform the life cycle cost and performance of fuel cell-powered lift trucks.
- Using a liquid fuel, instead of hydrogen, can significantly reduce the refueling infrastructure cost. Methanol has a low well-to-wheels efficiency. There is also a concern about methanol spills getting into the groundwater. Charging the batteries with a fuel cell is beneficial in that it increases the productivity of the

equipment. It is expected that the study will help with analysis of the suitability of this configuration with both a battery and a fuel cell contributing to the capital cost. An analysis of life cycle cost to compare against other configurations is also needed.

Question 5: Proposed future work

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

- The proposed analysis of the data should be completed.
- The proposed plan, given sufficient funding, is absolutely the right approach.
- A post-project debrief should be considered in which lessons learned are discussed and then amended to this report. The lessons learned may facilitate similar projects.
- The project is about to end, and the team identified issues stemming from a lack of data; no clear resolution was discussed to address this.
- Future steps all seem focused on just closing out a report and study on this project. The current lack of data (four months after project completion) makes this risky to some degree and suspect. There was no discussion about how the results/learnings/findings might roll into future improvement and development efforts, and Oorja was not present to discuss and elaborate.

Project strengths:

- This project is a great real-world application of fuel cells with a commercial fuel.
- Project strengths include focus and attention to detail in generating, collecting, and reducing the field data.
- Project strengths include project management and data collection, as well as collaboration between host sites and manufacturers.
- Data are being generated on DMFC system performance and durability. It allows exploration of another type of fuel cell in the MHE application. This is very valuable.
- This is a straightforward plan and demonstration to look at DMFC in an operational environment. It is very much built on the template from other MHE deployments. This provides some comparability among technologies.

Project weaknesses:

- This project needs better understanding of reasons for performance degradation and better access to performance data.
- Currently, the lack of data and inability to hit several of the performance objectives make it very hard to establish the value proposition at this stage.
- The Market Transformation project ultimately must prove commercial viability of the technology. This project does not fully demonstrate whether this will be competitive in the marketplace. The value proposition is key, and not much attention was paid to that analysis.
- This project needs additional data and information. For example, it is unclear what requirements and costs were associated with meeting the environmental safety and health standards, especially for methanol, which is toxic, absorbable through the skin, and water soluble. It is unclear what methods are in place to prevent operators' breathing in methanol vapor, or what the stack efficiencies were at the beginning and end of its life.
- As part of the safety input, while this is prototype hardware and would not have product listings, the hardware should have been designed to the applicable standards, such as UL 2267 "Fuel Cell Power Systems for Installation in Industrial Electric Trucks." The same holds true for the dispenser. It would also have been nice to note that CH_3OH is a heavier-than-air fuel that has the fire properties listed in NFPA 496. In future demonstration projects, this project should include the local AHJ in the activity early and include the AHJ as a collaborator. It will help with getting adoption of additional projects by the local AHJ.

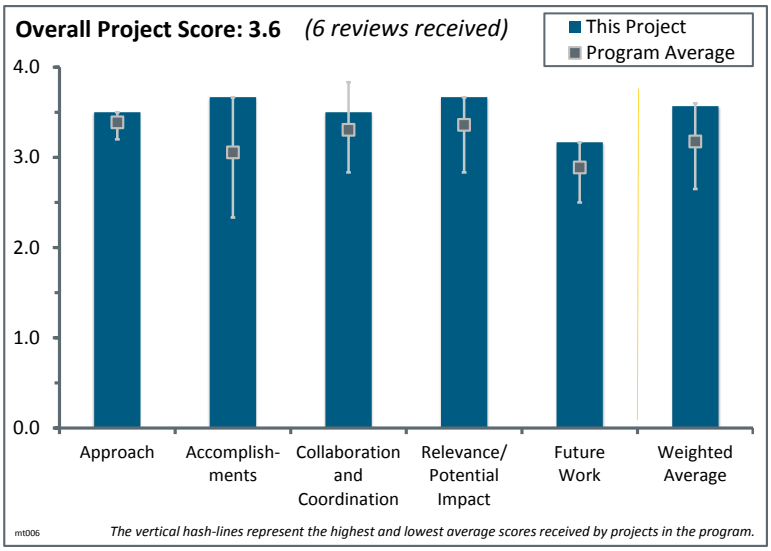
Recommendations for additions/deletions to project scope:

- This project should provide a business case for deployment by the industry, independent of DOE.
- The life cycle cost analysis is essential and preferably should be compared with other configurations, fuels, fuel cell types, etc.
- This project should place better attention on the quality of the methanol. Safety work is not necessary until the cell performance degradation issue is solved.
- A post-project debrief should be considered in which lessons learned are discussed and then amended to this report. The lessons learned may facilitate similar projects.
- The final study/report should highlight the areas and specific improvements/corrections that must be made for this technology in this type of operating environment.

Project # MT-006: Fuel Cell Combined Heat and Power Commercial Demonstration

Kriston Brooks; Pacific Northwest National Laboratory

Brief Summary of Project:



The objectives of this project are to demonstrate combined heat and power (CHP) fuel cell systems, objectively assess their performance, and analyze their market viability in commercial buildings. Fuel cells for CHP should demonstrate environmentally friendly technology, movement toward cost competitiveness with conventional technologies, reduced risk of electric grid disruptions and enhanced energy reliability, stability in the face of uncertain electricity prices, usefulness for applications such as base-load backup power or as a foundation for other renewable alternatives, reduction in the need for new transmission and distribution infrastructure, and enhancement of power grid security.

Question 1: Approach to performing the work

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

- This project has done a great job identifying and directly addressing specific barriers and achievable goals. Feasibility has been proven through deployments and successful operations, and the project is well rounded by being rooted in deployment of commercial technology and focused on education.
- The project was started in fiscal year 2011 and is scheduled to conclude in 2015. The project approach was laid out very well, and progress is continuing as planned. It is a very good evaluation and demonstration, with units currently in the field producing electricity and results.
- Polybenzimidazole (PBI) fuel cell-based CHP units have been set up for demonstration and data collection at four commercial facilities. Data from these systems will be collected and analyzed to gauge performance, while familiarizing the public with this new method of small distributed heat and power. A total of 15 CHP units are planned in this project. The planned five-year evaluation is more valuable for determining durability and conducting a life-cycle analysis.
- The approach is well described and seems to encompass the most important elements for consideration. However, the project length (five years) seems longer than necessary. It is described as an attribute (better than other three-to-six-month studies); however, it would seem that after a couple of years (two seasonal cycles), most of the necessary data and details would be available, unless a lot happens in performance in years 3–5 that is not necessarily demonstrated by the results. With the rapidly developing markets and technologies, this is a considerable time to be under study.

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

This project was rated **3.7** for its accomplishments and progress.

- Overall, the project has made progress toward achieving the DOE goal of demonstrating micro-CHP. The fact that the rated 5-kW capacity of the unit has not been achieved (and reset to 4 kW) impedes

demonstration of total system value. It appears a mitigation/revision plan is in place with original equipment manufacturers (OEMs) to rectify the decreased performance.

- All systems have been installed in previous years. Some modifications and updates to the balance of plant are in progress. The operation's working at lower-than-originally-rated capacity has improved performance and availability. This project has very good documentation of performance and analysis of costs.
- This is an excellent validation project. The CHP market will probably focus on the usage of the heat, and the generated electricity will be a secondary factor. If electricity is in surplus, it will be sold back to the grid. If a deficit is encountered, the grid would supplement. CHP for off-grid applications will be difficult to balance efficiently because the usage profiles vary.
- This is a commendable list of accomplishments, results, and actions taken as it relates to the project and improvement. This project is hitting some impressive numbers.
- This project is hitting all of the major milestones and addressing barriers as they occur. During the field trial, fuel cell degradation was identified. The manufacturer spotted the problem and is in the process of implementing corrective actions. This project has led to a product redesign by the manufacturer, which will improve the industry as a whole and supports the DOE's goals to improve U.S. industry. Past year milestones were met, and the data being collected are being compiled to supplement the previous year's work.
- Identifying that the units were not performing as expected, and working with the manufacturer to improve their product, demonstrates the high quality of this project and project team. This is very valuable to the manufacturer and could possibly prevent potentially very damaging impacts if it were to happen with a future real-world customer. While not presented in the peer review meeting, the business case developed along with this product will be very valuable to proving this technology in the real world.

Question 3: Collaboration and coordination with other institutions

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

- It appears the collaboration among participants was very good. Some different types of users help to form the potential market basis a little better.
- The project seems to have a great working relationship with the fuel cell manufacturer, and both seem to be striving to make this project a success. The host sites are also supportive of the project and seem to be active participants in this demonstration.
- The diverse set of end-use customers provides valuable data applicable across several markets. Collaboration with the end-use customers has and will continue to be key in developing the business case.
- The collaboration should have included one other reference, the local AHJ. The AHJs speak with one another. If the AHJ is included in the project, it makes the next project easier to site because the AHJ on the new project can chat with the AHJ of the previous project. This word of mouth ends up being an endorsement and eases the next AHJ's reluctance to allow a project.

Question 4: Relevance/potential impact on advancing progress toward DOE research, development, and demonstration (RD&D) goals

This project was rated **3.7** for its relevance/potential impact.

- This project directly addresses DOE's goal of reducing life-cycle costs and improving the performance of light commercial/residential power systems.
- The relevance is appropriate. CHP has the potential to greatly reduce energy costs by more effectively utilizing the waste-from-heat from current applications.
- This project is certainly relevant to DOE's targets and goals. But it is not clear what the market of small commercial buildings is. One slide talks about hotels, hospitals, and food operations, but many of these are sized well beyond the micro-CHP levels. Perhaps some discussion and quantification of this market would be helpful in the analysis and impact consideration.
- This project is offering commercial facilities the opportunity to experience the benefits of the fuel cell-based distributed micro-CHP. It is crucial that these systems deliver on their promise of high efficiency and availability. The data gathered will be very valuable in identifying the areas that need further development.

The set point change has increased the capital cost. It is unclear what the resulting gain in electrical and combined efficiencies has been.

- This project is providing a needed field demonstration and evaluation of commercially available fuel cell technology. The viability and feasibility are being tested. This demonstration is advancing the industry; already results from this project have allowed the fuel cell provider to perform a major redesign of the product to improve performance and minimize the fuel cell degradation that was observed during the demonstration. This project supports the DOE's goal to improve the U.S. economy/industry under the Market Transformation program.

Question 5: Proposed future work

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

- A post-project debrief should be considered in which lessons learned are discussed and then amended to this report. The lessons learned may facilitate similar projects.
- It is important to identify opportunities for improvement, especially efficiency. It is unclear what will fuel the truck auxiliary power unit (APU). Increasing the test period to at least a 1000 hours is suggested.
- Future work includes completing the business case and continuing the field demonstration to provide robust, long-term field results. A related research project involves the evaluation of the APU fuel cell demonstration. If progress continues in a similar fashion, this follow-on work should provide good results also.
- The project is well managed and on target. Future work includes expanding to additional markets and the completion of a very comprehensive business case. The improved systems triggered by the discovery of less-than-expected output should be incorporated, if possible, into the demonstration and data collected, especially if the costs are increased.
- It seems that all the future work for the next two years is composed of additional data collection and report writing. There is no discussion of how the present and future work will move the needle on the micro-CHP market. For example, it is unclear what and how action is being taken so that another request for proposals released in a year will result in more than one bidder. The relevance of the truck APU to the micro-CHP project is not obvious.

Project strengths:

- The project management and planning is a strength of this project.
- This project is very successful in capturing performance and cost-related data.
- This project is an excellent opportunity for data collection.
- The focus and attention to detail in generating, collecting, and reducing the field data is a strength.
- This is a well-laid-out and -executed research project that is hitting the milestones and producing good useable results.

Project weaknesses:

- Only one manufacturer is included; however, there are limited manufacturers in this range of CHP systems.
- This project lacks information on areas needing technical improvement (research and development).
- In future demonstration projects, this project should include the local AHJ in the activity early and include the AHJ as a collaborator. It will help with getting adoption by the local AHJ on additional projects.
- Although the approach was solid and the user partners are from different "markets," it appears all installations were in relatively moderate climates. Perhaps the study and demonstration would benefit from at least one "cold"-weather installation.

Recommendations for additions/deletions to project scope:

- Some additional details in the report/analysis would be useful.
- This project should continue as laid out in the statement of work. As more U.S. fuel cell manufacturers provide commercially available products, additional demonstrations may be required.

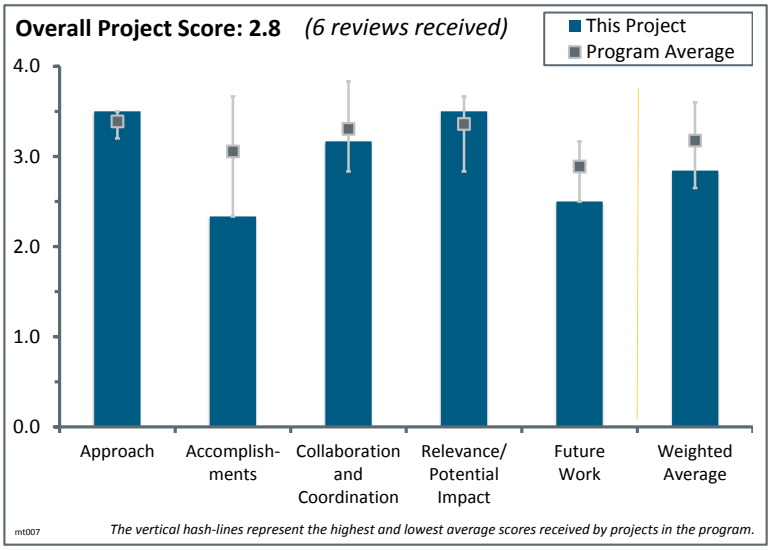
- This project should track the cost of ownership and then project it for the life cycle. The project should also compare the greenhouse gas emissions over the life cycle and compare them to a state-of-the-art central power plant for equivalent natural gas consumption.

Project # MT-007: Landfill Gas–to–Hydrogen

Shannon Baxter-Clemmons; South Carolina Hydrogen and Fuel Cell Alliance

Brief Summary of Project:

The objectives of this project are to validate the business case and technical feasibility of using landfill gas (LFG) as a distributed generation option for hydrogen production and to transfer lessons learned that may be applicable for other candidate waste streams. This project surveys commercially available equipment to draw conclusions regarding the economic viability of the LFG-to-hydrogen approach for potential end users; demonstrates the technical viability of current systems to produce sufficiently pure hydrogen for use in automotive or other applications; and confirms that there is no adverse impact on fuel cell systems that operate on LFG-sourced hydrogen.



Question 1: Approach to performing the work

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

- The project quickly focused on major barriers, such as the LFG cleanup and the economics of producing hydrogen using LFG versus cryo-hydrogen.
- This is a good demonstration project where the host (BMW) looks at using landfill gas to reduce their consumption of fossil fuels. Their willingness to host material-handling equipment (MHE) powered by fuel cells and fueled by hydrogen from LFG is a tremendous opportunity for a good demonstration project.
- The initial plan was well laid out, but issues arose in fiscal year 2012 that were detrimental to the schedule, and the project has not yet recovered. The schedule and outcome of the project will suffer. A major barrier to the appropriate purity of the hydrogen has not been overcome.. If the course correction is made, this could still be a very good and successful project.

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

This project was rated **2.3** for its accomplishments and progress.

- This project has made outstanding progress in cleaning up LFG with the major impediment—the showstopper—identified.
- The project seems to be facing a serious hurdle in separating the nitrogen and oxygen from the LFG. The high nitrogen and oxygen content is unusual, indicating a serious issue in the separations unit.
- This project is significantly behind schedule. The main point of the project is to look at the viability of using LFG to make hydrogen onsite. The project should be more creative in solving the gas clean-up problem, and maybe should have some foresight to avoid it.
- The project is approximately 70 percent complete, but full demonstration of the equipment has not been accomplished. As this is the main goal of the project, there is some concern that the schedule will not be met. In research, not every project meets all of the goals set out in the statement of work, but the project missed an opportunity to reach back to DOE and DOE's partners to get help. The feasibility study portion of this project is accomplished and well received. With the issue of the purity of the hydrogen, the schedule is not likely to be accomplished without an extension.

- When drawing the gas from the landfill, air is often entrained. This results in high nitrogen and oxygen levels in the feed stock. The nitrogen becomes an issue due to being a diluent and forming trace amounts of NH_3 in the reformate.

Question 3: Collaboration and coordination with other institutions

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

- There is fantastic coordination among all participants, particularly in terms of doing work at a real manufacturing facility.
- The host seems to have been accommodating, considering the delays. The Gas Technology Institute (GTI) and its gas separation vendor may need to work closely together to resolve the problem.
- The project has worked very well with its project partners, including BMW, GTI, Ameresco, and the South Carolina Hydrogen and Fuel Cell Alliance
- The excellent collaboration with BMW remains a stellar aspect of this project. An unsung benefit is the rather large amount of in-kind support BMW is providing. Although not actually credited in the project's overall financials, this de facto co-funding is a key to the project's potential success..
- Based on the issues noted above, the collaboration needs to be increased.

Question 4: Relevance/potential impact on advancing progress toward DOE research, development, and demonstration (RD&D) goals

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

- The relevance is clear. This has the potential to be a model demonstration project.
- LFG is a potentially fantastic source of hydrogen for forklift fuel cell trucks.
- The project offers good opportunities on several levels. Cleanup of the trace impurities is often a challenge. It is unclear if this project has resolved this issue..
- This project supports the goals of DOE very well and could showcase a way to utilize a fuel source that could provide cost-competitive hydrogen. Multiple entities in the industry have been contacting the principal investigator of this project to track the progress and inquire about implementation at additional sites. It seems that there is good interest in the industry to see this application or similar applications succeed.
- This project has direct relevance to the Market Transformation program mission. The project takes advantage of local resources to build a demonstration site that pioneers a "doubly-green" technology. Even if the reformer never produces usable hydrogen, the project still has some relevance.

Question 5: Proposed future work

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

- The removal of nitrogen was identified as an issue, but there is no clear path to do it.
- The project needs to focus on solving the hydrogen purity issue and complete the six-month demonstration.
- Others are able to create good-quality gas (i.e., stuff suitable for use in SMR) from landfill emissions. The South Carolina Research Authority (SCRA) should have already contacted some of these groups and had a good handle on the next steps.

Project strengths:

- This is an excellent opportunity to use a renewable fuel in an MHE application.
- This is a well-laid-out concept with industry applicability. The project has not yet been completed, and industry is asking for the results. The feasibility study has been completed and shows good potential for future applications of a certain size to be cost-competitive.

Project weaknesses:

- The lack of expertise in landfill gas and pressure swing absorptions is this project's weaknesses.
- There are no clear paths to remove nitrogen. This project should do preliminary economics to see if it is economic, assuming nitrogen can be removed at a minimal cost. This should be a go/no-go decision.
- This project incurred a major hurdle with the hydrogen purity issue. This delayed the timeline. The project is asking the right questions to solve the problem now, but a couple of attempts that lead to dead ends delayed progress. This project can still be successful. An extension will need to be put in place for the project to complete all of the goals laid out. They will probably not be able to meet the current timeline.
- This reviewer has misgivings about the effectiveness with which SCRA has handled things with the supplier of the gas cleanup system, but as that outfit is not really a "collaborator," this did not affect the collaboration and coordination score.

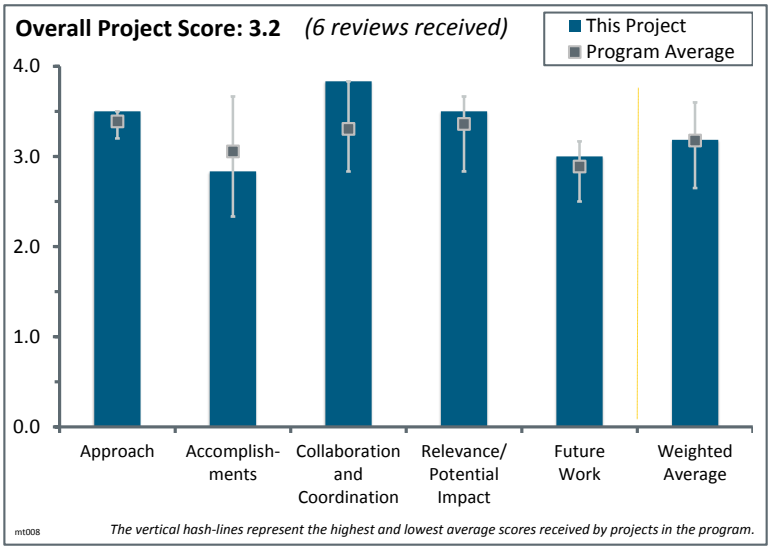
Recommendations for additions/deletions to project scope:

- An extension will need to be put in place for the project to complete all of the goals laid out in the project.
- This project should consider third-party evaluation/an alternate vendor for gas separations.
- This project should not continue experiments on nitrogen removal until the economic case is completed, assuming minimal cost for nitrogen removal.
- In future demonstration projects, this project should include the local AHJ in the activity early, and include the AHJ as a collaborator. It will help with getting adoption by the local AHJ on additional projects. A post-project debrief should be considered in which lessons learned are discussed and then amended in this report. The lessons learned may facilitate similar projects.
- The project should spend a few thousand dollars to locate and hire, as a consultant, a world expert on cleaning up LFG. Even if there is not enough money now to follow the suggestions, this could provide valuable insight into what it will take to make this a viable approach to providing feedstock for SMR systems in industrial environments.

Project # MT-008: Hydrogen Energy Systems as a Grid Management Tool

Mitch Ewan; Hawai'i Natural Energy Institute

Brief Summary of Project:



The objective of this project is to evaluate hydrogen energy systems for grid management through (1) demonstration of the use of electrolyzers to mitigate the impacts of intermittent renewable energy by regulating grid frequency; (2) characterization of the performance/durability of commercially available electrolyzers under dynamic load conditions; (3) supply of hydrogen to shuttle buses operated by the County of Hawaii Mass Transit Agency and Hawaii Volcanoes National Park; (4) performance and cost analysis to identify benefits of an integrated system, including grid ancillary services and off-grid revenue streams; and (5) evaluation of the effect on reducing overall hydrogen costs offset by value-added revenue streams.

Question 1: Approach to performing the work

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

- The project addresses all barriers from technical and operational barriers to getting signed agreements in place.
- This project uses a currently available hardware to encourage a utility company (a very conservative industry) to try something novel.
- The project approach is ambitious and well planned. However, it is not clear how the project will address the first objective of demonstrating electrolyzers as a grid management tool. It seems that all the work is through modeling and not through the actual installation and connection to the grid.
- Running an electrolyzer does provide a viable approach to converting geothermal energy to a form that can be (a) transported and (b) instantly converted to electrical energy. Comparing this storage medium with batteries is a good idea. However, it is not obvious how the comparison will be made or how rigorous it will be. Taking advantage of the resource (a hydrogen production facility) that results in the mainstream of the project by using its output hydrogen to run buses produces further "green" leverage that should make this project attractive to the local populace.
- This project has some serious problems getting all permissions and agreements with the owner of the location of the electrolyzer, and also with public acceptance due to the use of geothermal energy. However, the project has resolved the issues and managed to have everything ready now. They have also found a nice solution for the use of the hydrogen produced, which could lead to public acceptance because of its visibility. However, the project now has many fronts open including the hydrogen production with geothermal energy, the demonstration of grid balancing, the use of the hydrogen stations, and the use of the buses in very hard conditions. There is a risk of dispersing the efforts and that problems in one part of the project jeopardize the rest.

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 accomplishments and progress are excellent.
- This is an ambitious project that is often confronted with challenges. The main one here is obviously keeping on the timeline. There is not much progress in the actual demonstration of the electrolyzer in grid management.
- The project has made good progress by modeling the impact of a fuel cell on stabilizing the grid to securing agreements and funding from a number of sources. The stability of the electrolyser under real fluctuating loads still needs to be determined.
- The progress is slow. It has taken too long to get all permissions and to put all the equipment in place.
- Progress this year has been slow but seems to have picked up in the past few months.. The resulting need for a no-cost extension is very real; one hopes that the period requested is long enough to account for any more unforeseen delays. On the positive side, it seems that all but the regulatory-delayed activities have progressed as rapidly as possible, and the community acceptance issue now seems to be getting resolved.

Question 3: Collaboration and coordination with other institutions

This project was rated **3.8** for its collaboration and coordination.

- The collaboration and coordination are excellent.
- There is good collaboration between partners and also with other programs.
- This project has many, many partners and funding sources. The overall cooperation is impressive.
- This is probably one of the best lists of partners/collaborators on a project and includes levels of government and industry that are stakeholders. This adds to the complexity and coordination needs of the project, which has already had a slight impact on the schedule.
- This is one of the best-leveraged projects seen. Although significant non-DOE funds still come from the federal government, it is really impressive to see such a long list of contributors, all of whom seem genuinely interested in advancing the objectives of this project.

Question 4: Relevance/potential impact on advancing progress toward DOE research, development, and demonstration (RD&D) goals

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

- The relevance of this project should be self-evident. This project allows for the full utilization of the generating equipment (which is variable) and yet still results in a stable and predictable grid. This is a cool project.
- This project will have great impact on the ability of the grid to use fluctuating and steady-state renewable energy sources.
- The use of electrolyzer and hydrogen offer significant opportunities in the grid management and energy storage arena. It is not clear if the project will be able to fully deliver answers to some of the questions posed, but the relevancy and importance are certainly there.
- If the project succeeds, the use of hydrogen production for balancing the grid could become an option for the utility companies. This would greatly aid the use of renewable energy for Hawaii. The use of buses will help gather more data and allow the project to learn about their performance.
- The participation of the U.S. Department of Defense (DOD) in the project points to a national security-level interest in the project.

Question 5: Proposed future work

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

- This project was rated as good because the stability of the electrolyzer to fluctuating loads should be shown in the lab before going to a field test.
- This sounds like a commercial project.
- Most of the activity focused on completing the project is devoted to finishing out the work.

Project strengths:

- The concept and cooperation are strengths of this project.
- The collaboration and project objective in support of grid management are laudable.
- The high level of outside (state/DOD and other) participation is the main strength of the project.
- The ability to get all the partners to work together and get additional funding sources is a strength of this project.
- This project could have a lot of "visual" impact by the use of the buses. It covers all aspects, from renewable hydrogen production to its use for transport.

Project weaknesses:

- The project focus is very dispersed, and since it covers so many things, there are many risks.

Recommendations for additions/deletions to project scope:

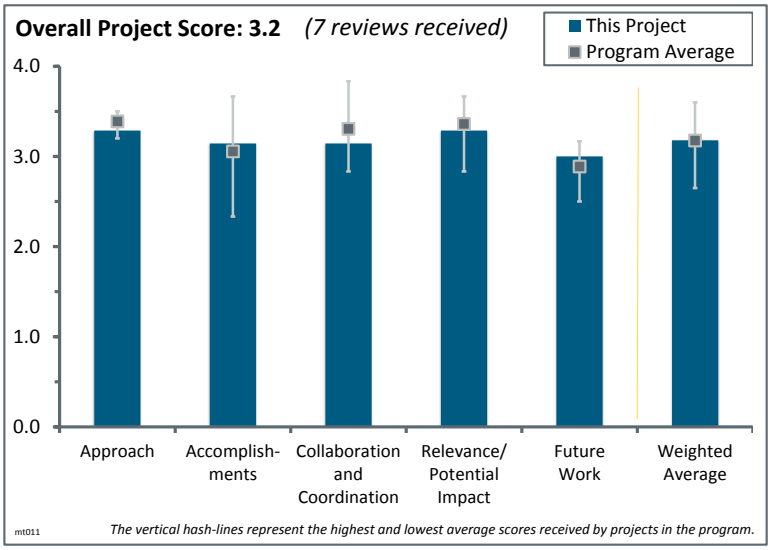
- This project should develop an option to expand and deliver some grid management capability.
- This project should increase the number of buses and connect the electrolyzers to a wind farm.
- This project should identify other potential uses for hydrogen and get real, off-site data on the impact of cycling loads on electrolyzer life.
- A post-project debrief should be considered in which lessons learned are discussed and then amended to this report. The lessons learned may facilitate similar projects.
- The project team should add an explicit task to develop an analytical format for comparing the benefits of the hydrogen approach with the battery approach. Although this comparison is mentioned as a key goal of the project, there seems to be a lack of attention to the way in which it will be done. The findings of the project will be much more useful to other sites if a formal cost–benefit analysis, or something close to it, comes out of it.

Project # MT-011: Ground Support Equipment Demonstration

Jim Petrecky; Plug Power

Brief Summary of Project:

This project creates a hydrogen-fuel-cell-based solution as a cost-competitive and more energy-efficient power source for baggage tow tractors (airport vehicles) compared to the incumbent internal-combustion-engine-powered vehicles. The fuel cell solution reduces consumption of gasoline and diesel fuels, achieves lower carbon emissions, and demonstrates a value proposition that shows decreased energy expenditures when compared to diesel-powered airport vehicles.



Question 1: Approach to performing the work

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

- The project is just starting, but it is very well focused and organized.
- This project and demonstration have a strong and solid approach. This has been a proven approach over several similar material handling equipment (MHE) demonstrations. The one component that is significantly new is the outside exposure.
- This is a well-planned project that appears to meet all of the requirements for a successful market transition effort. . Working with the largest customer and the leading original equipment manufacturer (OEM) in the market is a good way to approach the final product engineering and early deployment. The phased project plan, with a concrete go/no-go decision point, minimizes risk.
- The project will replace diesel engine baggage tow tractors with fuel cell- and battery-powered units. Hydrogen will fuel the fuel cells.
- The project kicked off in January 2013, and the component requirements have been identified. The biggest issue will be the timeline provided. In the first year, Plug Power states that both alpha and 15 beta units will be produced. This seems to be a very aggressive schedule and timeline.
- There is no clear path from demonstration to commercialization and several unknowns, which do not seem to be addressed. For example, it is unclear how these systems will operate outside, how the air quality at the airport sites will affect the units, and how the modified unit will perform. With a market of only 26,000 units per year nationwide, it is unclear how this technology will be expanded to other applications. This is a difficult deployment; however, these considerations should be part of the approach. Also, the choice of designing for one manufacturer limits the commercialization of this unit. While there seem to be some uniform standards across the industry, this is a unique tractor in that the seating is in the rear. It is not clear how this will be integrated into other units if the prototype is designed specifically for the Charlatte unit.

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.

- The work performed in only two months is already very promising.
- The accomplishments and progress are as to be expected.
- The project kicked off less than two months ago. The requirements have been defined, and partner coordination is in progress.

- The project was kicked off in January, and good progress has been made getting all players together and involved. Development of the new unit for deployment could delay this project and should be watched carefully.
- The rating is principally based on where the project is at this point, which is just getting under way. No significant progress has been made on objectives or barriers that can be accurately judged. Hopefully, this will move up during the next DOE Hydrogen and Fuel Cells Program Annual Merit Review.
- The project has only the groundwork laid, including the identification of requirements and some initial planning. Work on the alpha units needs to begin to meet the first year's deadlines. This project's kick-off meeting was held at the end of March, even though award was made in January.
- This project is only two months old. It appears to have started on time and to be proceeding according to schedule. It is important to note that DOE allows performers to "get ahead on the curve" on new projects by doing the first 60 days of work at their own risk before getting on contract. Had Plug Power done this, the progress would be ranked as outstanding.

Question 3: Collaboration and coordination with other institutions

This project was rated **3.1** for its collaboration and coordination.

- The Plug Power-led team is working with a hydrogen producer, airport authorities, the tractor manufacturer, and the end user.
- This is a good list of partners and is the best type of operating environment to demonstrate the value proposition.
- The coordination between the partners seems good for now. The close coordination between the baggage tow tractor (BTT) provider, the fuel cell system provider, the hydrogen station provider, and the end user is critical.
- Getting buy-in from the airport partners and Federal Express (FedEx) in this short timeframe is impressive. Careful management of these collaborations should be a priority. They will be key in the deployment stage of the project.
- Plug Power has assembled a good team of partners that seem to have bought into the project. The support from two host locations and FedEx will help this project succeed. Nuvera has also become a partner to supply the hydrogen fuel, which is a good partnering, as they bring experience doing these types of demonstrations.
- Although the performers appear to have established good working relationships with Charlatte and FedEx, contacts with other end-market customers and OEM suppliers seem to be limited.

Question 4: Relevance/potential impact on advancing progress toward DOE research, development, and demonstration (RD&D) goals

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

- The reported relevance is valid, and the task is commendable.
- Although it is relevant and has some potential impact, it is unclear how big a market this truly is. After FedEx, UPS, and a few major airports, it is unclear if this market dries up.
- This project opens a new market for fuel cells. It has good potential not only for the U.S. market but also for exportation to other markets.
- The project will replace diesel engines with clean fuel cell power, meeting Tier 4 emission standards. The fuel cell/battery systems are expected to reduce downtime since current diesel engine units need to regenerate the filters. A successful demonstration may attract other smaller airports to adopt these electric drive BTTs.
- The relevance of this project is aligned with the goals of the program; however, with the limited market size, the overall impact of this project, if successful, will be less significant in proving this technology against conventional technologies.
- This project could create a new product for the fuel cell industry, which would align well with the Market Transformation program goals. The overall impact may be smaller than hoped, as there need to be fairly specific situations for the fleet to be cost-effective. There may not be widespread applications that are

feasible, but there may be enough of a market to make it profitable for the fuel cell industry when bundled with other hydrogen/fuel cell applications.
- This project is well aligned with the Market Transformation program objectives. The projections of a two-year payback on investment for shippers at each major airport that adopts hydrogen-fueled Eagle MTT Electric Tow Tractors seems a little optimistic, but if true, it will certainly enable the life-cycle cost and performance so that it is on par with conventional technologies. (This is a Market Transformation objective in the 2012 *Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan*.) Even if the payoff takes three years, commercial adoption of hydrogen for vehicles in a demanding application like this one will get the attention of users in other transportation markets.

Question 5: Proposed future work

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

- The lessons learned were good, and hopefully that includes how to work with the authorities having jurisdiction (AHJs).
- The project has laid out a multi-year plan with go/no-go options. If it can meet all the milestones, this could be a successful project. An issue may occur with the very tight timeline in the first year to develop an alpha and 15 beta units. The future year's work seem reasonable and well laid out.
- The team is aware of potential setbacks and has built in go/no-go decision points that are appropriate. No decision point is outlined for proving the value proposition of this unit; this is key to aligning it with program goals and objectives.

Project strengths:

- Collaboration is the strength of this effort.
- The concept, collaboration, and the proposed future work are strengths.
- Collaboration and real-world potential are strengths of this project.
- This is an interesting project that builds on past forklift experience.
- This is a good project plan, and the very clear path to market makes this an attractive project.
- The demonstration of clean electric drive technology and the promise of capital cost recovery in 2.5 years due to fuel savings are strengths of this project.
- This project involves good partners and is well coordinated. It is well structured and, if successful, will open a new market for fuel cells.

Project weaknesses:

- The single unit and limited market team must outline how this technology can be applied to other markets.
- The hydrogen cost of $12/kg is high but understandable. Hopefully Nuvera and the team will explore options to reduce this cost.
- The market may require significant ground support equipment (GSE) population, which will limit the potential market.
- The market this project is targeting is very demanding and will give only one opportunity. The project has the potential to open a new market, but also risks closing it. The comparison with diesel vehicles is unfair since the comparison should be with battery vehicles. If the comparison is done against diesel, it is not clear if the environmental impact of hydrogen production has been included in it.
- The timeline of the first year is very progressive and may be too much for the project to accomplish. This may cause all the deliverables for the project to slip. The project must supply sufficient manpower dedicated to the project for it to be successful and meet the goals set up in the schedule.
- The number of sites at which this precise approach can be used is limited. Clearly the large-scale-shipper-material-transfer-truck market is not enough to sustain a business. What is unclear is whether this market will ever be net-positive for the Plug Power team/supply chain without DOE support.

Recommendations for additions/deletions to project scope:

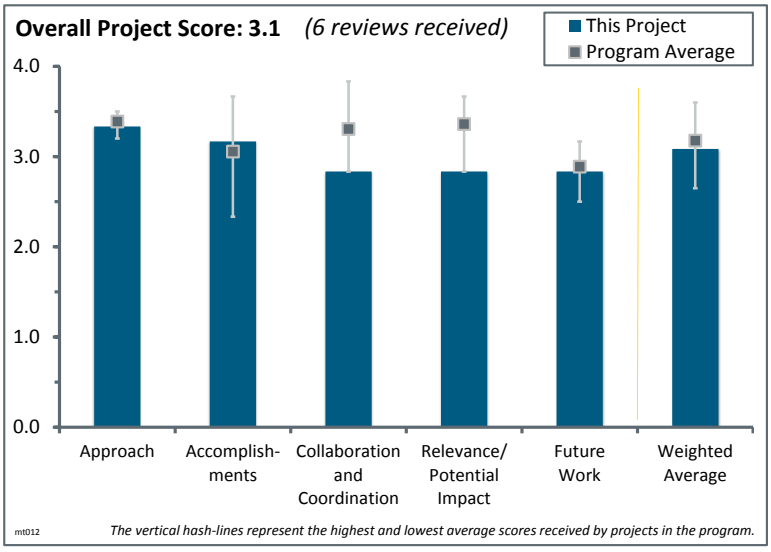
- This project should evaluate the use of steel tanks since the extra weight could reduce the need for the ballast and potentially reduce the cost of the system.
- This project should track the cost of ownership and greenhouse gas emissions and compare to the diesel-powered units they replaced. Projection of the costs and emissions should be done for the product life cycle. The independent assessment of project metrics will have higher credibility.
- The project should look at modifying the first-year deliverables. The project will probably not be able to create both alpha and beta units by the end of calendar year 2013. They will have trouble with permitting and need to address this early on in the project. The government point of contact should confirm and track progress on the permitting issues and track progress and milestones closely.
- The project should have serious discussions with other MTT truck makers as soon as possible. It might be good to add a specific task to the project that calls for the team to look at ways to rapidly add other fuel cell electric vehicle customers at the airports where reformers will be installed.
- This project should include other manufacturers in the design phase to plan for commercialization across the industry. Not including others could lead to tough competition during any commercialization stage.

Project # MT-012: Fuel Cells as Range Extenders for Battery Electric Vehicles

Aymeric Rousseau; Argonne National Laboratory

Brief Summary of Project:

The objective of this project is to evaluate the potential of using a fuel cell system to double the range of current battery electric vehicles. Aspects addressed in this research include the cost effectiveness of fuel cell systems versus battery systems for storage and for delivering power and determination of the optimal power usage in fuel cells to provide the lowest levelized cost of driving. The results are impacted by hydrogen cost, vehicle life, driving distance, and battery cost.



Question 1: Approach to performing the work

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

- This is a well-designed project from an analytical viewpoint.
- The modeling approach appears robust and sound. The current report does not compare the use of a gas engine as range extender for comparison purposes. That should be incorporated into the next look. Additionally, the analysis also considers the current state of battery technology, and it is constantly improving.
- The project has performed as expected. However, the results are predictable, and the way they are presented with the different charts is not clear (there is no resolution in the charts to really see any difference between options for the heavier vehicle).
- As this project is based purely on simulations, it is a low-cost way of evaluating fuel cells as battery range extenders. Definitive conclusions were produced, and this information will be valuable in proving the value proposition for fuel cells as battery range extenders.

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

This project was rated **3.2** for its accomplishments and progress.

- This project was completed on time and produced clear and defensible results.
- This project definitely showed the potential benefits of using a fuel cell as an electric vehicle cost reducer.
- The progress and accomplishments are as expected.
- The project has delivered the expected results.
- This study produced a relatively robust set of results, with specific findings that seem to validate the business case for the fuel cell electric vehicle (FCEV) approach to extending zero-emission vehicle range. If manufacturers and potential customers believe in these results, the study could be used to help promulgate this particular market as an early entry point for fuel cell systems.

Question 3: Collaboration and coordination with other institutions

This project was rated **2.8** for its collaboration and coordination.

- There has been some collaboration with other laboratories to obtain the necessary data and to harmonize results.
- The work of this project was accomplished almost entirely with in-house resources. Very little collaboration was necessary. The fact that the project objectives were accomplished on time and within budget means that relations with the subcontractor (Autonomie) were well handled.
- There is really no opportunity for coordination.
- This project lacks collaboration with real-world vehicle manufacturers.
- The level of collaboration from original equipment manufacturers (OEMs) is unclear.

Question 4: Relevance/potential impact on advancing progress toward DOE research, development, and demonstration (RD&D) goals

This project was rated **2.8** for its relevance/potential impact.

- This project has great relevance for FCEVs.
- This project met the need for a timely study of the FCEV hybrid approach to doubling the range of zero-hydrocarbon vehicles. The results seem to indicate that, in places where hydrogen is available, this approach would be more cost-effective than simply doubling the battery size, particularly for heavier vehicles.
- While this project was successful, it is based on a simulation and unfortunately has only so much value in achieving the goals of the program, which are to prove fuel cell technologies in real-world situations.
- It is hard to judge given the results and the current level of collaboration. The study suggests some opportunities, but it is unclear how that gets taken to the market.
- Hybridizing a battery electric vehicle with a fuel cell has very little potential. The study only tells us something that is already known: batteries are limited as a storage medium for electricity; hydrogen is a much better option. Hydrogen and fuel cells are more expensive when providing main power.

Question 5: Proposed future work

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

- Evaluating the approach for 2015 and 2020 using fuel cell cost targets is a great idea.
- The suggestion to look at different drive cycles and vehicle classes is probably worthwhile.
- Of the potential follow-on projects cited, validation of the study results using actual hardware embodiments of some of the vehicles studied would be the most interesting. Unfortunately, it also would be by far the most expensive. Looking at other vehicle classes (another proposed follow-on task) might be interesting, too.
- It is uncertain whether continuing this effort will provide value-added. The optimization of a system based on only a couple of variables can lead to questionable conclusions.
- The relevance of the results of the project, even if very interesting from a scientific/technical point of view, will not contribute to fuel cell and hydrogen deployment, nor to battery vehicles.

Project strengths:

- The results are clear and defensible.
- This was a well-rounded, well-executed project.
- The technical expertise in modeling is strong.
- The models seem sound, and the organization of the project is good.
- This project showed the impact of changing some variables on conclusions.

Project weaknesses:

- This project has no real-world demonstration and does not include vehicle manufacturers.
- The lack of real-world input and the limiting of the design parameters are weaknesses.
- It was not clear what the impact of CC on range was. Also, the project does not have good information on the impact of variable fuel cell costs.

Recommendations for additions/deletions to project scope:

- This project needs to show the impact of varying fuel cell costs on cents per mile.
- This project should include vehicle manufacturers in the analysis or at least to review findings.
- This project has ended and has achieved its goals. Adding a third dimension to the trade-off matrix (hydrogen fuel cost) to address the sensitivity of this scheme to the availability of hydrogen would probably be the best use of any additional money allocated to extend this project.
- The need for this effort should be reassessed.