Prologue

Dear Colleague:

This document summarizes the comments provided by peer reviewers on hydrogen and fuel cell projects presented at the fiscal year (FY) 2015 U.S. Department of Energy (DOE) Hydrogen and Fuel Cells Program Annual Merit Review and Peer Evaluation Meeting (AMR), held in conjunction with DOE's Vehicle Technologies Office Annual Merit Review on June 8–12, 2015, in Arlington, Virginia. In response to direction from various stakeholders, including the National Academies, this review process provides evaluations of the DOE-funded projects in applied research, development, demonstration, and analysis of hydrogen and fuel cell technologies. Under Secretary for Energy and Science Franklin Orr opened the joint plenary session with more than 1,000 attendees, followed by a keynote address from former Senator Byron Dorgan (D-ND). The joint plenary also included overview presentations from the Fuel Cell Technologies Office, the Vehicle Technologies Office, and the Basic Energy Sciences Program. A plenary for Hydrogen and Fuel Cells Program participants included overviews on each of the eight sub-programs: Hydrogen Production and Delivery; Hydrogen Storage; Fuel Cells; Manufacturing R&D; Technology Validation; Safety, Codes and Standards; Market Transformation; and Systems Analysis.

DOE values the transparent, public process of soliciting technical input on its projects and overall programs from relevant experts with depth and breadth of knowledge across a number of broad areas. The recommendations of the reviewers are taken into consideration by DOE technology managers in generating future work plans. The table in this report lists the projects presented at the review, evaluation scores, and the major actions to be taken during the upcoming fiscal year (October 1, 2015–September 30, 2016). The projects have been grouped according to sub-program and reviewed according to the appropriate evaluation criteria. The weighted scores for all of the projects are based on a four-point scale, with half-point intervals. To furnish principal investigators (PIs) with direct feedback, all of the evaluations and comments are provided to each presenter; however, the authors of the individual comments remain anonymous. The PIs are instructed by DOE to fully consider these summary evaluation comments, along with any other comments by DOE managers, in their FY 2016 plans. In addition, DOE managers contact each PI individually and discuss the comments and recommendations as future plans are developed.

In addition to thanking all participants of the AMR, I would like to express my sincere appreciation to the reviewers for your strong commitment, expertise, and interest in advancing hydrogen and fuel cell technologies. You make this report possible, and we rely on your comments, along with other management processes, to help make project decisions for the new fiscal year. We look forward to your participation in the FY 2016 AMR, which is presently scheduled for June 6–10 in Washington, DC. Thank you for participating in the FY 2015 AMR.

Sincerely,

Sunita Satyapal
Director
Hydrogen and Fuel Cells Program
U.S. Department of Energy

Hydrogen Production and Delivery

Project Number	Project Title *Principal Investigator Name & Organization*	Final Score	Continue	Discontinue/ Further Review	Completed	Summary Comments
PD-014	Hydrogen Delivery Infrastructure Analysis *Amgad Elgowainy; Argonne National Laboratory*	3.8	X			According to reviewers, the model developed in this project is robust and will be a valuable asset to the U.S. Department of Energy (DOE) and the state of California in establishing funding priorities. The reviewers praised the model for its basis in near-term costs, its variety of external checks and reviews, and its use of data from vendors and California Energy Commission solicitations. They also commended the project's analyses of the cost impacts of variables such as market penetration and station configuration. Reviewers suggested that future efforts involve increased collaboration with car companies, investors, and municipalities. In addition, they suggested expanding the model to simulate hybrid stations and station expansions.
PD-021	Development of High-Pressure Hydrogen Storage Tank for Storage and Gaseous Truck Delivery *Don Baldwin; Hexagon Lincoln*	3.4			X	Reviewers praised this project for its approach; relevance to the near-term fuel cell vehicle market; and collaboration with the American Bureau of Shipping, the U.S. Department of Transportation, Argonne National Laboratory, and Powertech. Reviewers commented that the design of 540 bar trailers would also be significant to the near-term market, and that the project should include the design of such trailers. They suggested codifying the project's designs to the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code Section XII if appropriate, and they noted that technologies to reduce the cost of carbon fiber are needed. Reviewers indicated that the project might fit better as a technology validation project, rather than a production and delivery research and development (R&D) project. This project is being completed in fiscal year 2015.
PD-022	Fiber-Reinforced Composite Pipelines *George Rawls; Savannah River National Laboratory*	3.5	X			Reviewers praised the project for its approach in codifying fiber-reinforced pipeline and for including testing of dry-wrap piping capable of on-site manufacture. Reviewers noted that the project has great relevance to lowering hydrogen delivery costs. Reviewers recommended expanding efforts to educate consumers on the adoption of the pipeline technology and searching for further ways to facilitate improvements to the technology and/or its installation and operation.

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PD-025	Hydrogen Embrittlement of Structural Steels *Brian Somerday; Sandia National Laboratories*	3.3	X			Reviewers praised this project for its technical robustness and calculation of the appropriate thickness of hydrogen pipelines, but they also emphasized the need for better interaction with stakeholders. Specific recognized strengths include the use of high-pressure test capabilities to simulate service conditions, the study of friction stir welds, and the accounting of residual stress. Reviewers suggested that future work include (1) a greater sample size of welds to ensure that results are representative of industry; (2) a greater range of temperatures and pressures to better simulate real-world pipeline conditions; and (3) greater interaction with pipeline operators and ASME to ensure the work is relevant to industry needs.
PD-031	Renewable Electrolysis Integrated System Development and Testing *Mike Peters; National Renewable Energy Laboratory*	3.2	X			The reviewers commended the near-term industrial relevance of this project for hydrogen production from renewable sources. They commented that the facilities, staff, organization, and approach are well suited to meet project its objectives. As a suggestion to strengthen the project, reviewers recommended that the team perform additional evaluations to determine the effect of load variability on long-term electrolyzer performance. They also recommended stronger engagement with outside experts.
PD-088	Vessel Design and Fabrication Technology for Stationary High-Pressure Hydrogen Storage *Zhili Feng; Oak Ridge National Laboratory*	3.3			X	Reviewers commended the project for manufacturing a representative prototype, and they praised the approach of developing finite element models that will be verified with cyclic testing. However, they stated that the project does not sufficiently address the vessel's relative cost benefit compared to existing technologies, and that the team has not adequately explained the role of concrete in the design. Reviewers suggested that the team better assess the lifetime of the tank, taking into account the impact of low volumes of hydrogen on the vent holes, as well as the properties of concrete.
PD-096	Electrolyzer Component Development for the Hybrid Sulfur Thermochemical Cycle *William Summers; Savannah River National Laboratory*	2.7	X			Reviewers commended the project's progress in developing the sulfur-depolarized electrolysis membranes and catalysts for the hybrid sulfur thermochemical cycle, and they appreciated the efforts on system analysis. The reviewers criticized the complexity and potential high cost of combining this thermochemical process with concentrated solar energy. Reviewers recognized the relevance of the work, but they expressed concern over the project approach's potential to meet hydrogen production cost goals. The reviewers recommended collaborating more extensively with experts in the solar thermal industry to better understand the long-term feasibility of this approach.

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PD-101	Cryogenically Flexible, Low-Permeability Hydrogen Delivery Hose *Jennifer Lalli; Nanosonic*	3.6	X			Reviewers commended the project's approach, accomplishments, and relevance to lowering the cost of dispensers. Specific strengths mentioned include: (1) developing a material that can tolerate the expected service conditions (e.g., temperature range, pressure range, solvents, and abrasion), (2) developing a novel means of adhering the hose to fittings, and (3) collaborating with relevant stakeholders. Reviewers suggested that the research team study the hose compatibility with hydrogen and polymer electrolyte membrane (PEM) fuel cells (e.g. the potential for off-gassing, leaching, and particulate formation), obtain guidance from standards development organizations to ensure the hose is tested for all relevant conditions, and obtain guidance from hose manufacturers on potential challenges related to crimping the hose to fittings.
PD-102	Analysis of Advanced Hydrogen Production Pathways *Brian James; Strategic Analysis, Inc.*	3.4	X			Reviewers commended the project team's development of analytical case studies for high-temperature solid-oxide electrolysis and fermentation, and they praised the approach, noting that it involves gathering information from research organizations and industry through quantitative questionnaires. The reviewers saw the results of the analyses as a necessary part of determining the feasibility of the evaluated technologies. The reviewers commented that it would be extremely valuable to evaluate near-term, low production volume costs in conjunction with the projected cost values based on high production volume. They also recommended that the team clearly articulate and document the current technical barriers to both solid oxide electrolysis and fermentation.
PD-103	High-Performance, Long-Lifetime Catalysts for Proton Exchange Membrane Electrolysis *Hui Xu; Giner, Inc.*	3.5			X	Reviewers commended the project for making progress toward lowering the platinum-group-metal catalyst loading in PEM electrolyzers (compared with commercial baselines) while maintaining electrolyzer performance and durability. The reviewers were pleased that all project milestones are being met, and they felt extremely optimistic that this work could have a significant near-term impact on PEM electrolysis performance and cost. They suggested placing more emphasis on efforts to gain a better molecular-level understanding of the catalyst surface structure reconstruction during operational conditions.

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PD-106	Reference Station Design *Daniel Terlip; National Renewable Energy Laboratory*	3.4			X	Reviewers commended the project for its thoroughness and strong relevance to near-term hydrogen station needs. They praised the project's clear identification of the economic challenges of station deployment and important potential value to the codes and standards communities in studying station risks. Reviewers suggested expanding the project to include designs of larger stations that may be valuable long-term investments, designs for fleets of material handling equipment, and designs for stations with on-site hydrogen production.
PD-107	Hydrogen Fueling Station Pre-Cooling Analysis *Amgad Elgowainy; Argonne National Laboratory*	3.7			X	Reviewers commended the project's relevance to lowering the costs of fueling stations. They praised the project for studying the energy consumption of pre-cooling in both continuous and on-demand modes of operation, collaborating with relevant domestic and international stakeholders, and explaining the impacts of alternative hydrogen cooling technologies. Reviewers suggested that project results be incorporated into the Hydrogen Refueling Station Analysis Model (HRSAM) and/or the Hydrogen Fueling Infrastructure Research and Station Technology (H2FIRST) Reference Station Design activities. In addition, reviewers recommended that the team expand analysis to account for the impacts of other factors on pre-cooling requirements, including the MC Method (the fueling protocol developed by Honda), dispenser location, ambient temperature of hydrogen gas, and regional U.S. location of the station.
PD-108	Hydrogen Compression Application of the Linear Motor Reciprocating Compressor *Eugene Broerman; Southwest Research Institute*	2.9	X			Reviewers commended the project's potential to lower station costs and improve reliability if successful; however, they recommended that the researchers complete a thermodynamic energy balance analysis to validate the compressor's potential. Reviewers noted that the thermodynamic efficiency of the device should be determined to ensure it is competitive with existing technologies, and that the temperatures of the piston and coils should be calculated to ensure they are within code requirements. Reviewers suggested that the team collaborate with organizations that have experience with the design of electric motors and compressors, as well as with hydrogen safety.

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PD-109	Steel Concrete Composite Vessel for 875 bar Stationary Hydrogen Storage *Zhili Feng;* *Oak Ridge National Laboratory*	3.3	X			Reviewers commended the project's potential to generate cost savings, if successful. They praised the project's progress to date and collaboration with experts in a wide range of areas such as material advancement, manufacturing, cost modeling, and commercialization. The reviewers expressed some concern that the technology might not be cost competitive with existing alternatives, and that the use of concrete may be unnecessary. They suggested that the research team assess the technology's maintenance costs and manufacturability, as well as complete an analysis of the strength of the vessel without concrete.
PD-110	Low-Cost Hydrogen Storage at 875 bar Using Steel Liner and Steel Wire Wrap *Amit Prakash;* *WireTough Cylinders*	3.1	X			Reviewers commended the project's potential to provide low-cost storage, contingent on successful achievement of project goals. Specific strengths mentioned include the approach of wire wrapping, the promising results of the burst test, and the assessment of hydrogen embrittlement risk. Reviewers noted the absence of technoeconomic modeling and expressed concern about the vessel's susceptibility to hydrogen embrittlement. They suggested expanding the project scope to include vessel acceptance by relevant codes, and partnering with station operators to better understand cost and operation requirements.
PD-111	Monolithic Piston-Type Reactor for Hydrogen Production through Rapid Swing of Reforming/Combustion Reactions *Wei Liu;* *Pacific Northwest National Laboratory*	3.0	X			Reviewers commended the project for achieving significant progress toward screening high-performance CO_2 sorbents for use in the swing-reactor for reforming bio-derived liquids, and they appreciated the initial efforts in technoeconomic analysis. They expressed some concern that the project does not sufficiently address the likelihood of poisoning and coking in the reforming of bio-oil. The reviewers suggested that the team expend more effort on catalyst R&D in order to reach the goals within the projected timeline.
PD-112	Reformer-Electrolyzer-Purifier for Production of Hydrogen *Fred Jahnke;* *FuelCell Energy, Inc.*	3.3	X			The reviewers praised the project's reformer-electrolyzer-purifier approach as a low-risk, high-impact technology with the potential to achieve <$2/kg of hydrogen in the near term. They gave specific credit to the experienced project team and its focused and realistic goals. However, the reviewers pointed out that the carbon emission of the technology was not sufficiently discussed, and that the "free" heat source that was used as an input in the Hydrogen Analysis (H2A) technoeconomic analysis was inadequately justified.

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PD-113	High-Efficiency Solar Thermochemical Reactor for Hydrogen Production *Tony McDaniel; Sandia National Laboratories*	3.1	X			The reviewers commended the project for its relevance to long-term, large-scale renewable hydrogen production, as well as for its effective project planning and division of well-defined roles to capable partners. The reviewers specifically praised the use of Materials Genome Initiative methods in materials discovery efforts to develop optimal redox materials for the solar thermochemical systems under development. Reviewers expressed concern over the complexity and potential high cost of the solar thermochemical approach, and they strongly recommended the development of more detailed technoeconomic analysis with clear technical and economic inputs and assumptions.
PD-114	Flowing Particle Bed Solarthermal Redox Process to Split Water *Al Weimer; University of Colorado*	3.1	X			Reviewers commended the project's progress, highlighting the areas of modeling and performance prediction, constructing and upgrading test reactor systems, and redox materials discovery. They praised the update of the AspenPlus model to include experimental results as an outstanding contribution and a major strength of the project. Reviewers expressed general concern over the complexity and potential high cost of the solar thermochemical approach, and they recommended the development of more detailed technoeconomic analysis with clear technical and economic inputs and assumptions. They also recommended the project team add collaboration partners with practical, large-scale engineering experience.
PD-115	High-Efficiency Tandem Absorbers for Economical Solar Hydrogen Production *Todd Deutsch; National Renewable Energy Laboratory*	3.5	X			The reviewers commended the project for its relevance to long-term, large-scale renewable hydrogen production based on the photoelectrochemical (PEC) approach. They were impressed by the project's progress in advancing the efficiency and durability of III–V semiconductor-based PEC devices, specifically highlighting the effective use of inverted metamorphic multifunctions and Pt/Ru surface treatments. Reviewers expressed skepticism regarding one of the project's proposed designs that would use 100x concentrated sunlight with low solution penetration and low resistive loss, and they stressed the need for a more detailed schematic of the new design. They also recommended the team pay additional attention to process scale-up issues.

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PD-116	Wide Bandgap Chalcopyrite Photoelectrodes for Direct Solar Water Splitting *Nicolas Gaillard; University of Hawaii*	3.3	X			The reviewers praised the project for its focus on an important class of chalcopyrite materials that has the potential to meet long-term DOE goals for PEC hydrogen production. They specifically commended the project team's ability to precisely tune the bandgap of these materials. Reviewers expressed some concern that the MoS_2 surface catalysts being developed may not be sufficient for achieving the project goal of >15% solar-to-hydrogen conversion, and that alternative approaches may be needed. They also recommended that the project team perform detailed technoeconomic analysis that considers the technology scale-up of chalcopyrite-based PEC systems.
PD-117	High-Temperature, High-Pressure Electrolysis *Cortney Mittelsteadt; Giner, Inc.*	3.3	X			The reviewers commended the project for screening and selecting candidate membranes that show long lifetimes (>30,000 hours) and high conductivity to permeability rations (>2) for use in membrane-based electrolyzers designed to operate under high pressures and high temperatures. The reviewers highlighted that this work contributes significantly to overcoming barriers related to electrolysis operated under these conditions to reduce the cost of delivered hydrogen. They recommended that the team develop a detailed cost analysis that clearly compares the cost of hydrogen prepared by high-pressure, high-temperature methods with the cost of hydrogen produced by low-pressure electrolysis coupled with a compressor.

Hydrogen Storage

Project Number	Project Title *Principal Investigator Name & Organization*	Final Score	Continue	Discontinue/ Further Review	Completed	Summary Comments
ST-001	System-Level Analysis of Hydrogen Storage Options *Rajesh Ahluwalia; Argonne National Laboratory*	3.4	X			Reviewers commended the project team's strong expertise in modeling thermodynamic, kinetic, and heat transfer phenomena and its development of a comprehensive and rigorous set of tools and methodologies that enable detailed predictions of materials and system performance. Reviewers also commended the project team for developing and understanding data from multiple research and development (R&D) efforts and integrating that data into cogent analyses from a wide spectrum of technical areas. Reviewers also noted the results of the relationship between high-density polyethylene (HDPE) liner properties and liner failure in Type IV tanks at cryo temperatures. Reviewers recommended the continued use of experimental data whenever available to test and benchmark models.
ST-004	Hydrogen Storage Engineering Center of Excellence *Don Anton; Savannah River National Laboratory*	3.5			X	This project is part of the Hydrogen Storage Engineering Center of Excellence (HSECoE). Overall, the reviewers commented that the HSECoE is well managed and appreciated the approach taken and progress made. The reviewers praised the down-selection process applied and the overall accomplishments of the HSECoE. They also applauded the HSECoE for the extent and quality of the collaboration and coordination among the partners and its relevance to the Hydrogen Storage sub-program. However, the reviewers expressed disappointment in the delays in evaluating the two prototype systems and felt the issues should have been solved more quickly.
ST-005	Systems Engineering of Chemical Hydrogen, Pressure Vessel, and Balance of Plant for Onboard Hydrogen Storage *Kriston Brooks; Pacific Northwest National Laboratory*	3.3			X	This project is part of the HSECoE. The reviewers commented that the project is well organized and executed. Reviewers cited the development and posting of the chemical hydrogen system model, evaluation of the liquid-nitrogen-cooled tank wall concept, and design of the consolidated valve block as noteworthy accomplishments. Reviewers commented positively on the collaboration to validate the cost analyses.

Project Number	Project Title *Principal Investigator Name & Organization*	Final Score	Continue	Discontinue/ Further Review	Completed	Summary Comments
ST-006	Advancement of Systems Designs and Key Engineering Technologies for Materials-Based Hydrogen Storage *Bart van Hassel; United Technologies Research Center*	3.5			X	This project is part of the HSECoE. The reviewers commended the United Technologies Research Center (UTRC) for its work on the publicly available hydrogen storage material system models. In particular, reviewers praised UTRC's work on the graphical user interface and the development of standard Simulink platforms for easy comparison across the various material-based storage systems. The reviewers were also pleased with UTRC's openness and flexibility in identifying and reacting to the host of challenges discovered throughout the life of the HSECoE. While reviewers applauded the work on the adsorbent system filters in relation to UTRC's generation of filter pressure drops at service flow rates, they mentioned that the cost analysis for these filters could use additional review.
ST-008	System Design, Analysis, and Modeling for Hydrogen Storage Systems *Matthew Thornton; National Renewable Energy Laboratory*	3.2			X	This project is part of the HSECoE. The reviewers commended the project for its effort in validating and making the framework system models that integrate vehicle, fuel cell, and storage system models with a user-friendly graphical interface that is publicly available to the research community. Reviewers also praised the extensive and highly coordinated collaboration between the project and the other HSECoE partners.
ST-010	Ford/BASF-SE/UM Activities in Support of the Hydrogen Storage Engineering Center of Excellence *Mike Veenstra; Ford Motor Company*	3.3			X	This project is part of the HSECoE. Overall, the reviewers commended the team for its work over the past year involving the evaluation of impurity effects, identification and mitigation of potential system failures, and maximization of metal-organic framework (MOF)-5 properties by compaction and enhancement in thermal conductivity. The reviewers expressed some concern about whether the results of the system model developed for MOF-5 can translate to other types of sorbent materials.
ST-044	Savannah River National Laboratory Technical Work Scope for the Hydrogen Storage Engineering Center of Excellence: Design and Testing of Adsorbent Storage *Bruce Hardy; Savannah River National Laboratory*	3.1			X	This project is part of the HSECoE. The reviewers commended the project team on its approach to designing, fabricating, and evaluating prototype hydrogen adsorbent systems. However, the reviewers also noted the delays in progress due to the leak issues encountered. Reviewers praised the strong collaborations between the project and the other HSECoE partners. Reviewers stated that the HSECoE should make a recommendation between the two heat exchanger designs based on its evaluation.

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ST-046	Microscale Enhancement of Heat and Mass Transfer for Hydrogen Energy Storage *Kevin Drost;* *Oregon State University*	3.1			X	This project is part of the HSECoE. The reviewers noted that the Modular Adsorption Tank Insert (MATI) heat exchanger design is innovative and addresses critical issues of cryo-adsorbent systems such as weight, volume, and charging time, while also addressing the impact on cost. While the reviewers were encouraged by the overall design concept, multiple reviewers raised concerns regarding the multiple setbacks and project delays observed during the last year of the project that significantly limited the project's progress. Specifically, they noted that the lack of any initial data from the system testing is particularly disappointing, given that the project is nearly over.
ST-063	Reversible Formation of Alane *Ragaiy Zidan;* *Savannah River National Laboratory*	3.0	X			Most reviewers found the project to be targeting appropriate barriers to lowering the cost of alane production. Several reviewers suggested that the project team include more computational guidance and use a design of experiments approach. Reviewers noted that this material is more appropriate for low-to-medium-power applications. Reviewers recognized the close collaboration between project partners. They also recommended avoiding duplicative efforts.
ST-093	Melt-Processable PAN Precursor for High-Strength, Low-Cost Carbon Fibers *Felix Paulauskas;* *Oak Ridge National Laboratory*	3.0		X		Reviewers commented that the project has a good potential to reduce cost. They expressed concern about the significant delay due to staffing and engineering issues. Reviewers commended the project for reaching out to previous BASF engineers and equipment vendors in dealing with the engineering issues. Reviewers suggested that the project develop a contingency plan and obtain additional external assistance to resolve the engineering issues. Reviewers also commented that the project needs to consider evaluating composite properties in addition to fiber properties. Reviewers recommended updating the cost model to better understand cost drivers.
ST-100	Hydrogen Storage Cost Analysis *Brian James;* *Strategic Analysis, Inc.*	3.4	X			Reviewers commented that the project is very relevant and has completed cost analyses for all key hydrogen storage systems under development to assist with the U.S. Department of Energy's R&D portfolio evaluation. Reviewers also commended the project's strong and close collaboration with national laboratories, original equipment manufacturers, and tank manufacturers. Reviewers noted that the project has done a good job in identifying major contributors to overall cost as well as pathways for cost reduction. Reviewers noted the need to provide cost uncertainties in general and include the range of possible costs for both sorbent systems analyzed for better comparison between them.

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ST-101	Enhanced Materials and Design Parameters for Reducing the Cost of Hydrogen Storage Tanks *David Gotthold; Pacific Northwest National Laboratory*	3.1	X			Reviewers praised the team's progress in predicting and validating tank model performance, as well as in validating lower-cost resin performance through actual tank burst tests. Reviewers also commended the strong collaboration among multiple partners with a variety of areas of expertise. They noted that these partners have contributed in useful ways. Reviewers suggested increasing the fiber supplier's participation. Reviewers also identified the need to consider the effect of the operating temperature during cycling, as well as the potential failure modes and the effect of loss of thermal insulation for cold gas operation.
ST-111	Thermomechanical Cycling of Thin-Liner, High-Fiber-Fraction Cryogenic Pressure Vessels Rapidly Refueled by Liquid Hydrogen Pump to 700 bar *Salvador Aceves; Lawrence Livermore National Laboratory*	3.3	X			This is a joint project funded by the Hydrogen Storage, Technology Validation, and Hydrogen Delivery sub-programs. The reviewers noted that the project is highly relevant because cryo-compressed hydrogen storage has been estimated as having high volumetric and gravimetric capacities. Pressure and temperature cycling is still needed to provide confidence in the technology. The reviewers also complimented the team for the physical installation of the cryo-pump and the associated hardware as well as the emphasis on ensuring safety during testing. The reviewers noted that the progress has been a bit slow and that future milestones could be harder to reach, but they expressed hope that the pace of progress will speed up as important aspects related to infrastructure and safety approval are completed. Reviewers noted that the team should put more emphasis on dormancy, better define project partners' roles in the project, and be more open regarding the potential liner materials.
ST-113	Innovative Development, Selection, and Testing to Reduce Cost and Weight of Materials for Balance-of-Plant Components *Chris San Marchi; Sandia National Laboratories*	3.3	X			Reviewers commended the project's combined experimental and computational approach for focusing on critical barriers. They emphasized the need to better integrate the experimental and computational work for model validation and prediction. Reviewers also praised the project's experienced and appropriate mix of partners, noting that the partners include balance-of-plant component and steel manufacturers as well as a fatigue testing organization.
ST-114	Next-Generation Hydrogen Storage Vessels Enabled by Carbon Fiber Infusion with a Low-Viscosity, High-Toughness Resin System *Brian Edgecombe; Materia*	2.9	X			Reviewers commented that the project has made good progress as a new project. They also noted the need for the team to consider sizing for the Materia resin and to focus on demonstrating the Materia resin in a pressure vessel configuration with 35% less fiber content. Reviewers also stressed the importance of including the additional costs associated with the vacuum-assisted resin transfer molding process, such as resin cost, cycle time, additional processing, and winding efficiency, in the cost analysis.

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ST-115	Achieving Hydrogen Storage Goals through High-Strength Fiber Glass *Hong Li;* *PPG Industries, Inc.*	3.0	X			Reviewers commended the project's potential for achieving cost savings by using high-strength glass fiber. They also emphasized the need to quantify the impact on gravimetric capacity. In addition, reviewers recognized the technical challenges presented by the high melting temperature and recommended considering countermeasures. Reviewers also commended the partners' well-balanced capabilities, noting that they range from modeling to experimenting to manufacturing.
ST-116	Low-Cost α-Alane for Hydrogen Storage *Richard Martin;* *Ardica*	2.7	X			The reviewers recognized the relevance of the project's focus to reduce the cost of alane production and investigate scale-up of the synthesis process for portable power applications. They questioned the project's potential for transportation applications. The reviewers expressed concern with the lack of details presented on the cost analysis and suggested that an independent organization verify the analysis. Reviewers praised the close coordination between project partners, but they identified knowledge transfer between partners as an area for improvement.
ST-117	Boron-Based Hydrogen Storage: Ternary Borides and Beyond *John Vajo;* *HRL Laboratories, LLC*	3.0	X			The reviewers found this project to be highly relevant. They acknowledged the success of the combined experimental and modeling efforts to effectively and rapidly screen and characterize many new materials. They noted that the results do not thus far show great potential to demonstrate reversible hydrogen storage. Reviewers recognized the close collaboration and integration between the project partners, theorists, and experimentalists as a strength of the project.
ST-118	Improving the Kinetics and Thermodynamics of $Mg(BH_4)_2$ for Hydrogen Storage *Brandon Wood;* *Lawrence Livermore National Laboratory*	2.9	X			The reviewers applauded the project team for its combined theory (i.e., density functional theory and phase-field modeling conducted at multiple length and time scales), synthesis, and characterization. They described this approach as a rational method to better understand kinetic limitations and address rate-limiting steps. The reviewers also indicated that the project has not completely addressed how it plans to handle the critical issue of multiple-phase formation during reactions, and they expressed concern that the team's work on validating models based on the Li-N-H system is distracting the researchers from their efforts on the Mg-based system. Reviewers suggested that the team test some of the models using existing literature data on nano-confined Mg-based systems instead of Li_3N.

Fuel Cells

Project Number	Project Title *Principal Investigator Name & Organization*	Final Score	Continue	Discontinue/ Further Review	Completed	Summary Comments
FC-007	Extended, Continuous Pt Nanostructures in Thick, Dispersed Electrodes *Bryan Pivovar; National Renewable Energy Laboratory*	3.0			X	Reviewers commented that the approach of making extended, continuous Pt nanostructures is promising based on previous results with similar structures. They commended the project for its progress toward generation of high-mass-activity electrocatalysts that are also durable against potential cycling. However, they expressed concern that the results have been demonstrated in only rotating disk electrodes (RDEs) and not in membrane electrode assemblies (MEAs). In addition, they were concerned that the membrane deactivation due to leached transition metal ions such as Ni^{+2} is not a major consideration. The reviewers had mixed recommendations, with some recommending that the project end on schedule with no additional work, and others suggesting that the project focus all remaining resources on getting the fuel cell test results that provide "proof" that the new electrocatalyst materials are worth pursuing.
FC-008	Nanosegregated Cathode Catalysts with Ultra-Low Pt Loading *Vojislav Stamenkovic; Argonne National Laboratory*	3.2			X	Reviewers stated that the outstanding capabilities of the world-class team in electrocatalyst synthesis and the partnership with world-class MEA fabrication and fuel cell testing entities have led to world-leading advancements in fuel cell catalyst design ability for performance and stability. They also noted that the project's very basic scientific approach to fundamental studies of the factors leading to high oxygen reduction reaction (ORR) activity and durability have been critical to developments throughout the field. Reviewers stated that the project would benefit from assessments in MEAs, but that industry collaboration may be required for these assessments.
FC-009	Contiguous Pt Monolayer Oxygen Reduction Electrocatalysts on High-Stability, Low-Cost Supports *Radoslav Adzic; Brookhaven National Laboratory*	3.3			X	Reviewers were particularly impressed by the novel approaches to catalyst synthesis that have been developed by this knowledgeable team of collaborators from industry, academia, and national laboratories. They noted that these novel approaches have resulted in "extremely high activities" in electrochemical cells. Reviewers suggested that additional collaboration with industry is required to improve MEA performance.
FC-017	Fuel Cells Systems Analysis *Rajesh Ahluwalia; Argonne National Laboratory*	3.5	X			Reviewers commented that the project's complete fuel cell system model demonstrates an ability to predict the system-level impact of component-level changes. They stated that this ability comes from the project's great collaboration among highly qualified team members. Reviewers expressed concern that the model relies on performance and durability validation data that lack consensus and recommended that the team validate the system against stack and system data.

Project Number	Project Title *Principal Investigator Name & Organization*	Final Score	Continue	Discontinue/ Further Review	Completed	Summary Comments
FC-018	Fuel Cell Vehicle and Bus Cost Analysis *Brian James;* *Strategic Analysis, Inc.*	3.5	X			Reviewers were universally impressed with this project's approach. They stated that the project incorporates learning and feedback into future work, provides a systematic and effective framework for providing cost projections, and uses exemplary detailed and methodical approaches at all levels of the analysis. Reviewers expressed concern about the project's real-world applicability, including its model validation, benchmarking, and transferability.
FC-020	Characterization of Fuel Cell Materials *Karren More;* *Oak Ridge National Laboratory*	3.6	X			Reviewers commended this characterization project for being well integrated into the portfolio of DOE projects, having a highly collaborative nature and an excellent team, and making excellent progress with characterizing the ionomer layer of MEAs. Reviewers had few recommendations for the project, but one reviewer stated that a user-accessible database for distribution of data would be helpful.
FC-021	Neutron Imaging Study of the Water Transport in Operating Fuel Cells *Muhammad Arif;* *National Institute of Standards and Technology*	3.5	X			Reviewers stated that the project's unique approach and technique for identifying water in polymer electrolyte membrane fuel cells are its greatest strength. They also agreed that NIST facilities represent a significant focal point for diagnostics related to in situ water content analysis and provide a key technique for the fuel cell community. Reviewers recommended a greater focus on size and time resolution to capture dynamic processes.
FC-026	Fuel Cell Fundamentals at Low and Subzero Temperatures *Adam Weber;* *Lawrence Berkeley National Laboratory*	3.3			X	Reviewers were impressed with the team's expertise in most, if not all, of the critical areas that could lead to an understanding of water distribution in the cell and unanimously lauded this project for its collaboration among laboratories, universities, and industry. They found the project to be well designed with in situ and ex situ testing and praised the solid progress on integrating gas diffusion layer (GDL) properties into the transport model. Some reviewers commented that the project has still not produced insights regarding nanostructured thin-film (NSTF) electrodes during cold start.
FC-048	Effect of System Contaminants on Polymer Electrolyte Membrane Fuel Cell Performance and Durability *Huyen Dihn;* *National Renewable Energy Laboratory*	3.3			X	Reviewers stated that the project had demonstrated good progress, particularly in developing gas chromatography mass spectrometry (GCMS) methods to quantify contaminant concentrations. In addition, reviewers were impressed with the user-friendly and interactive website displaying the contaminants studied by the team and with the strength of the project team's collaboration. Reviewers noted that the project would benefit from a more rapid screening approach and from greater consideration to environmental effects such as heat and ambient environment.

Project Number	Project Title *Principal Investigator Name & Organization*	Final Score	Continue	Discontinue/ Further Review	Completed	Summary Comments
FC-052	Technical Assistance to Developers *Tommy Rockward; Los Alamos National Laboratory*	3.4	X			Reviewers unanimously lauded LANL's capabilities, facilities, and support for the fuel cell community. They were impressed by the number of projects LANL is able to support under the project's budget.
FC-065	The Effect of Airborne Contaminants on Fuel Cell Performance and Durability *Jean St-Pierre; Hawaii Natural Energy Institute*	3.0			X	Reviewers found the approach to be "reasonable," "correct," "well balanced," and "effective." They provided mixed comments on the effort to determine the effect of acetonitrile intermediate or reaction products on membrane conductivity, with some reviewers finding this work particularly interesting and others expressing concern that the degradation rate in reference conditions creates doubt regarding the reliability of the acetonitrile impact findings. Multiple reviewers expressed concern that an in-depth description of the mechanisms is not yet available.
FC-081	Fuel Cell Technology Status: Degradation *Jennifer Kurtz; National Renewable Energy Laboratory*	3.4	X			Reviewers stated that the project has provided a valuable service in collecting, analyzing, and communicating real-world data through its good relationships with fuel cell developers. However, they also stated that the project is limited in its ability to identify accurate trends by the voluntary nature of the data collection.
FC-097	Stationary and Emerging Market Fuel Cell System Cost Analysis—Primary Power and Combined Heat and Power Applications *Vincent Contini; Battelle*	3.0	X			Reviewers praised the strength of the collaboration partners. However, they expressed a number of concerns regarding the approach, stating that the project has not considered several real-world aspects such as the combined heat and power efficiency of low-temperature proton exchange membrane fuel cells and the cost of support after sale.
FC-098	A Total Cost of Ownership Model for Design and Manufacturing Optimization of Fuel Cells in Stationary and Emerging Market Applications *Max Wei; Lawrence Berkeley National Laboratory*	3.2	X			Reviewers liked the Total Cost of Ownership Model approach. They also noted that the Manufacturing Cost Model shows that solid oxide fuel cell (SOFC) systems are close to DOE cost goals. Reviewers were concerned that the project does not provide sufficient direction for research and development efforts.
FC-103	Roots Air Management System with Integrated Expander *Dale Stretch; Eaton Corporation*	2.8			X	Reviewers stated that the project is of great relevance because compressor cost is a key contributor to fuel cell system cost, and that the project includes collaborations among relevant partners such as a fuel cell integrator. They expressed concern, however, that the project has not met all of its targets and that there does not appear to be a path for meeting the targets. They recommended conducting integrated system testing and minimizing efforts on plastic component fabrication to focus more on closing performance gaps.

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FC-104	High-Performance, Durable, Low-Cost Membrane Electrode Assemblies for Transportation Applications *Andrew Steinbach; 3M*	3.1	X			Reviewers commented that the project brings together an excellent team of well-managed collaborators to address a critical challenge facing DOE—development of catalysts with inherently excellent performance and durability. They stated that the best-of-class MEAs exhibit promising results. However, the reviewers were concerned about the durability of the membrane, and that performance is still 10%–15% below 2020 targets. The reviewers expressed concern regarding the fundamental architecture of the NSTF catalyst layer structure and whether NSTF systems could ever be operationally robust.
FC-106	Rationally Designed Catalyst Layers for Polymer Electrolyte Membrane Fuel Cell Performance Optimization *Deborah Myers; Argonne National Laboratory*	3.1	X			Reviewers were impressed that the project has met almost all of the go/no-go milestones and that ANL has provided meaningful data on the effects of ionomer content and the type of organic solvent in ink. They commented that the project is well designed by a well-coordinated team of strong partners. However, reviewers expressed various concerns about the approach (e.g., engineering processes are ignored) and accomplishments (e.g., the performance-limiting property has not been identified). One reviewer recommended that the project team consider a PtCo catalyst because the project may be in a good position to clarify the leaching tendencies of Co versus Ni from a dealloyed catalyst.
FC-107	Non-Precious-Metal Fuel Cell Cathodes: Catalyst Development and Electrode Structure Design *Piotr Zelenay; Los Alamos National Laboratory*	3.3	X			Reviewers stated that the project's creative, capable, and collaborative team has made incremental progress in performance this year. They were impressed with the project's characterization accomplishments, including the Nafion mapping and x-ray absorption spectroscopy on Fe-only catalysts. Reviewers recommended additional durability studies.
FC-108	Advanced Ionomers and Membrane Electrode Assemblies for Alkaline Membrane Fuel Cells *Bryan Pivovar; National Renewable Energy Laboratory*	3.0			X	Reviewers agreed that the project's approach to utilize perfluoro polymer electrolytes is sound and worth exploring. They also stated that despite a diverse and strong project team, the project has made little progress this year due to setbacks in synthesis.
FC-109	New Fuel Cell Membranes with Improved Durability and Performance *Michael Yandrasits; 3M*	3.5	X			Reviewers stated that this project is relevant based on its potential for achieving performance and durability improvements and for cost reductions in the balance of plant (BOP). They lauded the project's key achievement, exceeding 0.1 S/cm at 50% relative humidity (RH), noting that this is a fivefold improvement over previous materials. Reviewers were concerned about a lack of data at high temperatures (90°C–120°C) and high humidity (100% RH).

Project Number	Project Title *Principal Investigator Name & Organization*	Final Score	Continue	Discontinue/ Further Review	Completed	Summary Comments
FC-110	Advanced Hybrid Membranes for Next-Generation Polymer Electrolyte Membrane Fuel Cell Automotive Applications *Andrew Herring; Colorado School of Mines*	2.8	X			Reviewers appreciated that this project's innovative approach using heteropoly acid (HPA) functionalized membranes is the only DOE project focusing on potentially game-changing PEM concepts. Despite this promising approach, reviewers expressed concern about the lack of progress to date and the inability of the project team to make reproducibly quality films. Reviewers recommended that the project team begin testing swelling, mechanical properties, low-RH performance, and durability.
FC-114	High-Throughput Synthesis, Oxygen Reduction Reaction Activity Modeling, and Testing of Non-Platinum-Group-Metal Polymer Electrolyte Membrane Fuel Cell Cathode Catalysts *Deborah Myers; Argonne National Laboratory*	2.9			X	Reviewers stated that the project team consists of strong team members who are collaborating well on a good theoretical approach to understanding the ORR active sites of a non-platinum-group-metal (PGM) catalyst. However, they expressed concern that the project team has not defined how much throughput is required and has too wide of a focus, noting that this has led to limited accomplishments.
FC-115	Affordable, High-Performance, Intermediate-Temperature Solid Oxide Fuel Cells *Bryan Blackburn; Redox Fuel Cells, Inc.*	3.1	X			Reviewers found that the project has made reasonable progress, including a power density of 0.95 W/cm^2 at 600°C. Reviewers also commented that the approach is appropriately structured with clearly defined go/no-go decision points. However, reviewers expressed concern that there has been no durability testing and that the project team has not planned for durability testing.
FC-116	Smart Matrix Development for Direct Carbonate Fuel Cells *Chao-yi Yuh; FuelCell Energy, Inc.*	3.2	X			Reviewers commented that the project team brings extensive experience in molten carbonate fuel cells and has demonstrated improved pore structure and durability. They also noted that the presentation did not include sufficient information on how existing accelerated testing would demonstrate 80,000-hour durability.
FC-118	Novel Non-Platinum-Group-Metal Catalysts from Rationally Designed Three-Dimensional Precursors *D.J. Liu; Argonne National Laboratory*	3.0			X	Reviewers stated the project team demonstrated good material synthesis, activity, and performance. Reviewers further commented on the remarkable activity and encouraging MEA data. Reviewers recommended that the project team begin testing and improving durability. Reviewers also recommended that the project continue investigating Fe-free non-PGM catalysts

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FC-119	Platinum-Group-Metal-Free Catalysts for Polymer Electrolyte Membrane Fuel Cells *Hector Colon-Mercado; Savannah River National Laboratory*	2.7			X	Reviewers commented that the project includes good input from industry and advances the state of the art for non-PGM catalysts. They expressed concern about the project team's approach, noting that catalyst evaluation relies on RDE measurement, the project team needs much more familiarity with this technique, and the RDE activity targets for this project were not revised as they were for other projects. Reviewers recommended that the project team establish collaborations with experts in catalyst theory and characterization.
FC-120	High-Performance and Durable Low-Platinum-Group-Metal Cathode Catalysts *Yong Wang; Pacific Northwest National Laboratory*	2.9			X	Reviewers found this project to feature good collaboration among laboratories to address DOE's goals for reduced cost. They stated that while RDE results have been good, there have been no MEA results. In addition, the reviewers commented that the project team has not provided a rationale for why indium tin oxide will improve durability.
FC-121	Magnetic Annealing of Pt-Alloy Nanostructured Thin-Film Catalysts for Enhanced Activity *David Cullen; Oak Ridge National Laboratory*	2.7			X	Reviewers stated that the strengths of this project are the technical skills of the group of collaborators it has assembled and the execution of the stated work. Reviewers commented that the electrochemical surface area (ECA), specific activity, and mass activity achieved for magnetically annealed Pt-alloy catalysts are all lower than for the catalyst as received. They recommended that the project team focus on addressing the existing problems rather than on sophisticated modeling and analysis.
FC-122	High-Conductivity, Durable, Anion-Conducting Membranes *Tom Zawodzinski; Oak Ridge National Laboratory*	2.7			X	Reviewers noted that the project has met its conductivity goals. However, they expressed concern that there is insufficient data to support the goal claims and that 0.1 Ohm/cm^2 is an insufficient goal. In addition, the reviewers commented that the approach is not sufficiently described, there is little evidence of collaboration, and the future work is overambitious. They recommended that the project team test whether the anion exchange membranes (AEM) lose KOH and thus conductivity during extended fuel cell operation at wet conditions.
FC-123	Advanced Hydroxide-Conducting Membranes *Yu Seung Kim; Los Alamos National Laboratory*	3.4			X	Reviewers stated that the approach of investigating multiple backbone chemistries is good and provides reduced risks. They also commented that the project team has made good progress in the number of membranes synthesized and analyzed and in meeting project milestones.
FC-124	High-Temperature and Low-Humidity Membranes *Cy Fujimoto; Sandia National Laboratories*	3.3			X	Reviewers stated that the project team has done good evolutionary work with existing membrane chemistry, demonstrating conductivity almost double that of Nafion at 120°C and ~30% RH. However, reviewers recommended that the project team focus on testing stability and mechanical properties.

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FC-125	Engineered Low-Pt Catalyst Layers *Mahlon Wilson; Los Alamos National Laboratory*	3.4			X	Reviewers noted that performance results exceed the milestone target of 550 mV at 1 A/cm^2 and 100% RH for MEAs with less than 0.05 mg Pt/cm^2. They stated that engineering a catalyst/ionomer interface with better oxygen utilization is a very good approach to meeting DOE cost targets and the modeling provides good guidance for the project.
FC-126	Semi-Automated Membrane Electrode Assembly Fabrication with Ultra-Low Total Platinum-Group-Metal Loadings *Stoyan Bliznakov; Brookhaven National Laboratory*	2.7			X	Reviewers were impressed that the project team has successfully engineered, developed, and deployed an automated system for the fabrication of electrodeposited catalysts directly on GDLs in a short period of time. However, they expressed concern about the poor air performance in MEAs and that plans to improve this performance probably do not go far enough. Reviewers recommended that the project team focus future efforts on diagnosing and resolving this poor performance.
FC-127	Durability Improvements through Degradation Mechanism Studies *Rod Borup; Los Alamos National Laboratory*	3.3			X	Reviewers found that this project aligns well with Fuel Cell Technologies Office barriers and that it exhibits excellent collaboration among strong team members. In addition, they commented positively on the balance between experiments and theory and on the team's ability to identify new accelerated stress test protocols. The reviewers noted that the project does not use state-of-the-art materials in some cases, such as in its carbon corrosion activities.

Manufacturing R&D

Project Number	Project Title *Principal Investigator Name & Organization*	Final Score	Continue	Discontinue/ Further Review	Completed	Summary Comments
MN-001	Fuel Cell Membrane Electrode Assembly Manufacturing Research and Development *Michael Ulsh; National Renewable Energy Laboratory*	3.4	X			Reviewers noted that the approach for the project is very good and that collaboration with industry and other partners has been, and continues to be, very good. Reviewers also noted that the National Renewable Energy Laboratory (NREL) made significant progress this year in further developing the reactive impinging flow technique, increasing its scale at high moving rates. The reviewers encouraged NREL to determine the statistical performance of each approach and increase its focus on correlating defect size (as detected in a webline) with fuel cell performance.

Technology Validation

Project Number	Project Title *Principal Investigator Name & Organization*	Final Score	Continue	Discontinue/ Further Review	Completed	Summary Comments
TV-001	Fuel Cell Electric Vehicle Evaluation *Jennifer Kurtz; National Renewable Energy Laboratory*	3.3	X			The reviewers believe that continuing to validate fuel cell vehicle performance and compare findings to technical targets remains essential to reaching the U.S. Department of Energy's goals, and that these insights are useful to a variety of stakeholders. Reviewers also praised the project staff for maintaining the cooperation of several automotive companies, and they suggested that these partners continue to provide data during increased rollout and commercialization. Reviewers suggested segmenting data based on vehicle model year, disaggregating vehicle classes, collecting data for fuel efficiency at one-quarter and full power for newer model vehicles, looking more closely at fuel cell stack vintage, and evaluating the effects of climate on vehicle performance.
TV-008	Fuel Cell Bus Evaluations *Leslie Eudy; National Renewable Energy Laboratory*	3.9	X			The reviewers noted that this project serves as the only consistent source of fuel cell electric bus (FCEB) data in the United States, and that evaluations use transparent and accurate methodologies to evaluate technical targets. Reviewers commended the coordination and cooperation with transit agencies over the many years, and they saw the focus on obtaining feedback from both bus drivers and passengers as highly valuable in gauging technology adoption. Reviewers suggested that the project: include hybrid diesel and battery-electric technology buses for comparison, investigate the effect of larger numbers of FCEBs at a single site, consider other geographic areas and fleets, and examine climate impacts on bus performance.

Project Number	Project Title *Principal Investigator Name & Organization*	Final Score	Continue	Discontinue/ Further Review	Completed	Summary Comments
TV-017	Hydrogen Station Data Collection and Analysis *Sam Sprik; National Renewable Energy Laboratory*	3.5	X			Reviewers noted that the project's efforts in data collection and data evaluation on hydrogen refueling stations have provided a long history of reliable information and greatly advanced knowledge on station characteristics and performance. Reviewers especially found data on maintenance to be valuable and relevant in deriving preventive operations and maintenance schedules in order to maximize the availability of stations and reduce costs. Reviewers recommended that the project team start identifying next-generation "open" retail stations in data reporting separately from previous-generation non-retail stations, as well as evaluate the correlation between usage of station and compressor failure events.
TV-019	Hydrogen Component Validation *Daniel Terlip; National Renewable Energy Laboratory*	3.0	X			Reviewers recognized the need for reliable data on the performance and failure modes of compressors and viewed this effort as important in the deployment of commercial hydrogen stations. While reviewers acknowledged that the team has generated useful data and made significant progress in the evaluations, they also noted that there has been limited operational data and run time. Reviewers suggested performing more hours of compressor testing, evaluating other compressor types, investigating the impact of start-up mode and frequency on compressor performance and failure modes, and adding a separate mass flow sensor to confirm the calculation of the mass flow.

Project Number	Project Title *Principal Investigator Name & Organization*	Final Score	Continue	Discontinue/ Further Review	Completed	Summary Comments
TV-020	Validation of an Advanced High-Pressure Polymer Electrolyte Membrane Electrolyzer and Composite Hydrogen Storage, with Data Reporting, for SunHydro Stations *Larry Moulthrop; Proton OnSite*	3.2	X			Reviewers indicated that the project has contributed considerable data in demonstrating hydrogen station performance. They also found the project to have a solid plan to reduce the cost of hydrogen through a combination of increasing efficiency and standardizing packaging of station components. They suggested that the project team document lessons learned related to station siting and approvals; consider how the project is supported by, and will support, automakers introducing fuel cell electric vehicles on the East Coast; and engage in additional collaborations with U.S. DRIVE Partnership tech teams. Reviewers further added that the data collected from this project should feed into engineering models such as the Macro-System Model (MSM) and Hydrogen Analysis (H2A) model to provide early market cost and performance data.
TV-021	Material Handling Equipment Data Collection and Analysis *Chris Ainscough; National Renewable Energy Laboratory*	3.8	X			Reviewers saw this project as having the potential to identify optimization potentials for commercialization of fuel cells in key early markets. Reviewers stated that major strengths of the project are the people working on it, the background knowledge, and interaction in the field. Reviewers stated that the project has shown excellent coordination with a variety of relevant industrial partners. Reviewers noted that suppliers are still voluntarily providing data which is a testament that they find the compiled results useful. Reviewers also noted that including fueling and operation times adds value to the data set, and that data collection on fueling behavior should continue.

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TV-025	Performance Evaluation of Delivered Hydrogen Fueling Stations *Ted Barnes;* *Gas Technology Institute*	3.4	X			Reviewers saw the involvement and contributions of capable partners as a strength, and they praised the progress achieved to date. Reviewers viewed the completion of the West Sacramento site data acquisition system and submission of initial quarterly data as significant project accomplishments, but they cautioned that the project team should focus intensively on working with permitting authorities for the final three project sites. They noted that having data from five stations will help validate the technology, and that project partners should document lessons learned to aid the industry in overcoming barriers for future hydrogen station installations. Reviewers further suggested that the project team address cost barriers.
TV-026	Development of the Hydrogen Station Equipment Performance (HyStEP) Device *Terry Johnson;* *Sandia National Laboratories*	3.6	X			Reviewers praised the project for being well designed and achieving significant accomplishments in a relatively brief time period. Reviewers viewed the organizations involved as having significant expertise, and they commended the collaborations with these partners. Reviewers cautioned the team about the potential changing standardization requirements (CSA HGV 4.3) and revision of SAE International J2601, and they remarked that it may be prudent to synchronize completion of this project with the publication of the revised standards. Reviewers further remarked that other stakeholders should also be informed of project progress, perhaps through SAE.

Project Number	Project Title *Principal Investigator Name & Organization*	Final Score	Continue	Discontinue/ Further Review	Completed	Summary Comments
TV-027	Station Operational Status System (SOSS) 3.0 Upgrade *Ben Xiong; California Fuel Cell Partnership*	3.4	X			Reviewers saw this project as valuable in addressing the barrier of public acceptance and as having the potential to contribute to the more rapid acceptance of fuel cell technology by consumers. Reviewers commended the project team's efforts in working with most stations to add real-time data, and they noted that integration with all stations is essential for the success of the project. Reviewers identified key project strengths as the adaptability of the system to different station configurations, the mobile app providing easy access to real-time station status, and the strong support from the members of the California Fuel Cell Partnership. Reviewers suggested that it would be useful to also include a customer feedback mechanism in the app design in order to gauge customer satisfaction and obtain feedback for enhancements.
TV-029	Performance and Durability Testing of Volumetrically Efficient Cryogenic Vessels and High-Pressure Liquid Hydrogen Pump *Salvador Aceves; Lawrence Livermore National Laboratory*	3.4	X			Reviewers noted that this project has demonstrated progress and generated useful operational data. They found the safety analysis conducted by the project team to be very thorough and capable of serving as a model plan, as well as a demonstration of the quality work done by the project team. Reviewers commented that the partners on the project possess complementary expertise and are well chosen for their ability to contribute. Reviewers suggested that the project team obtain further input from vehicle manufacturers (especially to evaluate whether the increased volumetric hydrogen density is worth the added cost and complexity of a cryogenic system), more fully specify performance benchmarks (e.g., cryo pump degradation over time and anticipated heat leaking into the thinly insulated vessel), identify the cost of the system, and analyze the economics and pressure excursions during dormancy. Reviewers noted the lack of a broader liquid hydrogen research community and stakeholders to share knowledge with, and thus also recommended that more emphasis should be put on collaborating with institutions outside the consortium.

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TV-030	Fuel Cell Technologies Office INTEGRATE Stack Test Bed and Grid Interoperability *Kevin Harrison; National Renewable Energy Laboratory*	3.4	X			Reviewers noted that this project provides a unique effort to adapt electrolyzers to the grid in an efficient and synergistic manner, allowing for better utilization of time-variable renewable energy sources. They commended the amount of progress the project has demonstrated in a short time frame on both electrolyzer technology and communications. Reviewers advised that the project could be enhanced by including utilities and Independent System Operators in order to obtain feedback on their experiences in incorporating renewables, as well as their needs.

Safety, Codes and Standards

Project Number	Project Title *Principal Investigator Name & Organization*	Final Score	Continue	Discontinue/ Further Review	Completed	Summary Comments
SCS-001	National Codes and Standards Deployment and Outreach *Carl Rivkin; National Renewable Energy Laboratory*	3.2	X			Reviewers praised this project for acknowledging the importance of efforts beyond the completion of the initial codes and standards. They saw the lack of outreach to states' authorities having jurisdiction (AHJs) through state fire marshals and building inspectors as a weakness. Reviewers recommended closer collaboration and better coordination with both domestic and international stakeholders to maximize the impact of this work.
SCS-002	Component Standard Research and Development *Robert Burgess; National Renewable Energy Laboratory*	2.4		X		Reviewers commended this project for developing a knowledge base of the hydrogen component reliability and component testing efforts that are key for commercialization. However, they noted that closer collaboration with other laboratories would permit those laboratories to better leverage their expertise and limit redundant efforts. Reviewers recommended investigating the operational wear of components previously in service and collaborating with industry and third-party testing entities.
SCS-004	Hydrogen Safety, Codes and Standards: Sensors *Eric Brosha; Los Alamos National Laboratory*	3.8			X	Reviewers applauded the project team's collaboration, citing the importance of sensor work and the focus on proper deployment. They noted the need for further collaboration with instrument makers and commercialization partners for more field testing. Reviewers recommended that the team place additional focus on testing in different environments and engage with major manufacturers.
SCS-005	Research and Development for Safety, Codes and Standards: Materials and Components Compatibility *Brian Somerday; Sandia National Laboratories*	3.8	X			Reviewers praised the technical expertise and collaborative efforts with industry stakeholders through the American Society of Mechanical Engineers. However, they identified the lack of more direct engagement with industry and coordination to harmonize standards at the international level as a weakness. Reviewers recommended better harmonization with activities taking place in the International Partnership for Hydrogen and Fuel Cells in the Economy and investigation of other alloy steels and stainless steels.
SCS-007	Hydrogen Fuel Quality *Tommy Rockward; Los Alamos National Laboratory*	3.6	X			Reviewers applauded the project team's technical competence and critical work in addressing key technical barriers to infrastructure and vehicle deployment. They noted the lack of collaboration and communication with academic laboratories as project weaknesses. Reviewers encouraged closer collaboration with domestic laboratories, code development organizations (CDOs), and standards development organizations (SDOs).

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SCS-011	Hydrogen Behavior and Quantitative Risk Assessment *Katrina Groth; Sandia National Laboratories*	3.6	X			Reviewers commended this project for its engagement with industry and its approach to addressing key technical barriers. They felt that the project's main weakness is the need for acceptance by AHJs and a path to adoption for regulations, codes, and standards activities. Reviewers recommended expanding the focus on liquid hydrogen in the Hydrogen Risk Assessment Model (HyRAM) and increasing the direct collaboration with industry groups to develop code change proposals and standard requirements for risk-informed decisions.
SCS-017	Hands-On Hydrogen Safety Training *Salvador Aceves; Lawrence Livermore National Laboratory*	2.9		X		Reviewers saw the project's focus on hands-on training and tools for education about interacting with hydrogen as its main strength. They identified the project's main weakness as the lack of understanding about whether the tools are effective in transferring knowledge during trainings. Reviewers' recommendations include examining other audiences (e.g., technical colleges and gas utilities) for these trainings and considering a certification element to validate the knowledge transfer during the trainings.
SCS-019	Hydrogen Safety Panel, Safety Knowledge Tools, and First Responder Training Resources *Nick Barilo; Pacific Northwest National Laboratory*	3.7	X			Reviewers praised the quality of the safety training content and safety knowledge tools and the coordination of the project's early adoption efforts. They identified the project's main weakness as the difficulties involved in accomplishing widespread adoption and deployment of the tools to ensure the appropriate level of training for all stakeholders. Reviewers recommended that the team expand video resources, improve leveraging of the Hydrogen Safety Panel (HSP), and evaluate the quantitative and qualitative impact of these resources.
SCS-021	National Renewable Energy Laboratory Hydrogen Sensor Testing Laboratory *Bill Buttner; National Renewable Energy Laboratory*	3.5	X			Reviewers praised the technical competence and expertise of the project team. However, they also noted the lack of communication with industry (directly or through a standard committee) to broadly share research. Reviewers encouraged the project team to couple the work with risk assessment tools to develop guidance on optimal sensor placement, installation, and maintenance.
SCS-022	Fuel Cell & Hydrogen Energy Association Codes and Standards Support *Morry Markowitz; Fuel Cell & Hydrogen Energy Association*	3.6	X			Reviewers commended this project for coordinating and facilitating communication with key stakeholders, both domestically and internationally. However, they identified the lack of engagement with ongoing research activities as a weakness. Reviewers suggested the project take on the role of interfacing between normative and research activities, as well as explore integrating efforts with H2 Tools and HSP to provide centralized access to information.

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SCS-024	Hydrogen Contaminant Detector *Daniel Terlip; National Renewable Energy Laboratory*	3.4			X	Reviewers praised this project for its evaluation of currently available technologies and related technical gaps, and for developing the associated requirements for cleanliness and testing of hydrogen fuel. They cited the lack of relevant collaborations and the approach to addressing barriers and technical challenges as weaknesses. Reviewers recommended interfacing with CDOs and SDOs to bolster data requirements and initiating outreach to instrument manufacturers to investigate a path forward.
SCS-025	Enabling Hydrogen Infrastructure through Science-Based Codes and Standards *Chris LaFleur; Sandia National Laboratories*	3.6	X			Reviewers complimented the project team's strategic interfaces with stakeholders and approach to addressing industry needs. They identified the lack of an outreach strategy for adoption of performance-based design methods by AHJs as the project's main weakness. Reviewers recommended demonstrating the results of a real case to encourage adoption among targeted stakeholders and focusing outreach on states with central jurisdiction (e.g., New York) to accelerate acceptance of the methodology.

Market Transformation

Project Number	Project Title *Principal Investigator Name & Organization*	Final Score	Continue	Discontinue/ Further Review	Completed	Summary Comments
MT-008	Hydrogen Energy Systems as a Grid Management Tool *Richard Rocheleau; Hawaii Natural Energy Institute*	3.4	X			Reviewers stated that this project will have an impact on the ability to use renewables by mitigating the grid instability caused by those renewables. Reviewers recommended continuing the project but noted that more attention is needed on data collection and determining a business case. They identified not having an operating system installed as a weakness. They stated that more economic analysis showing cost breakdowns of component equipment and operating expenses is an immediate need.
MT-011	Ground Support Equipment Demonstration *Jim Petrecky; Plug Power*	3.4	X			Reviewers reported that the plan to complete this project is reasonable and that progress to date is on schedule, scope, and budget. However, they mentioned that the cost of delivered hydrogen was not reported, which makes it impossible to understand the value proposition. Also, reviewers were concerned that the data set for fleet operations was not reported, since this data is critical for identifying further technology improvements.
MT-013	Maritime Fuel Cell Generator Project *Joe Pratt; Sandia National Laboratories*	3.5	X			Reviewers noted that this project seeks to develop, design, and test a hydrogen fuel cell generator for maritime power. They stated that the project continues to do an outstanding job of coordinating efforts among the fuel cell supplier, fuel cell customer, infrastructure support, and relevant regulatory agencies. They felt that good progress has been made to date; however, they noted that more attention is needed on cost analysis and potential markets.
MT-016	Fuel Cell Hybrid Electric Delivery Van Project *Jason Hanlin; Center for Transportation and the Environment*	2.3	X			Reviewers stated that while this is a good project in concept, it has fallen behind schedule because of supplier issues and other problems. Reviewers commented that the project has a good strategy and plan for implementation; however, they also noted that it has failed to deliver on its commitments to obtain the required cost-share resources. (This project has an upcoming go/no-go decision point.)

Systems Analysis

Project Number	Project Title *Principal Investigator Name & Organization*	Final Score	Continue	Discontinue/ Further Review	Completed	Summary Comments
SA-033	Analysis of Optimal Onboard Storage Pressure for Hydrogen Fuel Cell Vehicles *Zhenhong Lin; Oak Ridge National Laboratory*	3.1			X	Reviewers observed that the project approach is reasonable but felt it should examine fueling pressures in a continuum. They stated that the project would benefit from additional input and review from the original equipment manufacturers (OEMs). Reviewers noted that future consideration should be given to examining the impact of potential incentives, such as the Low Carbon Fuel Standard and Zero Emissions Vehicle programs.
SA-035	Employment Impacts of Infrastructure Development for Hydrogen and Fuel Cell Technologies *Marianne Mintz; Argonne National Laboratory*	3.5	X			Reviewers acknowledged the project is well developed and uses a sound approach of applying "input/output" modeling. They stated that the project has benefited from good collaboration with industry and academia, and that this collaboration makes the project useful for policymakers to understand the societal benefits of fuel cell electric vehicles (FCEVs) and the development of hydrogen infrastructure. Reviewers noted that the project team should consider expanding the model to include larger capacity stations, liquid delivery, and net job analysis.
SA-036	Pathway Analysis: Projected Cost, Life Cycle Energy Use, and Emissions of Emerging Hydrogen Technologies *Todd Ramsden; National Renewable Energy Laboratory*	3.5	X			Reviewers commented that the project is critically important and provides a clear and transparent understanding of current and future hydrogen pathway costs. They reported that the project collaboration is good but should be expanded to include input from industry stakeholders with specific technology expertise. They found that the pathway analysis and Macro-System Model (MSM) benefits from the linkage of multiple sub-program models to deliver a systems-approach for cost and greenhouse gas (GHG) assessment.
SA-039	Life Cycle Analysis of Water Consumption for Hydrogen Production *Amgad Elgowainy; Argonne National Laboratory*	3.6	X			Reviewers agreed the project has established a good fundamental understanding of water consumption associated with hydrogen pathways, and that this understanding is essential for comparing multiple fuel pathways and resource analysis. They noted that the project would benefit by expanding collaboration to multiple stakeholders, including the international community. They also recommended expanding the model to include mid-to-low–Technology Readiness Level hydrogen production technologies and a regional water assessment.

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SA-044	Impact of Fuel Cell System Peak Efficiency on Fuel Consumption and Cost *Aymeric Rousseau; Argonne National Laboratory*	3.5	X			Reviewers observed that the project strategy is sound and uses the well-respected ANL Autonomie model to assess the impact of future fuel cell improvements on FCEV cost and performance. They noted that the project results are extremely useful and relevant to the Fuel Cell Technologies Office (FCTO) in developing future research and development strategies. They recommended expanding the project to include sensitivity and parametric analyses of the complex issues of crosscutting vehicle performance and cost.
SA-045	Analysis of Incremental Fueling Pressure Cost *Amgad Elgowainy; Argonne National Laboratory*	3.6			X	Reviewers complimented the project's approach of including multiple refueling protocols and identifying the main cost drivers, such as the precooling requirements for multiple pressure levels. They found the analysis to be technically sound and robust. Reviewers felt the project would benefit from input from additional stakeholders, such as industrial gas companies. They recommended that the project team consider the price elasticity of refueling time for the consumer in its future work.
SA-047	Tri-Generation Fuel Cell Technologies for Location-Specific Applications *Brendan Shaffer; University of California, Irvine*	3.2			X	Reviewers stated that the project approach is reasonable but should have expanded the co-location strategy to include the benefits of integrating hydrogen with electricity and heat. Reviewers noted that the project provides good insight on the benefits of tri-generation and should be expanded to other regions.
SA-050	Government Performance and Results Act Analysis: Impact of Program Targets on Vehicle Penetration and Benefits *Zhenhong Lin; Oak Ridge National Laboratory*	3.3	X			Reviewers commented that the project includes an exhaustive comparison of FCEVs to other relevant powertrains to understand petroleum use and GHG emissions. They reported that the project has made excellent progress in assessing many scenarios of FCEV penetrations but has not fully explained the project goal of evaluating FCTO targets. They suggested that the project team consider expanding collaboration to multiple OEMs. Reviewers recommended that future work include scenarios based on FCEV rollout announcements from OEMs and other forecasts from the California Air Resources Board.
SA-051	Infrastructure Investment and Finance Scenario Analysis *Marc Melaina; National Renewable Energy Laboratory*	3.6			X	Reviewers applauded the project's progress and accomplishments in developing the Internet-based model to answer investor questions about hydrogen infrastructure decision-making. They noted that the tool is relevant to DOE goals, especially for engaging the financial, policy, and regulatory communities for risk and cost assessments. Reviewers suggested that the project team consider adding a few "standard" cases to the model as a starting point as well as regional factors.

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SA-052	The Business Case for Hydrogen-Powered Passenger Cars: Competition and Solving the Infrastructure Puzzle *Robert Rosner; University of Chicago*	3.0	X			Reviewers noted that the project is in the early stages of development and analysis, but that it would benefit from gathering data and input from multiple stakeholders. They felt the project team should elaborate on the project's value and applicability. The reviewers stated that the project's value would improve with input and review by industry stakeholders such as the financial community, OEMs, and industrial gas suppliers.
SA-053	Retail Marketing Analysis: Hydrogen Refueling Stations *Kent Schlesselman; Kalibrate*	3.4			X	The reviewers observed that the project team has a clear understanding and expertise in siting fueling stations, and they noted that this is relevant to projecting future hydrogen refueling infrastructure. They felt that the results of the project are limited by restricted access to the proprietary model and the lack of an accompanying user-friendly software tool that could be used by station developers. Reviewers reported that the project would benefit from additional input and calibration from hydrogen infrastructure providers, such as industrial gas suppliers. They recommended that the team consider expanding the analysis to other regions of the United States where there are plans to introduce FCEVs.
SA-054	Performance and Cost Analysis for a 300 kW Tri-Generation Molten Carbonate Fuel Cell System *Shabbir Ahmed; Argonne National Laboratory*	3.5			X	Reviewers acknowledged that the project's approach is comprehensive and effective in analyzing the actual costs and performance, with modeled fuel cell performance to assess opportunities for cost reduction. They observed that the project has made excellent progress and that the parametric analysis of multiple variables is well done. They noted that the project would benefit from additional input from industry stakeholders. Reviewers recommended improving the explanation of the project results and findings to accurately explain the inherent trade-offs between electricity, heat, power, and hydrogen.
SA-055	Hydrogen Analysis with the Sandia ParaChoice Model *Dawn Manley; Sandia National Laboratories*	3.1	X			Reviewers commented that the project has a good approach but is limited by the quality of the input data. They stated that the project team should improve the data quality, accuracy, and relevance by adding industry collaboration. Reviewers noted that the project team needs to differentiate between the project's efforts and models and other DOE models. They felt that FCTO will benefit from parametric analysis of multiple cases and scenarios from the ParaChoice model, but that data input and selection need to be refined to increase confidence in the model's output. They suggested that the project would benefit from additional collaboration with industry stakeholders.

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SA-056	Status and Prospects of the North American Non-Automotive Fuel Cell Industry: 2014 Update *David Greene; University of Tennessee*	3.6			X	Reviewers complimented the project on its approach and accomplishments in assessing how current and future policies support and accelerate the commercialization of non-automotive fuel cell technologies. They noted that the results of the analysis provide insight on early market behavior to two diverse industries—material handling equipment and backup power—and on industry acceptance of the technologies without market scale. Reviewers stated that the project has an adequate level of collaboration and input from key stakeholders. They recommended that the team refine the "learning curves" with data and calibration and consider adding supply chain, export markets, and market segmentation.