2015 — Systems Analysis
Summary of Annual Merit Review of the Systems Analysis Sub-Program

Summary of Reviewer Comments on the Systems Analysis Sub-Program:

The reviewers considered the Systems Analysis sub-program to be an essential component of the U.S. Department of Energy (DOE) Hydrogen and Fuel Cells Program's (the Program's) mission. They found the projects to be appropriately diverse and focused on addressing technical barriers and meeting targets. In general, the reviewers noted that the Systems Analysis sub-program is balanced between near- and long-term research and development (R&D) and well managed. They stated that the sub-program has extensive collaboration with industry, national laboratories, and academia, and that it exhibits the ability to address immediate analytical needs, meet overall objectives, and focus on supporting hydrogen infrastructure development.

Some reviewers commented that the sub-program is effective in providing analytical support and key insights for the Program's R&D efforts and guidance for R&D efforts to address key barriers. Reviewers also noted that the analysis and model portfolio is balanced and has made good progress toward understanding the issues, challenges, and opportunities related to achieving the Program's technical targets. In addition, reviewers commented that the models, tools, and financial analyses are helpful in understanding the current status of the technologies and near-term challenges; in particular, reviewers highlighted the development of the Hydrogen Financial Analysis Scenario Tool (H2FAST) and its benefit to states that are developing and evaluating infrastructure deployment.

Key reviewer recommendations for this sub-program include the following: (1) more emphasis is warranted on near-term market barriers and the transition to and early deployment of hydrogen fuel cell electric vehicles (FCEVs) and infrastructure; (2) international technological progress, policies, and implementation should be closely tracked, and the global learnings should be incorporated into the Program; (3) analysis of consumer behavior should continue and be explored with stakeholders; (4) low-volume production and market penetration should be incorporated into the cost analysis; (5) the FCEV fuel economy range should be updated and compared to current FCEVs; and (6) funding for the sub-program should be increased so that it can continue to address a wide range of analytical topics.

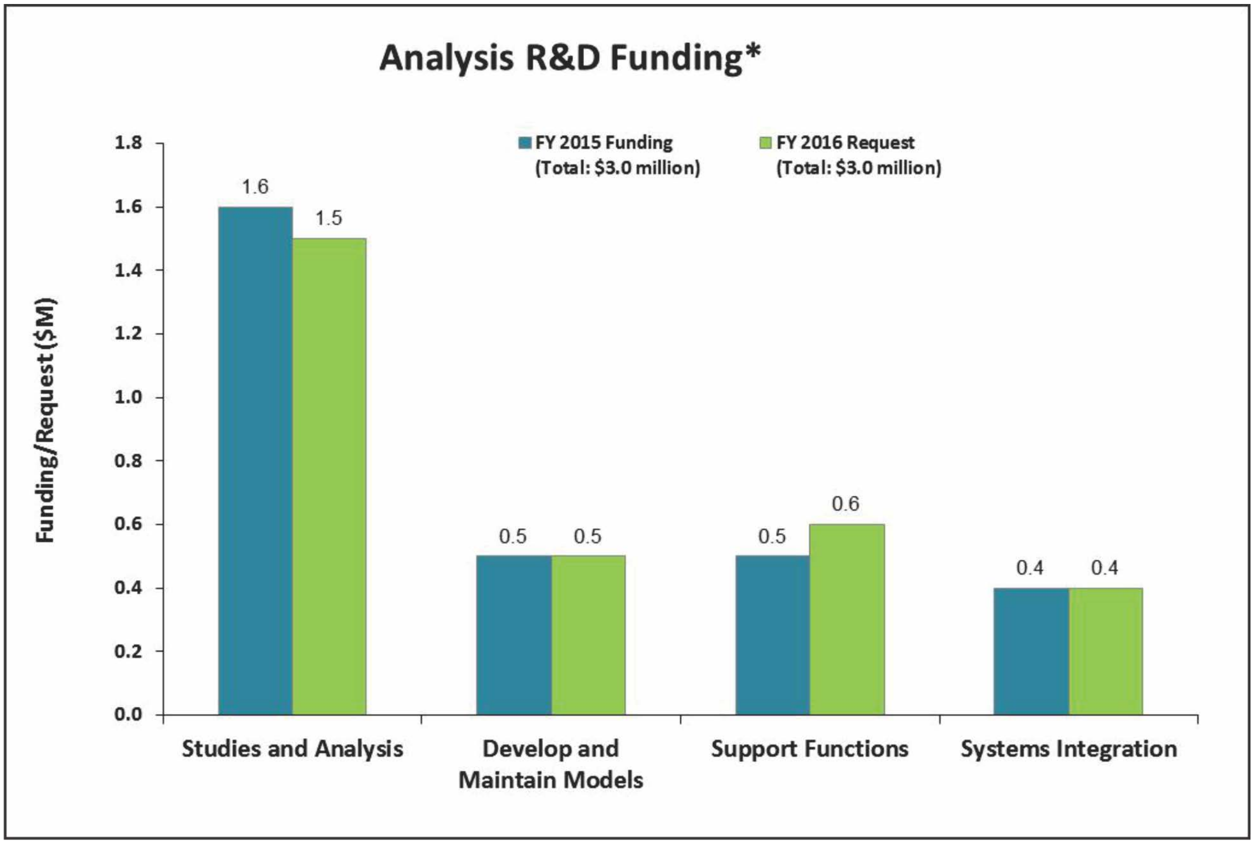
Systems Analysis Funding:

The fiscal year (FY) 2015 appropriation for the Systems Analysis sub-program was $3 million, as shown in the chart on the following page. Funding continues to focus on conducting analysis using the models developed by the sub-program. In particular, analysis projects are concentrated on analysis of hydrogen for energy storage and transmission, early market adoption of fuel cells, continued life cycle analysis of water use for advanced hydrogen production technology pathways, the levelized cost of hydrogen from emerging hydrogen production pathways, the impacts of consumer behavior, the cost of onboard hydrogen storage options and associated greenhouse gas (GHG) emissions and petroleum use, and hydrogen fueling station business assessments. The FY 2016 request level of $3 million, subject to congressional appropriation, provides greater emphasis on analysis of the employment impacts of hydrogen and fuel cell technologies; sustainability; early market adoption of fuel cells; life cycle analysis of GHG emissions and petroleum use for future hydrogen production technology pathways such as solar thermochemical and photoelectrochemical; the levelized cost of hydrogen from emerging hydrogen production pathways; and the impacts of consumer behavior.

Majority of Reviewer Comments and Recommendations:

The maximum, minimum, and average scores for the 14 Systems Analysis projects reviewed in the 2015 Annual Merit Review were 3.6, 3.0, and 3.4, respectively.

Infrastructure: The four analysis projects reviewed in this topic area received a favorable average score of 3.3 for assessing the costs of hydrogen infrastructure development and understanding the hydrogen infrastructure costs compared to other alternative vehicle infrastructure. Reviewers acknowledged that the projects enable a better understanding of the station configuration, hydrogen station components, the trade-off between consumer refueling time and vehicle range, and the cost of dispensed hydrogen at various dispensing pressures. In terms of next steps,



* Subject to appropriations, project go/no-go decisions, and competitive selections. Exact amounts will be determined based on research and development progress in each area.

they suggested the projects examine and apply learning-by-doing curves based on actual data for future stations, conduct more in-depth collaboration and consultation with original equipment manufacturers to calibrate costs, explore trade-offs between refueling rates, and investigate the cost for different pre-cooling designs and the price elasticity of refill time.

Model Development and Systems Integration: Four projects involving model development were reviewed, receiving an average score of 3.5. These projects received favorable reviews and were regarded as well aligned with the current sub-program goals and objectives.

Reviewers commented that the JOBS H2 (JOBS and economic impacts of Hydrogen) model provides a useful understanding of the range of potential employment impacts due to hydrogen infrastructure deployment and identifies focus areas for R&D funding. Reviewers recommended expanding the project to include an analysis of the infrastructure rollout in California, employment benefits of federal versus state or regional infrastructure investment, and an analysis option for the "net impact" of potential job displacement.

Reviewers acknowledged that expanding the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model platform to include water-use life cycle assessment addresses critical and relevant Program issues associated with hydrogen production, and that the comparative evaluation to conventional fuels is significant. They noted that the model enables industry stakeholders and energy producers to understand the water consumption sensitivity associated with electricity, biofuels, and process cooling methods. Reviewers also found the future work for the GREET project to be robust, but they noted the need for more collaboration with stakeholders, such as utilities. They also stated that future analysis should include uncertainty ranges for the reported results and regional impacts of fuel production on water consumption.

Reviewers commented that the *Infrastructure Investment and Finance Scenario Analysis* project with H2FAST is well thought-out and addresses a critical barrier in engaging the investment community. The reviewers noted that the Internet-based and Excel models represent a significant accomplishment and enable potential investors to make quick financial investment evaluations of hydrogen fueling infrastructure. They also stated that the project exhibits excellent collaboration and validation of the model. The reviewers recommended making the H2FAST model details and code available to the public.

Programmatic Benefits Analysis: Two projects were reviewed in this topic area, receiving an average score of 3.4 for assessing the costs and GHG emissions for multiple hydrogen production pathways. The reviewers commented that these analysis projects, which assess the Program's benefits (in terms of cost and reducing GHG emissions and petroleum use) and the emerging hydrogen pathways with renewable resources, are relevant to the Program's objectives and illustrate the merits of hydrogen as an alternative transportation fuel for light-duty vehicles. Reviewers commented that the projects have strong collaboration with industry and academic stakeholders and enable the benefits and impacts of emerging technologies to be assessed for a wide range of variables and scenarios. The reviewers recommended assessing near-term, lower-market penetration, and low-volume production in the scenario evaluations.

Studies and Analysis: Four analysis projects were reviewed, receiving an average score of 3.4. The projects covered a range of topics, including the status of non-automotive fuel cells, fuel cell cost analysis, and the application of tri-generation fuel cells for infrastructure development.

Reviewers commented that the *Status and Prospects of the Non-Automotive Fuel Cell Industry* project provides an understanding of how market incentives can excite disruptive technologies such as fuel cells in new markets. They found the analysis to be valuable for the assessment of current and future policy in support of fuel cell technology and product commercialization. The reviewers recommended expanding the work scope to explore the effect of state and market incentives, such as the California Self-Generation Incentive Program and Renewable Identification Numbers (RINs) for material handling equipment and hydrogen infrastructure development.

Reviewers noted that the *Impact of Fuel Cell System Peak Efficiency on Fuel Consumption and Cost* project has used a very good strategy and has applied the well-respected Argonne National Laboratory Autonomie model to configure FCEV subsystems and assess vehicle cost changes resulting from improved fuel cell peak efficiency. The reviewers acknowledged the project's strengths in assessing the impacts of meeting targets on the vehicle cost and providing key insights for setting R&D priorities. The reviewers recommended the results include a sensitivity analysis of key input variables to assess the main drivers for reducing the vehicle cost.

Reviewers stated that the *Tri-Generation Fuel Cell Technologies for Location-Specific Applications* project provides insight about the potential number and location of tri-generation fuel cell systems in an early FCEV market as an infrastructure build-out supplement. The reviewers observed that the project provides scenarios that will help developers consider the business case for tri-generation and help drive policies toward favorable incentives to assist technology implementation. Reviewers suggested sharing the project with key stakeholders in the Northeast for the development of a market transformation strategy.

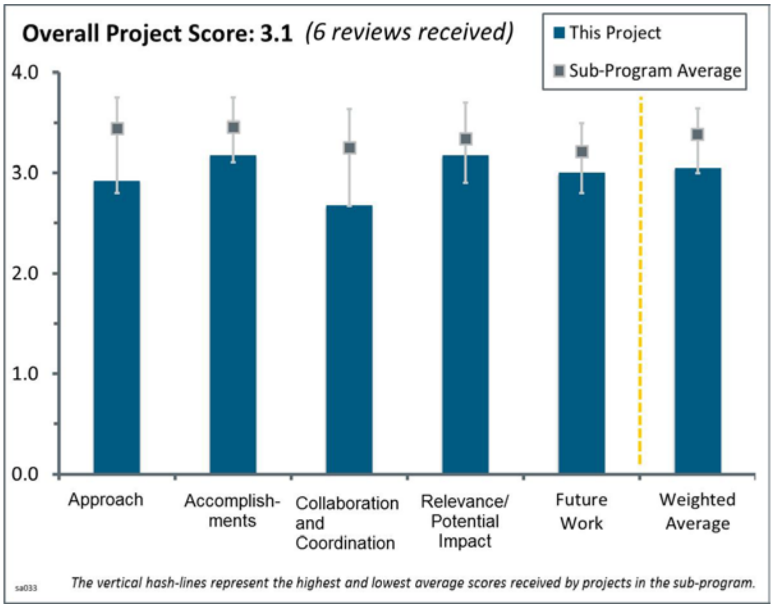
Reviewers commented that the *Performance and Cost Analysis for a 300 kW Tri-Generation Molten Carbonate Fuel Cell System* project provides a comprehensive approach to validating modeled capital and operating costs against actual costs at the Fountain Valley tri-generation fuel cell unit to compare efficiency, economics, and system integration. Reviewers noted that the project's collaboration and strategy provide a useful assessment of the tri-generation system and will be beneficial in assessing other tri-generation applications, such as buildings and hospitals, to help provide hydrogen fuel at reasonable cost, particularly during the transition phase. Reviewers recommended improving the presentation of the project results to convey the inherent trade-offs between electricity, hydrogen, and heat.

Project # SA-033: Analysis of Optimal Onboard Storage Pressure for Hydrogen Fuel Cell Vehicles

Zhenhong Lin; Oak Ridge National Laboratory

Brief Summary of Project:

The overall objectives of this project are to (1) develop a method to optimize onboard hydrogen pressure in fuel cell electric vehicles (FCEVs) by integrating a wide range of factors, (2) conduct case studies and provide useful insights for the industry and research and development planning, and (3) identify the optimal pressure that reduces system cost and increases market acceptance of hydrogen FCEVs..



Question 1: Approach to performing the work

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

- The project researcher employed an effective approach to this work by integrating all of the necessary parameters required to develop this optimization analysis, including hydrogen station costs, vehicle onboard storage cost, and the costs associated with refueling inconvenience. The external models and tools look like they are the adequate ones for this type of analysis.
- This project seeks to understand the optimal hydrogen pressure for onboard storage in a hydrogen-powered fuel cell vehicle based on tank and fueling station costs and driver inconvenience. As such, it does a good job of modeling a complex problem using a simple model, but the system is probably more complex than can be represented by the few parameters used here.
- The approach is very good, but it is not clear how it addresses the barriers of system life cycle assessments and codes and standards. Understanding optimal pressure given an array of dependent variables can help station owners determine the best configuration in the early market. The results could have been better presented—they were confusing and difficult to understand.
- The researchers have taken a reasonable approach to the difficult problem of addressing consumer behavior. For the work to be credible, it must somehow be validated with observations of actual consumer behavior.
- Pressures should be considered in a continuum, not just at the three pressure levels. The optimum level sought by the project might not be one of the individual pressure levels considered. Maybe there is a benefit of going to 15,000 psi—analysis should not be truncated at the round number of 10 ksi because it is the standard today. The volume of storage should be considered as a parameter as well. For example, hydrogen could be stored in the roof of the car if this would make the car twice as desirable; perhaps this is not the case, but it should be considered. Or perhaps vehicles could be 1 foot longer to increase range by “x.”
- It was not entirely clear what barriers were being addressed or what approach was used to address those barriers.

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 team made very good progress in terms of the upgrades to the Hydrogen Optimal Pressure model by including both range value and zero-emission vehicle (ZEV) credit values. This makes the analysis more complete. It will be good to see how the implementation of mixed pressures within the same station will affect the overall results of this analysis.
- The researchers have made very good progress in creating a tool that all users can use to gauge optimum hydrogen pressure. The ZEV aspects are intriguing, but the researchers need to closely follow any congressional action.
- The model development work has progressed well.
- Although the work was interesting and it was good to see that it is providing a publicly available model, there are some weaknesses in the modeling approach. First, it did not appear that the model was considering vehicles that were designed for high pressure but were being refueled at lower pressures. This would seem to be the most likely adoption of lower-pressure refueling. It also appears that policy and consumer impacts are being handled in a very simplistic manner. Because ZEV credits and consumer choice play so significantly into the results, it is important to spend time making sure these are a robust and detailed part of the model.
- The results are good, but it is difficult to understand them in the way they are presented. For instance, on slide 12, the principal investigator (PI) presented potential cost components in dollars/kilogram using variables that are not additive; ZEV loss is an original equipment manufacturer (OEM) cost, while hydrogen cost and refueling hassle are costs only from the driver's perspective. It would have been interesting for the presentation to have had at least one slide summarizing results from previous years, particularly those from the model, which are interesting and show the extent of the work that has been done.

Question 3: Collaboration and coordination with other institutions

This project was rated **2.7** for its collaboration and coordination.

- There is good collaboration with Argonne National Laboratory (ANL) and the National Renewable Energy Laboratory in terms of generating the proper input and parameters from the hydrogen station side. The researchers will get great benefits if they also try to establish some collaboration with the automobile industry, especially now that hydrogen fuel cell vehicles are being introduced to the market.
- The project features a good set of national laboratories working together. This project desperately needs direct input from OEMs. The OEMs have already decided on the pressure of hydrogen to be used in the next-generation rollout of cars; if this model is to be of any use, it needs to be part of the engineering design of the generation of vehicles after this one.
- Not having OEMs directly collaborating on this analysis seems like a major gap because pressure would have a direct impact on their products. Perhaps OEMs are not interested in collaborating. It may even be worthwhile to get a set of consultants with backgrounds in the OEM world to provide inside information (of course, no proprietary information should be shared).
- It would be good to see more collaboration with stakeholders. Although Air Products is a collaborator, it appears to be the only stakeholder, and the connection is through the U.S. DRIVE Partnership, which is a weak linkage. It would be good to see input from OEMs and suppliers.
- The PIs need to extend collaboration to organizations with access to consumer behavior data. Kalibrate has a project to site hydrogen stations and long-standing expertise in understanding consumer fueling behavior. Collaboration with Kalibrate would be a good place to start.
- A quick check with automotive manufacturers would have uncovered a number of potential improvements for the work. Otherwise, the collaborations are adequate.

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

This project was rated **3.2** for its relevance/potential impact.

- This project is relevant and provides essential analysis for the system cost of storage, codes and standards for storage, and market transformation to enable hydrogen-fueled vehicles. The synergistic relationship is very good between the cost of the tank and station with consumer needs and ZEV tax credits.
- This project aligns with some of the other pressure optimization work being done by ANL and the Fuel Pathways Integration Tech Team, which has been of interest to U.S. DRIVE partners. It is particularly interesting to understand the effects of ZEVs on market penetration.
- Even though 700 bar delivery pressure has been established as the delivery pressure for the fuel cell electric vehicles entering the market in the initial rollout, it is clear this type of analysis will be extremely valuable to station operators and consumers regarding what may be the most optimal delivery pressure once the market has been established.
- If the results can be validated, the model could yield important information.
- It seems that industry momentum for 70 MPa is so significant that it is unclear whether analysis could make a difference. However, this analysis provides an understanding of the trade-offs.
- Because the barriers this work is addressing are unclear, it is not apparent how the project is adding value. For example, it is not clear how this project is adding value above and beyond the very similar work in pressure analysis done at ANL, which seemed to have a more defined objective and approach to address barriers.

Question 5: Proposed future work

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

- Adding daily distance variability and uncertainty analysis will strengthen this project.
- It would be good to bring voices of OEMs into the “discussion.” It may be necessary to aggregate OEM contributions to avoid proprietary issues and competitive conflicts. Maybe questionnaires/reviewer feedback would be a good way to get OEM input.
- In addition to the proposed future work, the team should include collaboration with OEMs to obtain feedback on the model; perhaps the software tool should be shared with automotive manufacturers to conduct “deep-dives” and case studies and to get their input.
- The proposed work seems appropriate, but the end date stated at the beginning of the presentation will definitely need to be extended for the team to complete the proposed future work.

Project strengths:

- The project features strong modeling capabilities and expertise, as well as a good understanding of the issue.
- Having a publicly available model as an output is a project strength.
- The synergistic interdependence of all relevant factors is a strength.

Project weaknesses:

- This project suffers from being poorly defined. A better definition of the objective and the barriers would help a lot. The team should make sure the future work addresses these issues. Additionally, the way policy and consumer aspects are being addressed is overly simplistic. For example, it is probably not realistic to use a rental car cost as the cost of consumer inconvenience. This may be a realistic approach for someone who can plan well ahead and then make a rational choice. Consumers often do not have the luxury of planning well ahead, and they are well known not to make rational decisions. Inconvenience even one time during a year will often means a consumer will never go back to that brand.

- Early adopters have already decided on the tank pressure, and there is no real attempt in the model to accept that tank and station costs are very variable. Just looking at the Toyota Mirai and Toyota's ability to rapidly reduce tank costs shows that this is a dynamic market. The project needs to collaborate with several vehicle OEMs and potentially station developers for real-world experience.
- Weaknesses include the lack of OEM input and validation of consumer behavior, as well as the difficulty of using the tool.

Recommendations for additions/deletions to project scope:

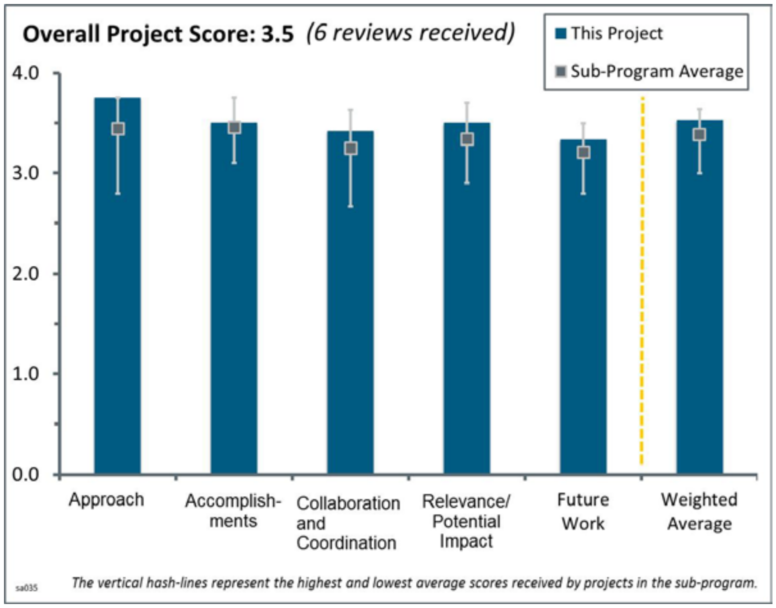
- The researchers need to seek a way to validate their model assumptions. A diary study might be useful. They could consider a survey, for example, to assess consumer preference for vehicles with various ranges. They should also work with companies whose business it is to understand how consumers behave.
- The team should consider collaborating with automotive manufacturers. The team should also include other potential incentives, such as low-carbon fuel standard credits and ZEVs post-2018. The team should also produce charts that reflect the points of view of different stakeholders—consumers, OEMs, and station owners—instead of lumping together all of the costs.
- The value this adds beyond the work at ANL (i.e., SA-045) needs to be more clearly defined.
- More interaction with OEMs is needed.

Project # SA-035: Employment Impacts of Infrastructure Development for Hydrogen and Fuel Cell Technologies

Marianne Mintz; Argonne National Laboratory

Brief Summary of Project:

The objectives of this project are to (1) develop a consistent framework to estimate the impact of hydrogen infrastructure investments by the Fuel Cell Technologies Office (FCTO) and others; (2) develop a tool to address barriers/gaps in the FCTO analysis/modeling portfolio; (3) evaluate the impacts of alternative hydrogen and fuel cell infrastructure deployment scenarios; (4) provide input for evaluating FCTO research, development, and deployment targets; (5) work with stakeholders to develop robust, user-friendly tools with appropriate functionality; and (6) report analytical results to demonstrate the benefits of the FCTO activities.



Question 1: Approach to performing the work

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

- This project uses a well-developed modeling platform for consistent analyses of job creation associated with the development of hydrogen fueling infrastructure. The analytic framework makes excellent use of existing models and analyses as the basis for its modeling.
- The project uses an input–output approach that captures supply chain input, which is very important. It distinguishes development versus operation. The project covers the full life cycle labor supply chain—planning, construction, equipment, and operation. The researchers looked at gaseous delivered hydrogen; it is unclear how the jobs landscape changes with the use of distributed generation, for which the system has to be monitored/maintained as well (and may add supply chain jobs).
- The team makes good use of preexisting models by incorporating them into the work. It would be good to know, at least conceptually, the sensitivity of the model to detecting losses from other sectors. This may be out of this project's scope. As it stands, this model calculates how many total jobs can be related to hydrogen, but not the net number of extra jobs created. Perhaps there could be a conceptual effort put toward identifying how many jobs are created versus shifted. Determining the net jobs seems more important. In the early years, it is understandable that this work on hydrogen stations is mostly creating additional jobs, but it is unclear when and how hydrogen station job activities subtract from other sectors to the degree that it would make a difference. For example, the team should imagine a 50% penetration scenario.
- The approach appears to be very sound and rooted in standard approaches for the subject. However, it might be good by way of explanation to review other activities or sector studies that have been evaluated using the same set of tools and general approach. Also, it is not certain that the model would not also be able to predict the impact of less gasoline consumption to generate a net impact. These types of models should be able to evaluate any level of marginal change.
- The approach is excellent, but some of the assumptions from California and other U.S. areas might require refinement with new incoming data.

- The analysis should consider even larger hydrogen stations. In the "longer" term, one expects to see stations as large as ~9,000 kg/day. The analysis seems to be artificially truncated at 1,000 kg/day and may not benefit from economies of scale.

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

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

- This project is progressing well. The initial analysis of the California hydrogen roadmap using both California multipliers and U.S. multipliers provides an understanding of the range of employment impacts that might accrue as a result of infrastructure deployment. The stochastic simulation capabilities that have been added to the modeling will be very useful in further understanding the range of employment impacts that might occur as a result of the rollout of hydrogen infrastructure.
- The ability to tie jobs to industry development on a project and/or system basis is of high value and very useful for industry, developers, and public officials.
- The project is important to improving understanding of regional differences and providing objective information.
- The results seem reasonable and show the impact of infrastructure rollout; it makes sense that development starts right away with start-up, then drops off, then grows, while station operations activities add jobs each year with new stations/larger stations. Economic activity peaks in 2022—the last year of new station development in the current plan, in the California case only. It is unclear what would need to happen beyond 2022, from an infrastructure perspective, to meet the needs of the hydrogen vehicle market, and whether there is currently a plan in place. The level of station development jobs is much higher for the United States case than the California case, as the development jobs are mainly imported from outside of the state of California. It would be useful to understand the job impacts if other station components are imported from overseas. It might be nice to see a proposed breakdown of total jobs versus location-specific information.
- The progress looks good. Inclusion of the California Fuel Cell Partnership rollout in the analysis is good. This is an important metric to track accurately and compare with other regions. A potential criticism of the project could be that it does not advance hydrogen directly into implementation; instead, the project tracks its progress. It is unclear how tracking progress fits DOE's goals.

Question 3: Collaboration and coordination with other institutions

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

- The collaboration on this project is very good. The JOBS Advisory Group, in particular, provides an excellent mechanism for feedback from stakeholders. The project team should better acknowledge and recognize the role played by other DOE researchers and industry collaborators in providing necessary data and modeling (e.g., Hydrogen Analysis [H2A] model, Hydrogen Delivery Scenario Analysis Model [HDSAM], and Regional Input–Output Modeling System [RIMS] modeling; National Renewable Energy Laboratory composite data products [CDPs]; and original equipment manufacturer [OEM] costs) for this project, although they are not direct collaborators.
- The collaboration with industry, academics, associations, and others is all appropriate and well received.
- The collaboration is good, and the project is integrated with many institutions.
- Collaboration and coordination were not specified that much on the slides, but a very good description of how the team is working with others and feedback loops is shown on slide 4. Quick response cards can direct users to access the jobs models and are an interesting idea for spreading usage/information sharing. An advisory board is an important point of a project such as this one; perhaps H2USA could be a member.

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

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

- Job creation has often been overlooked, but it is a key element for public support. This project fills a needed area to identify jobs and associated economic output development, and to build support for policy that will encourage project development that creates jobs in the supply chain.
- The main role of this work will be to prove to policymakers the value of hydrogen. In this way, it broadly helps DOE reach its goals of proving the effectiveness of FCTO funding.
- The project seems valuable and supportive of the Hydrogen and Fuel Cells Program.
- It is good to see the overall context of models, including the commerce model. This project is fairly different from other models in that it is not technology-focused. Maybe it is not as high of a priority in some ways, but as a unique and small project, it belongs in the portfolio and fills a gap.
- It will be useful for policymakers to understand the economic benefits of fuel cell vehicles and hydrogen fueling infrastructure, especially as public investment in infrastructure is considered. This project helps inform policymakers of those benefits. Because the number of jobs created may be low compared to the overall investment in hydrogen and fuel cells, it would be useful for the project to note that hydrogen fuel cell vehicles accrue other benefits that might be considered by policymakers, particularly environmental and greenhouse gas emission reduction benefits (although it is understood that analyzing those benefits is outside the scope of this study). In addition, because policy decisions regarding public infrastructure investment may be made at both the federal and state levels, it would be useful for this project to analyze the effects of federal investment in stations in California and California investments in hydrogen infrastructure (some of the hydrogen stations that will be part of the overall station rollout in California have received federal funding, but many have or will not).

Question 5: Proposed future work

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

- The future work for stationary fuel cell deployment and liquid hydrogen is important and timely to meeting future infrastructure needs for zero-emission vehicle rollouts and fuel cell deployment associated with end users and grid applications, and the work could potentially be used to justify public support and incentives.
- The project team is adding liquid hydrogen stations and larger stations. The team is also adding uncertainty analysis for fuel cells and rollout options. The presentation includes good examples of what could be funded if money were available—this information is not present in that many talks.
- The future work looks good.
- The future work is headed in a good direction. It is unclear whether uncertainties can be identified sufficiently.
- The project should be reviewed by high-caliber economists. Also, adding reviewers from the oil and gas and automotive OEM industries (with economic backgrounds) should be considered. These have to be the "right" people—folks who set policies and do macroanalysis for companies/governments. Also, downstream benefits and job contributions should be considered. Each car on the road contributes to the economy in terms of productivity and jobs. There should be a way to attribute economic benefit for the number of cars supported by the infrastructure. Even though fuel cell electric vehicles are a small percentage of the total fleet on the road, they have a proportional benefit—just the same as how hydrogen stations are a small percentage of the total fueling infrastructure. It is a significant omission to stop the analysis at the nozzle. Job and productivity benefits should extend to services rendered by the end result (miles traveled by vehicles).
- To the extent possible, it would be better for the project to focus on analyzing employment benefits and not on further model expansion/refinement (although it is recognized that some expansion of modeling capabilities may be needed). For future work, the project should consider alternative infrastructure rollouts, particularly potential infrastructure rollouts in regions outside California. It would also be useful if the analysis considered the impacts of actual/planned/projected infrastructure investments by states and the

federal government separately, particularly to understand the employment impacts of federal investments in infrastructure.

Project strengths:

- Good baselines have been set up; the team can replace current data with better data as they become available. Range versus uncertainty versus sensitivity analysis—these tools are linked now.
- The project proves the value of hydrogen. The project has good collaboration. It specifically compares California to the United States. It could help identify areas to focus funding more effectively.
- This project provides a useful understanding of the range of employment impacts that might accrue as a result of hydrogen infrastructure deployment.
- Strengths include (1) the objective analysis to identify job creation and economic development and (2) the easy-to-operate-and-use calculator tool.
- The project is relevant at the project level and flexible.

Project weaknesses:

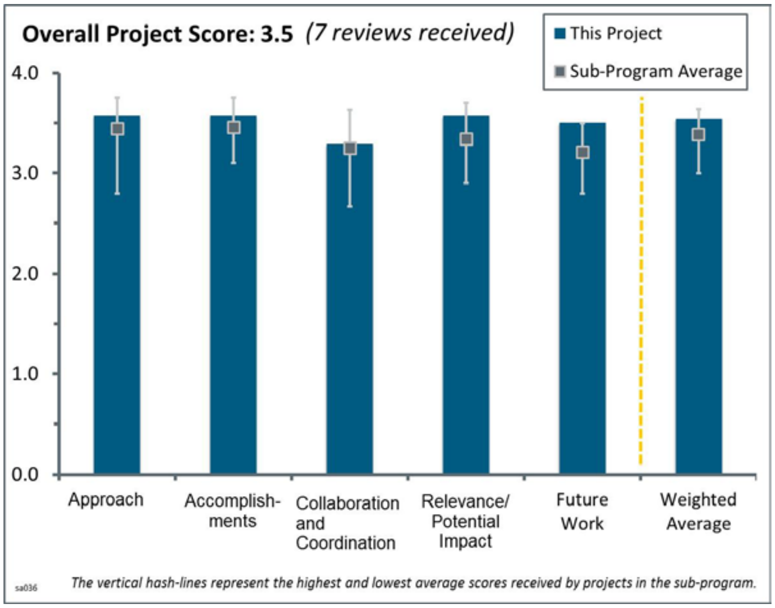
- In terms of gross versus net, the project does not take into account jobs displaced in gasoline dispensing, etc. This is challenging at this stage, as discussed by the presenter. It is not clear what a "good" or "acceptable" number of jobs created would be—there is a good deal of hype around battery plants creating lots of jobs, which has not materialized. It is also unclear what a good measure of a technology is in terms of how many jobs are created up the supply chain. These numbers seem more reasonable and realistic, but it is unclear whether they are "attractive" from a U.S. investment perspective.
- It is understood that a full macroeconomic analysis of job creation and job transfers is outside the scope of this analysis. However, from a policy decision-making perspective, it is difficult to propose public funding of hydrogen and fuel cell vehicles without knowing whether such funding will actually lead to greater employment or just a shift to producing/staffing hydrogen fueling stations instead of gasoline stations, and to producing fuel cell vehicles rather than gasoline vehicles.
- Weaknesses include the following needs:
  - Clarify direct, indirect, and induced jobs.
  - Confirm and refine, as needed, the difference in variables for application to California and other U.S. areas.
  - Consider a marketing plan, potentially for use with the U.S. Department of Commerce and/or the Small Business Administration, to encourage job-creating projects.
  - Consider whether/how many existing jobs are displaced.
- Simply tracking metrics could be considered noncritical because the model is not actually creating the jobs that it is tracking in a direct way, but rather it is creating them indirectly.
- The project is not able to determine net impacts.

Recommendations for additions/deletions to project scope:

- The project should consider infrastructure rollouts outside of California. Understanding the employment benefits of federal infrastructure investment versus state or regional infrastructure investment would be useful.
- The project team needs to consider a marketing plan and marketing partners to encourage use of the model and development of the appropriate public policies to encourage job-creating projects.
- The project's scope should be expanded to include the method of hydrogen generation, if it is not existing natural gas reforming plants.
- At some point, the project will have to look at net jobs. When there is high penetration, it is unclear when hydrogen station deployment becomes a zero-sum game.
- The project should include gasoline and calculate net impacts.

Project # SA-036: Pathway Analysis: Projected Cost, Life Cycle Energy Use, and Emissions of Emerging Hydrogen Technologies

Todd Ramsden; National Renewable Energy Laboratory



Brief Summary of Project:

The objectives of this project are to (1) determine cost, energy use, and greenhouse gas (GHG) emissions of hydrogen fuel pathways deployed in a mature market; (2) provide detailed reporting of hydrogen cost and capital costs of complete hydrogen fuel pathways to support fuel cell electric vehicles; and (3) report the life cycle of energy and feedstock usage and GHG emissions.

Question 1: Approach to performing the work

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

- The objective of the project is to determine the cost, energy use, and GHG emissions of different hydrogen pathways, assuming they are deployed in a mature market. The project uses existing models, tools, and studies by others to analyze different pathways. Seven prior pathways were reported out in last year's U.S. Department of Energy (DOE) Hydrogen and Fuel Cells Program Annual Merit Review meeting. The current activities added four new pathways not previously analyzed, involving pipeline delivery and dispensing at 700 bar. The use of preexisting analyses and studies is a very efficient use of data and avoids needless duplication of effort.
- This is a great example of the kind of analysis the Systems Analysis sub-program should be doing to help inform DOE's research and development (R&D) agenda. It points directly to reducing the costs of producing low-carbon hydrogen (production, compression, storage, and delivery) as a critical research objective. It shows the relative importance of each step to the total cost of vehicle ownership for different pathways, but it also clearly shows that compression, storage, and dispensing are critical for all pathways.
- This project takes a very sound approach by utilizing very robust tools (e.g., the Hydrogen Delivery Scenario Analysis Model [HDSAM]; the Hydrogen Analysis [H2A] model; and the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation [GREET] model) that are essential for estimating hydrogen production and delivery costs as well as for estimating GHG emissions. The analysis demonstrates good consistency by following the same approach used in previous analyses on eight previous technology pathways. The four new emerging pathways being analyzed will provide DOE with valuable information in order for research work to continue on these advanced production pathways.
- This is a critically important task that needs to be performed so that DOE can make informed decisions about funding, demonstration, and implementation of hydrogen production pathways. The task is fully integrated into the existing modeling framework.
- Analysis tools supporting the project are well developed and vetted through previous analysis work. The analysis of emerging hydrogen production pathways leverages DOE's investment in past work and provides a common basis for evaluating existing and future production technologies and hydrogen supply pathways.
- The work is pretty good, although there has not been enough time for a thorough review of the new pathways by members of the U.S. DRIVE Partnership Fuel Pathways Integration Technical Team (FPITT), as was done previously. These reviews have uncovered a number of issues in the past. The work is important because it has to be done and stakeholders need to know the cost, GHG emissions, and energy inputs of these pathways, but these results are less meaningful when all the components are assumed to be produced "at volume" and market penetration is assumed to be high.

- The approach is generally good. However, one concern is that the inputs from a multitude of models are being taken without much concern for vetting those models. As a result, there is a risk that assumptions that may be unrealistic are being used to develop the technoeconomic and emissions results.

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

This project was rated **3.6** for its accomplishments and progress.

- The project provides a clear and transparent understanding of the relative costs of current and future hydrogen supply pathways, including infrastructure. The analysis results are well documented in the future technologies report that is already complete and under review. The analysis provided a thorough and consistent understanding of new emerging hydrogen production technologies not previously available.
- Four additional pathways for hydrogen production were considered, providing excellent comparative data to the pathways considered in the previous year. The up-to-date results of the analysis will be publicly available in DOE-reviewed reports.
- The researcher presented on the project's significant progress, including the completion of the report on future technologies, which will complement the report published last year on current technologies. Very detailed preliminary cost information was presented for the new pathways being analyzed.
- There has been quite a lot of progress toward understanding emerging pathways.
- The accomplishments and progress are good.
- This project would have merited an "outstanding" rating for this question, but it features a curious choice of time frame and vehicle penetration levels. It is highly unlikely that by 2025, 15% of the vehicles on the road will be hydrogen fuel cell vehicles. That may seem to be a minor issue, but in a time frame after 2025, such as in 2040, when 15% (or more) of the vehicles on the road could be hydrogen fuel cell vehicles, there will be a different electricity grid (which affects the GHG emissions of different pathways, especially electrolysis using the grid). There will also be a different fleet average miles per gallon, which will affect the importance of fuel cost in the total cost of ownership. Road loads might be reduced, favoring battery electric and fuel cell powertrains over internal combustion engines (ICEs) and ICE hybrids. Finally, the choice of time period affects technological readiness, which affects costs, as noted in the presentation. Getting the scenario right matters and affects the answers.
- Given the lack of publicly available data, it is quite an accomplishment to develop these cases, but there is much work to be done to refine them.

Question 3: Collaboration and coordination with other institutions

This project was rated **3.3** for its collaboration and coordination.

- The Macro-System Model required ongoing collaboration and alignment with other national laboratories and was vetted by the U.S. DRIVE FPITT and Hydrogen Production Technical Teams and others. There is ongoing work that will incorporate the learnings from this project into the various models/tools that interface with the Macro-System Model.
- The collaboration with other national laboratories and the experts on the models and tools being employed in this work seems to be very appropriate.
- The collaborations are excellent.
- The budget was not big enough to support a lot of collaboration, so it is not surprising that there are only a couple of active collaborators listed (probably not funded). However, equivalent credit is deserved for appropriately choosing and using the models developed by others.
- There is good collaboration with industry representatives and the other national laboratories involved in the analysis tasks. The team should consider input from the industries that would actually develop some of these technologies, especially the technologies further out, such as photoelectrochemical (PEC) and photobiological production.
- A thorough review of the pathways by FPITT would be useful to make sure the inputs are technically sound. The principal investigator (PI) mentioned additional vetting by other U.S. DRIVE technical teams.

This will be very valuable to ensure the technologies selected for the pathways are reasonable, given the many possible configurations.
- It would be good to include inputs from experts in the technologies that were involved in the pathways analysis. Currently, it appears the only involvement by experts in coming up with the pathways is in the models for the individual components, but these experts should also help vet the systems analysis.

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

This project was rated **3.6** for its relevance/potential impact.

- This project is essential to DOE-funded R&D on the future hydrogen production pathways because it will provide much additional information on these technologies, which in the end will contribute to the direction and efforts of these R&D programs. The project will also enable DOE to fund additional work on carbon capture and sequestration.
- The analysis provides good direction for DOE's R&D activities related to photobiological hydrogen, PEC, and solar thermochemical hydrogen (STCH) production methods. This work establishes a foundation of hydrogen cost related to these emerging technologies, along with an understanding on GHG emissions.
- The impact of these models cannot be overstated. As long as the inputs can be updated as the technology matures, the work will allow DOE to make informed decisions.
- The entire life cycle cost and GHG impacts are the most important metrics to understand in evaluating any technology. This is clearly one of the most important activities in the hydrogen space.
- By improving the scenario assumptions and carrying out the planned additional pathway analyses, this should become an outstanding project.
- The emerging technology pathways are known to be uneconomic at this time, but it is unclear how far they are from meeting DOE targets. This analysis attempts to answer that question, and to some extent it provides an answer. Because the assumptions are based on a potential future scenario, the results do not reflect current costs, but they do provide a way to assess the delta between near-term technologies and emerging technologies.

Question 5: Proposed future work

This project was rated **3.5** for its proposed future work.

- Completing this work with the new GREET cases on emerging renewable production pathways, in addition to looking at emerging delivery and storage technologies, will make this analysis work very complete.
- The PIs have identified additional pathways to consider in the future, including high-pressure truck delivery, dispensing at 500 bar, and cold and cryo-compressed onboard storage.
- A reassessment of the time frame and other scenario(s) assumptions should be an important part of the future work. Expanding the portfolio of pathways analyzed is the right direction.
- The team will meet to discuss gaps that should be filled and commit to continuously updating the model. This latter task should be funded until the hydrogen economy becomes a mature reality.
- This project analyzed only pathways published in H2A. There are many potential component combinations in the PEC, STCH, and photobiological pathways. The work could benefit from sensitivity analyses looking at different technology combinations that are more likely to succeed in the marketplace. The team needs to discuss potential technology configurations with the Hydrogen Production Technical Team—the PI mentioned this is in the plans. None of the emerging technology cases demonstrated economic feasibility. Given that, the value of additional work is questionable, unless there is a substantial reduction of GHG emissions or another kind of societal benefit. The team should consider including the impact of renewable identification numbers and low-carbon fuel standard credits on hydrogen production cost through different pathways, including biomethane.
- The future work is somewhat limited to refining results with the U.S. DRIVE FPITT and Hydrogen Production Technical Team. Additional analysis from this work has been identified but is pending future funding.

Project strengths:

- Linking together the appropriate models from the Systems Analysis sub-program library is exactly the way projects like this should be done. There are state-of-the-art models in the library, and the researcher has appropriately chosen which ones to use. The subject of this analysis (understanding which parts of the production, delivery, compression, storage, dispensing, and vehicle system are responsible for the most life cycle cost) is precisely the kind of systems analysis that contributes to formulating an intelligent research agenda.
- This analysis fills a DOE gap related to understanding hydrogen production cost and GHG emissions associated with emerging technologies.
- The ability to study the impact of emerging technologies on the overall hydrogen economy is valuable and is needed to integrate the wide range of options available.
- Strengths include the collaboration with the U.S. DRIVE teams and the use of a set of models that are reputable and constantly reviewed.
- The project features a thorough understanding of hydrogen production and delivery from all sources under consideration.
- Strengths include the robust Macro-System Model and the leveraging of U.S. DRIVE and technical teams.

Project weaknesses:

- The project objective was to determine the cost, energy use, and GHG emissions of emerging hydrogen production pathways. In the area of energy use, only direct energy use from non-renewable energy sources is included. It may be good to understand the total energy requirements (non-renewable and renewable) for the emerging hydrogen pathways. It is somewhat unclear whether the total cost of energy is included in the production cost estimates.
- Assuming a 15% vehicle penetration is unrealistic. Some of the efficiencies/yields of the advanced technologies are location-specific. The results are generic, and it is difficult to assess where the technologies would result in the costs/GHG emissions presented. The results present only single-number results without considering variations. It would be more useful to have some sort of uncertainty charts.
- The only concern is the value of conducting such analyses for future scenarios (many years in the future) based on current data and knowledge. As the hydrogen market approaches maturity, these analyses will need to be performed once again, and one thus questions the value of the current studies. It is unclear how sensitive the results are to the input.
- The time period chosen does not match the market penetration assumption. This needs to be corrected, even if it costs more to do it.
- The project needs better inputs for the less mature technologies, such as PEC and solar thermal.

Recommendations for additions/deletions to project scope:

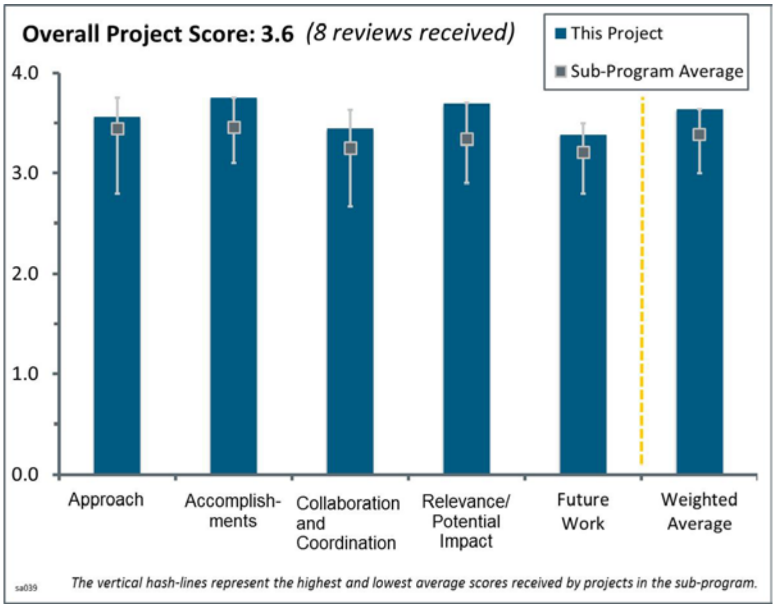
- The team should do the following:
    - Conduct “deep-dives” into project assumptions.
    - Develop a GHG life-cycle analysis before additional cost modeling is performed.
    - Consider near-term cases with lower market penetration, low-volume production, etc.
    - Produce variability ranges or mention what the potential cost variations could be.
- The team should reprioritize the future work so the assessment of biomethane steam methane reforming can be set as a higher-priority analysis that should be performed.
- The team should keep up the good work; these studies provide a consistent framework to judge the different pathways available to bring about a hydrogen economy.
- There should be more industrial input.

Project # SA-039: Life Cycle Analysis of Water Consumption for Hydrogen Production

Amgad Elgowainy; Argonne National Laboratory

Brief Summary of Project:

Argonne National Laboratory (ANL) has expanded the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model to include water consumption. ANL has (1) identified major contributors to water consumption in the upstream supply chain, and (2) evaluated water consumption for the fuel production stage.



Question 1: Approach to performing the work

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

- Adding water consumption data to hydrogen production pathways is absolutely essential for the development of sustainable, environmentally sound practices. This is an outstanding addition to the modeling suite's capabilities.
- The approach is excellent, with a comprehensive analysis of multiple fuel products that lends itself to comparative assessment.
- This work establishes a good fundamental understanding of the water consumption associated with hydrogen and energy production. The information and knowledge gathered through this project has been transferred into an updated GREET model.
- The principal investigator (PI) employs a logical, methodical approach to investigate each aspect of water impact. The evaluation of parameters and subsequent exportation into the GREET model is reasonable and appropriate. The focus on current production pathways is logical. The PI's approach is to holistically look at issues surrounding water consumption in each hydrogen production pathway. The PI is thorough and well organized, but this approach could lead to some critical aspect of water usage being missed. Peer review is recommended.
- The project team has a very good understanding of the issues around water consumption. The definition of "consumption" can be fuzzy, particularly in systems that are difficult to measure, such as evotranspiration of biomass; the researchers are doing a very good job delineating boundaries and defining conditions for the analysis. This is a very challenging topic, but it is very important.
- It would be better to take the approach of a consequential life-cycle analysis (LCA) rather than an attributional LCA for understanding water consumption.

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

This project was rated **3.8** for its accomplishments and progress.

- It is very nice to see the water consumption model improve each year; the researchers' commitment to making the water model as good as possible is outstanding. It was particularly nice to see the dry versus wet cooling trade-off for water consumption and its impact on the energy balance.
- The accomplishments were clearly discussed for each production pathway and indicate a logical consideration of water usage for each. The total impact is a thoughtful examination of water usage that provides considerable confidence that the analysis captures all relevant factors.

- This project has developed information on water use that was not previously available, including information on water use for different types of fuel, technology, and geographic areas for fuel production.
- The latest work refined previous water consumption factors for hydrogen production and established new water consumption factors for new renewable hydrogen production pathways. The team integrated the latest information into the GREET model.
- The presenter did not show the results of evaluating different water treatment options, which is part of the approach. Otherwise, the presenter covered the points outlined in the approach.

Question 3: Collaboration and coordination with other institutions

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

- The model is clearly improving, as the researchers are seeking input from the best industrial and governmental sources.
- The team collaborated with the previous researchers studying water consumption within DOE and solicited input and feedback from industry players.
- The collaboration and partnerships appear to be broad, well based, and appropriate.
- The researchers have reached out to industry, DOE, and DOE laboratories to obtain information. This reviewer's company was also approached to provide feedback. The researchers have done a tremendous job of reaching out to pertinent stakeholders. It is understood that the overall water consumption of the water flooding pathway is small, but the researchers should find a more up-to-date source of data for water injection in water flooding. The reference cited is from 1964.
- There appears to be a lack of peer review, leading to the fear that some (unknown) aspects of water usage were potentially overlooked.

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

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

- Water is a critical resource and will become even more critical in the future. It is important that industry stakeholders and energy producers understand water consumption within their industries and markets because it is often overlooked today. This work provided new knowledge of water consumption associated with hydrogen and energy production. Also, the work developed and updated water consumption for major power and energy production processes.
- The water cycle for energy generation is relevant and tremendously important. Researchers have mostly focused on greenhouse gases (GHGs) and energy LCA, but very little importance has been given to water, which is becoming a more restricted and expensive commodity in certain regions, such as California.
- Water consumption is just as important to consider for energy production as energy inputs, and it is an extremely relevant issue for DOE to consider. Making this into a real LCA is impressive.
- This project will meet research needs to develop information on water use to help decision making for fuel production, including type of fuel, technology, and geographic area for production.
- The project analysis revealed some surprising aspects and adds to the Hydrogen and Fuel Cells Program's understanding.
- Water is a very important topic, especially if one is considering fuel production at the local level and starting in California.
- Water use is a critical issue that DOE needs to address for all pathways.

Question 5: Proposed future work

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

- It is nice to see this project expanded into all factors and industries that consume water. It is very good to see that purification will become part of the project.

- The team plans to refine existing work and explore new areas, including hydrogen pathways involving low and no water consumption. It will be valuable to understand regional and seasonality differences in water consumption, water life cycle, and availability.
- The future work proposed is adequate. It would be good to see the integration of different LCA results for fuels production, including GHG, energy, and water, on the same slide to have a clearer picture of how the fuels fare against one another. Also, it would be good to see the variability of the results represented by uncertainty bars, or the research team should pick a region or a set of regions and do a "deep dive" into how the numbers vary; water stresses (e.g., the need for irrigation, and water constraints in California versus Florida) and feedstock availability (e.g., biomass and wind) will be different in different parts of the country.
- The future work for tri-generation technology is appropriate to expand the scope to meet the needs of the hydrogen fuel cell industry and automotive original equipment manufacturers seeking fuel supply for fuel cell electric vehicles. Additional information on heat and power may provide additional value to end users and help reduce energy costs.
- The team should include some more mid- to high-technology-readiness-level (TRL) technologies, for example, algae biomass systems.
- It would be good if the project leader could include work toward an index for water stress.

Project strengths:

- The PI's logical, thoughtful, and comprehensive analysis approach is the project's main strength. The numerical assessment of water usage and incorporating that information into the GREET model are strengths.
- The project team takes a nice, pragmatic approach in closing the DOE gap related to water consumption and energy and hydrogen production.
- The comprehensive approach and comparative analysis of multiple fuel products are strengths of this project.
- The project fills a critical need that is not currently addressed by existing models.
- Integrating water consumption into the whole LCA is a strength of this project.
- The project includes a good definition of project boundaries.
- The project features good stakeholder involvement.

Project weaknesses:

- The team needs to find mechanisms to get information to decision makers in energy sectors, drought/water constrained areas, and transportation markets. These weaknesses may be beyond the scope of this research project, but such consideration of a pathway to decision makers at this time might be helpful to the research design.
- The project needs more involvement from industry and peer reviewers at a very technical level.
- Collaboration and peer review with outside groups does not appear to have occurred.
- There are still some unknowns about total water usage.
- The lack of current data is a weakness.

Recommendations for additions/deletions to project scope:

- There are no obvious recommendations.
- It would be good to see the integration of different LCA results for fuels production, including GHG, energy, and water, on the same slide to have a clearer picture of how fuels fare against one another. Also, it would be good to see the variability of the results represented by uncertainty bars, or the team should pick a region or a set of regions and do a "deep-dive" on how the numbers vary; water stresses and feedstock availability (e.g., biomass and wind) will be different in different parts of the country. The presenter did acknowledge that other analyses at ANL are already looking into local water stresses and that the project may integrate this work. The team should definitely integrate other ANL work into this analysis.

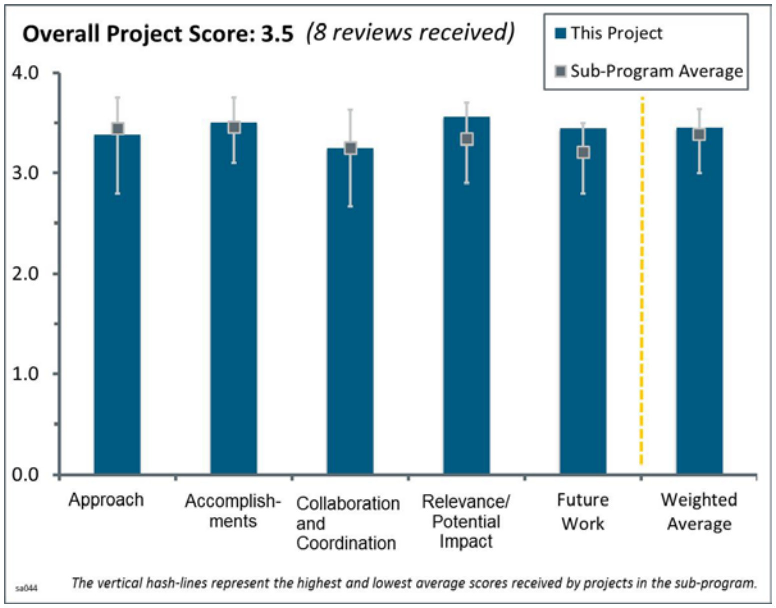
- The team should consider internalizing the full regional value and cost of water in the comparative fuel cost analysis. This will be difficult and potentially beyond the current scope of the research, but it may help with assessments for regional production of hydrogen and other fuels.
- These water consumption results should be added to a mapping utility so the information can become geographic; it would be great if this could be done to at least the county resolution level.
- Peer review with industry practitioners of each hydrogen production pathway would strengthen confidence in the project’s analysis.

Project # SA-044: Impact of Fuel Cell System Peak Efficiency on Fuel Consumption and Cost

Aymeric Rousseau; Argonne National Laboratory

Brief Summary of Project:

The objectives of this project are to (1) evaluate the benefits of advanced fuel cell systems and hydrogen storage from an energy consumption and cost point of view, and (2) provide guidance on future research priorities by evaluating the potential of technologies to accelerate petroleum displacement. Argonne National Laboratory (ANL) will gather component and vehicle assumptions, size the vehicles to meet similar vehicle technical specifications, model several light duty vehicle classes, evaluate the impact of advanced fuel cell systems on component sizing and weight, and perform the simulations on the U.S. standard driving cycles.



Question 1: Approach to performing the work

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

- The study's approach used the existing Autonomie model, which is well developed. The principal focus areas were fuel cell and vehicle hydrogen storage, which represent the greatest areas for performance improvement and cost reductions. The work scope evaluated the design of fuel cell hybrid vehicles across a broad class of consumer vehicle platforms.
- The project is taking data from all sources (i.e., Vehicle Technologies Office [VTO] and Fuel Cell Technologies Office [FCTO]), including information for fuel cell, drivetrain, storage, and other programs. It includes aspects such as the fuel cell size trade-off with battery size, cost, and efficiency and the contribution of each. The goal is to use modeling to provide feedback to programs on research needed to meet targets versus what research targets can be relaxed. The project includes the U.S. DRIVE Partnership and industry/academia, acknowledgment of fast-moving technology and the need to adapt, and state of the art versus predictions. The project team's process involves putting data together and synthesizing them, feeding them into modeling tools, and releasing results reports to stakeholders. The project team clearly defined "low" as business as usual and "high" as U.S. Department of Energy (DOE) targets.
- It is a very good strategy to include future improvements and their impact on fuel cell electric vehicles (FCEVs). Vehicle performance parameters and contributing factors are included nicely.
- The project uses the well-respected Autonomie model to configure FCEV subsystems and assess vehicle cost changes resulting from improved fuel cell peak efficiency. The project assesses the impact on FCEV configuration and cost resulting from an assumed increase in fuel cell peak performance to 70% efficiency. This helps one understand how increased fuel cell efficiencies can affect FCEV design and cost. The project would have benefited from assessing whether a 70% peak efficiency assumption was reasonable, and from further analyzing FCEV configurations and cost resulting from the project team's best assessment of a reasonable upper-end fuel cell system efficiency.
- The technical work is very solid; the models are carried out well, and the evaluations are very comprehensive. It is difficult to evaluate a project that is based on the assumption that everything is produced at volume only. Generating results for the early markets, too, would help one better assess the gaps for the transition. Some of the input numbers do not seem reasonable, and the Autonomie team should have questioned that aspect of the project.

- As conventional cars have incorporated better technologies, they have not become more fuel-efficient; instead, they have become faster (better acceleration) and larger. Original equipment manufacturers (OEMs) target sales, not fuel efficiency. This analysis should consider the adoptability factor of cars and the cars' sales appeal, not just their improved efficiency/fuel economy.

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

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

- The work provided validation that fuel cell hybrid vehicles will maintain their fuel cell efficiency advantage over conventional vehicles in the long term, and that performance improvements in conventional vehicles can cost effectively be applied to fuel cell vehicles. The scope of work encompassed a broad population of vehicles, which is valuable in understanding total petroleum and greenhouse gas emission reductions countrywide.
- The project team has done an excellent job evaluating how FCEV component configurations and the resulting vehicle costs, fuel economy, and weight will change as a result of improvements in fuel cell system efficiency.
- The impact of improvements by FCTO and private work is included. There is good consideration of uncertainty. The technology improvement monitoring is quite comprehensive. There is a good basis for project improvements. The simulation efforts and model development efforts are well focused. The tools are capable of future use and enhancements in technology.
- The team identified relative fuel economy improvements compared to other platforms, consistently, across targets.
- The team has made good progress since the last review; it accomplished an assessment of the impact of lightweighting and higher-efficiency components on overall system energy consumption and cost. However, the main slides do not show petroleum displacement results, which is one of the goals of the analysis. Slide 29 (one of the reviewer-only slides) shows there was an analysis of fuel consumption, but there is no mention of petroleum displacement results.
- The team generated assumptions through inputs based on experts' opinions on feasibility and status. The team walked through high-impact variables and the ability to drop fuel mass and engine power (e.g., lighter storage and more efficient balance of plant). This leads to a >50% decrease in the cost of storage and a >70% drop in fuel cell cost. The gap between fuel cell hybrid electric vehicles and conventional vehicles drops to ~10% in 2025; the weight is approximately equal. There is a good tie to the big picture from a modeling perspective; it is hard to say how the work overcomes the barriers because it depends on what the other groups do with this information.

Question 3: Collaboration and coordination with other institutions

This project was rated **3.3** for its collaboration and coordination.

- The project included two-way collaboration and coordination with other organizations. Inbound collaboration to the study included cost and technical performance data from automotive components to the entire vehicle. The project learnings and results are being shared with DOE and other government organizations in a number of ways.
- Realistic projections of improvements can make this analysis quite valuable to OEMs and FCTO. The project features good collaborative efforts.
- The collaboration is good, but researchers should question some of the inputs from DOE/national laboratories. For example, slide 8 shows specific power for the fuel cell system (watts/kilogram) in the 2025 medium case as lower than in 2020. Also, it would be good to see a review by the U.S. DRIVE Fuel Pathways Integration Technical Team before the results are published.
- The project team appears to have very good collaboration with U.S. DRIVE partners. The project does not seem to have strong collaboration with other national laboratories or academic researchers. It is unclear how some of the listed collaborators assisted in the project analysis (e.g., the MA^3T and Greenhouse Gas, Regulated Emissions, and Energy Use in Transportation [GREET] modeling).

- Collaboration and coordination were mentioned, but actual specifics were not provided in much detail. The presenter stated several times that there are many partners, etc., involved; it might help to have a slide that lists the contributors, similar to the slide Karren More (ORNL) and others sometimes include.
- The team should list the direct OEM contributors/reviewers for the analysis.
- It was not apparent how industry is involved. The team should make this clearer.

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

This project was rated **3.6** for its relevance/potential impact.

- The project's assessment of fuel cell vehicle configuration and costs resulting from fuel cell system efficiency improvements and performance targets for power density, storage, etc. provides a useful understanding of the impacts technology advancements will have. This analysis will aid DOE in setting its research priorities.
- The project's simulation results support the long-term viability of fuel cell hybrid vehicles compared to conventional internal combustion engines (ICEs).
- This is a great way to connect DOE investment with its impact on commercialization.
- Generally, understanding how the forecasts for components will play out in the entire system is valuable.
- The potential impact is high if the work is used to set strategy, which is not under the principal investigator's control. A plan to make the model publicly available would increase the significance of the project. The team has a good perspective on the difference between maintaining competitive balance versus the necessary end targets (e.g., 70% efficiency is not needed by 2020; 62%–64% may be fine).
- The work is good, and it is relevant; however, the assumptions are skewing the results. Autonomie considers components to be produced at volume, which is a problem, and some of the input data on power of the fuel cell system and power density are questionable.
- This is very relevant analysis. It would be good to have explicit concurrence from automotive OEMs.

Question 5: Proposed future work

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

- The future work will address the fuel cell hybrid vehicle in comparison to other vehicle power train platforms and vehicle classes that one assumes will include hybrid vehicles, plug-in hybrid vehicles, and battery electric vehicles. The plan to conduct sensitivity analysis on market penetration is valuable in advancing understanding of short- and mid-term cost effectiveness of fuel cell hybrid vehicles.
- It is a good strategy to get feedback from stakeholders. Checking assumptions and their adequacy is important. The impact of the trade-off between battery pack size and fuel cell size is expected to play a major role.
- Sensitivity analysis would be very helpful; it is good to see it on the list. The fiscal year 2016 tasks appear to be reasonable and directed.
- The proposed future activities appear to be useful and appropriate. One missing area is an investigation into whether 70% efficiency represents a reasonable upper-end efficiency and, if not, what the resulting cost and FCEV configuration at the upper-end efficiency would be.
- It would be useful to provide a parametric model of this analysis. It could help drive research goals and targets. The team should consider incorporating market adoption analysis into the modeling effort—models such as the Automotive Deployment Options Projection Tool (ADOPT) can shed light on the likelihood of OEM products being larger/sportier versus more fuel-efficient with the introduction of better technology options.
- It will be particularly interesting to see the results of the sensitivity analysis and the detailed analysis by component. It is understood that the results of this analysis will be given to Oak Ridge National Laboratory to further its market penetration analysis. The value of that analysis is questionable, given the assumption of production "at volume."

Project strengths:

- There are good collaborations with others. The project is iterative in that Autonomie's results provide feedback to DOE to assess whether targets are too aggressive, just right, or not aggressive enough. This can help DOE direct research and development funds and change targets when needed. The analysis looks at the system as a whole, integrating the performance of different components.
- The work involved input from industry. The simulation analysis further validated the long-term cost-effectiveness of fuel cell hybrid vehicles and provided an understanding of the impact of projected development in fuel cell efficiency and hydrogen storage. The work included a broad range of vehicle classes.
- Information goes in both directions—provides consistency across DOE offices and vehicles. The project defines pathways through scenario modeling to determine the impact. The modelers get inputs and targets, but also try to reset realistic expectations.
- The project's assessment of fuel cell vehicle configuration and costs resulting from fuel cell system efficiency improvements will aid DOE in setting its research priorities. The analysis is based on the well-regarded Autonomie model.
- The project is based on good tools and input from stakeholders. It features good collaboration efforts.

Project weaknesses:

- The model is set up to meet DOE targets instead of assessing technology changes and analyzing how fuel cell system components can improve in the out years and, based on that, calculating energy consumption, cost, fuel economy, and other parameters of interest. The model always assumes that components are manufactured at volume, which is not a realistic assumption in the early years.
- The weakness of the project is the inputs. Simply using DOE targets does not inform reality. It would be better to use more realistic projections of how technology, pricing, etc., will come into the market. Also, a sensitivity analysis would add value.
- The hydrogen storage cost analysis—particularly the 80% reduction assumption—needs to be checked. It is very significant. For comparison, ICE engine efficiency improvements are modest—this also needs to be double-checked.
- Considering the number of assumptions that underpinned the scenario analysis, it would have been valuable to provide sensitivity analysis of the results presented.
- The project findings are somewhat limited because the team did not complete a companion investigation into whether peak fuel cell system efficiencies of 70% are reasonable.

Recommendations for additions/deletions to project scope:

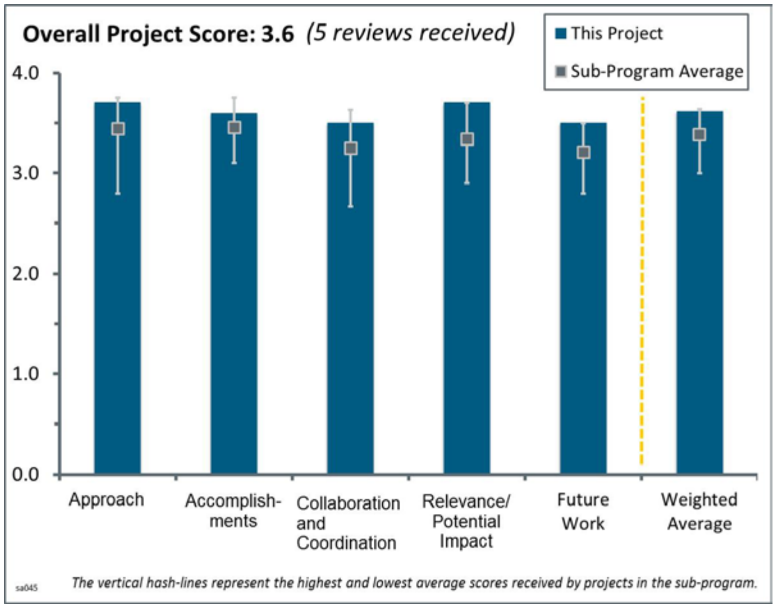
- On slide 7, costs should also be evaluated at low volumes. On slide 9, the team should compare hydrogen storage cost forecasts against historical compressed natural gas tank cost changes. The charts would be easier to understand if the key assumptions were stated on the slide. The researchers should review DOE input on slide 8—if power density did not change between 2010 and 2015, it is unclear why a jump from 640 watts/liter to 720 watts/liter is expected between 2015 and 2020. It is also unclear why the medium case specific power (watts/kilogram) system is lower in 2025 than in 2020.
- Battery advancements and their impact on FCEV progress present a great opportunity to increase the value of the project.

Project # SA-045: Analysis of Incremental Fueling Pressure Cost

Amgad Elgowainy; Argonne National Laboratory

Brief Summary of Project:

The objectives of this project are to (1) provide a platform for comparing the impact of alternative refueling methods and fueling pressures on the cost of dispensed hydrogen, (2) assist in the Fuel Cell Technologies Office's planning efforts, and (3) support existing U.S. Department of Energy (DOE)-sponsored tools. Argonne National Laboratory (ANL) will evaluate the impact of fueling pressure on fill rate and refueling cost, incorporate implications of SAE J2601 and MC Default Fill refueling protocols in the modeling of hydrogen refueling stations, identify cost drivers of various fueling technologies and configurations, and evaluate the potential of new concepts to reduce refueling cost.



Question 1: Approach to performing the work

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

- The researcher took a very sound approach in this analysis by using the proper modeling tools while at the same time using already established refueling protocols and identifying main cost drivers, such as precooling requirements for the different pressures analyzed.
- The approach is good and straightforward. Energy goes in, and hydrogen comes out. The team calculates cost, evaluates sensitivities, and makes recommendations.
- The approach is good. Clearly the investigators have given thought to building a model based on fundamentals and bringing in expert input. However, vetting the analysis through the U.S. DRIVE Partnership may not be sufficient. Important stakeholders, such as industrial gas suppliers, station owners, and key original equipment manufacturers (OEMs), are not members of U.S. DRIVE.
- The work is technically solid, and the strategy is well developed. This reviewer had not seen an analysis comparing both refueling protocols. It will be good to validate the results of the model in real-life conditions. The principal investigators did an excellent job addressing the barriers/challenges listed in the presentation.
- It would be helpful to have dynamic finite element analysis of a fill process to show the thermal dynamics of the gas and the layers of a tank. Hot spots in the tank are a concern to watch for, and the presentation is unclear in showing that the dynamics of the tank would not allow for the thermal diffusivity of the system to alleviate any hot spots. Dynamic analysis can also help drive design choices to make tanks more resistant to temperature escalations during fill processes.

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

This project was rated **3.6** for its accomplishments and progress.

- It is good this work is being performed; it is exactly what DOE should be doing. Looking at the issue of precooling may shed light on where research dollars need to be spent or on the cost benefit of providing or requiring precooling. The analysis of SAE J2601 is also very relevant to improving fill standards.
- The presenter discussed the project's significant accomplishments, including how the project team (1) determined the impact of precooling temperature on fill times at several ambient conditions and compared these two fill protocols, (2) achieved the preliminary results shown on the impact of refueling pressure on fill times at different precooling temperatures, and (3) identified the effect of partial vehicle fills on reducing refueling costs.
- This project is conducting excellent work, as usual.
- The cases analyzed in the preliminary results are adequate, given that they reflect a comprehensive range of ambient and precooling temperature conditions.
- A good deal of detailed modeling has been done. It would be good to see more attention paid to communicating the results and the meaning of the results. There were a large number of similar tables; it is unclear what these mean.

Question 3: Collaboration and coordination with other institutions

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

- This project utilized outside experts to verify calculations to give some assurance the calculations are relatively correct and relevant for industry.
- There is very good collaboration on this project, and it is good to see that a vehicle OEM provided input on the refueling protocols. For future work, collaborating with a hydrogen station supplier and operator could provide additional value to this work.
- The collaboration and coordination are good, but the investigators should consider additional collaboration with stakeholders not in the U.S. DRIVE Partnership or with existing connections to ANL.
- It will be good to validate the results with companies that already operate under the conditions analyzed in the model. Additional collaboration with companies such as Linde, Air Products, and Air Liquide would be favorable to test fill duration and potential system cost using different refueling protocols. Alternatively, this could be done at a testing facility that can recreate different ambient temperatures.

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

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

- This project will enable further development, optimization, and flexibility of upcoming hydrogen stations and their operations. It will also provide options to hydrogen station operators for reducing operating costs, and it will improve customers' experiences when fueling at hydrogen retail stations.
- Besides characterization, such research should generate ideas for making tanks more resistant to hot spots and for possibly reducing/removing the need for precooling. Also, the research could be applied in materials development for more thermally stable components or higher thermal diffusivity material sets.
- It is to be hoped that this work can be used to better direct funds toward optimizing precooling and help station owners know what to expect based on utilization. This project also furthers understanding of how to conceptualize the value of different pressures.
- This type of analysis is important to further understanding of how a free market will develop and would be affected by different pressures.
- This work has the potential to influence SAE J2601 and how dispensers are instrumented and operated.

Question 5: Proposed future work

This project was rated **3.5** for its proposed future work.

- The proposed future work on the trade-off between refueling speed and cost for different precooling designs will be a great addition to this work. Incorporating the MC fill protocol in the Hydrogen Delivery Scenario Analysis Model (HDSAM) and the Hydrogen Refueling Station Analysis Model (HRSAM) will also be a great addition.
- It is great to see that the results will be integrated into HDSAM and HRSAM. It is to be hoped that the results will also be shared with SAE to help fill knowledge gaps and contribute to the creation of a 500 bar refueling protocol.
- The future work is logical. It makes a lot of sense to vet the results, update impacted models, and publish the findings. It is unclear whether there are any parties involved with codes and standards or policy that should be engaged with these results early on.
- The future work looks appropriate. This work must be benchmarked to measured data.
- The researchers should consider the price elasticity of refill time. The worth to the station and end customer of waiting an additional 30 seconds is unclear. For example, slower fill may require less refrigeration but induce fewer turnovers per dispensing position. On the other hand, the hydrogen could be cheaper to the end consumer.

Project strengths:

- The analysis is robust and features a great amount of detail and a good process to get feedback from outside parties.
- The project helps define costs and direct research and money toward high-impact projects. It advances standards.
- Strengths include the technical knowledge and experience of the researchers.

Project weaknesses:

- One weakness is that the results are not communicated in a clear way. There are many similar plots, and this project would benefit from clear conclusions and useful takeaways. The team should spend time thinking about what the key conclusions and takeaways from the work are.
- The researchers could incorporate more refueling options/better ways of precooling.
- The project needs to include interaction with SAE.

Recommendations for additions/deletions to project scope:

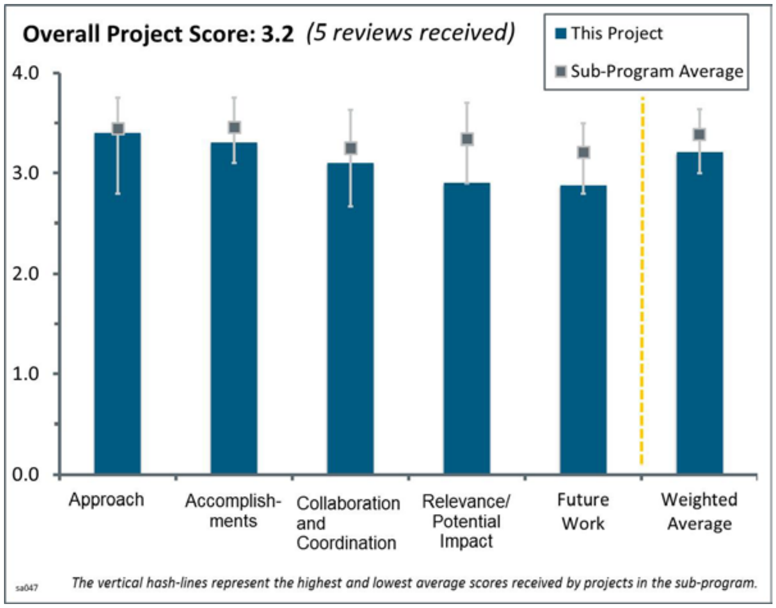
- The team should research the benefit of going directly from liquid to precooled hydrogen to recast the value of liquid hydrogen delivery. This is out of scope for this project, but the work that really needs to be done is to look at how much the consumer values a three-minute fill. If given a choice, this reviewer would choose a slower, lower-pressure fill at a lower price. The three-minute goal seems arbitrary. Assuming five-minute fills on 350 bar were acceptable, it is not clear how many more dispensers would be needed. It is unclear how this affects station costs, especially at low utilization rates. The cost for refrigeration in early markets was quoted at $5–$7 per kg. It is not clear how common this situation will be and how it can be mitigated. It is not clear what would happen if refrigeration equipment were bought (incurring capital expenditure) but not operated (incurring an operating expenditure) unless utilization reached a certain threshold.
- The team should validate the results with companies with stations on the ground or in the laboratory. Autonomie predicts that with component improvements, the hydrogen mass needed for a 300-mile range can be reduced by up to ~3 kg by approximately 2045. This model can feed some of the results into Autonomie for assessment of the potential impact of precooling options on future vehicle cost.

Project # SA-047: Tri-Generation Fuel Cell Technologies for Location-Specific Applications

Brendan Shaffer; University of California, Irvine

Brief Summary of Project:

The objective of this project is to assess the potential number and location of tri-generation fuel cells, producing electricity, heat, and hydrogen, in an early fuel cell electric vehicle (FCEV) market scenario (circa 2015) in New York, New Jersey, Connecticut, and Massachusetts. The project will consider the use of natural gas and anaerobic digester gas as feedstock, as well as the viability of tri-generation units serving as a local hub for hydrogen production.



Question 1: Approach to performing the work

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

- Tri-generation is an attractive technology, but its implementation will be challenging because it must be sited correctly. This project makes a good start at siting such a system, by defining its size and markets. It seems to be well integrated with the other modeling efforts.
- It was a good strategy to include all relevant parameters and stakeholders for siting tri-generation systems. It will be valuable to include local collaborative partners. The market needs for the co-products are addressed well. The environmental benefits of the combined heat, hydrogen, and power (CHHP) system are estimated—this is good input for the subsequent analysis.
- The project's goal is to site a tri-generation system in the Northeast for fueling. The project team went after real data—sales of alternative fuel vehicles, demographics, etc. The project recognizes that siting is a major issue/question/concern with multiple products—location of the system at a fueling station site (distributed) versus at a wastewater plant site (central).
- The project assesses the potential number and location of tri-generation fuel cell systems (that produce electricity, heat, and hydrogen) in an early FCEV market scenario (circa 2015) in northeastern states. The project compares the results of hydrogen derived from natural gas with hydrogen derived from anaerobic digester gas.
- The approach to this work was good. However, it appeared the researchers ran out of time and did not complete all they set out to do. The budget may have been limited, but they should have done much more with the heat and electricity aspects of the technology. Also, the co-location strategy should have been more developed. This project depends on a very diverse set of siting criteria, and it required a little more coordination between uses. The hydrogen delivery did not seem optimized. The long distances the hydrogen is required to travel to some stations seemed unrealistic; it seemed that these distances would drive costs to be so high that delivery might not be an option.

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

This project was rated **3.3** for its accomplishments and progress.

- Excellent progress was made in identifying opportunities for deployment of a tri-generation system.
  - The >8 MW potential is a good start for top-25 sites. The parameter of driving distance for vehicles to stations is a quick check of commercial viability.
  - The cluster strategy is a good way to introduce FCEVs.
  - The scenario analysis results are relevant.
  - Anaerobic digester gas site characteristics are important—the use of biogas, or sludge to biogas, will provide additional hydrogen.
- The project team did a very nice job of considering all the possible sites in the Northeast. The team also did a very good job with the various trade-offs and provided a number of different scenarios that will help developers consider the business case for tri-generation and hopefully drive policy toward favorable conditions for implementation.
- The researchers made excellent progress on their stated deliverables and achieved a 98% completion rate. The final report will be issued shortly.
- The project features reasonable analysis of available locations of >8 MW. The cost is lower at a longer driving distance—it is unclear whether this is a capacity factor issue. The hub model seems much less cost dependent on the vehicles sold—it is unclear why that is the case. Distributed generation sites needed 80 MW installations; this results in some very expensive (e.g., $50/kg) stations. The hub model needs 10 hubs because of the low delivery cost. The project generally features good coverage of the trade space.
- This project proved that co-locating wastewater recovery facilities (WWRFs) and tri-generation hydrogen stations is a bad idea, but it is unclear whether the researchers quantified the extent of the problem in a very concrete way for anything but hydrogen delivery. Perhaps the concept was mentioned, but there are questions about competing uses for energy at a WWRF. Many make methane and electricity from that biogas energy. Questions remain about how this alternate use of biogas energy compares, and how this analysis helps DOE decide whether hydrogen is an added value on top of simple electricity generation.

Question 3: Collaboration and coordination with other institutions

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

- The researchers reached out to many entities—including the Massachusetts Clean Energy Center and the New York State Department of Environmental Conservation—for site data, etc. They also discussed the impact of the National Renewable Energy Laboratory (NREL) work (e.g., the Hydrogen Analysis [H2A] model).
- The study engages key stakeholders very well.
  - Northeast hydrogen groups should be included to increase the value of the work.
  - The team should include liquid hydrogen versus gaseous hydrogen trucks and suppliers.
- There was some collaboration with other institutions, such as NREL.
- The project only involved NREL; it should have had a broader set of inputs from all national laboratories in the analysis portfolio. Only one automotive original equipment manufacturer was involved. The project really needs input from the relevant industrial supplier of the technology.

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

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

- Renewable hydrogen co-production is very important for DOE goals. The project addresses this concept very well.
  - Green hydrogen from biogas is important.
  - Connecting biogas resources with tri-generation is a key to meeting DOE goals.
  - The hub production concept is useful during the transition to the ramp-up in deployment units.
- The project developed a consistent approach to assess the number and siting of systems in several northeastern population corridors. The approach is needed for judging different locations once the market is mature.
- There are some good cost numbers on hydrogen production at WWRFs and some good comparisons with other hydrogen production options. There would be more impact if the other aspects of tri-generation were incorporated in a more comprehensive way.
- Showing the business case for tri-generation should create more interest in this idea. Its place alongside other hydrogen production technologies should be more thoroughly investigated.
- It is good to show different scenarios in the project and how they impact dollars/kilogram—independent studies are useful. The team also needs to consider customer impact.

Question 5: Proposed future work

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

- The project was ending, but the team could still have provided better indications of what would need to happen next or what follow-on funds would accomplish; it is not clear that everything is really understood.
- The project is ending, so no future work was proposed.
- No future activity was proposed.
- No future work was proposed.

Project strengths:

- The project team has a good perspective on renewable hydrogen and the need/scarcity. The researchers made a good observation that feedstock matters—there is a need to use the biogas where it most makes sense, because it is not abundantly available.
- Hydrogen production and delivery costs for light-duty vehicles were covered, and the team made some good comparisons to other production technology.
- The study builds on existing tri-generation projects at the University of California, Irvine, and its collaborative partners. Leveraging the experience from Fountain Valley helps the effectiveness of the study.
- The team takes a consistent approach to locate tri-generation facilities.
- The research team considers all the factors that would play into a tri-generation scenario.

Project weaknesses:

- Identifying anaerobic versus aerobic facilities separately is critical. In addition, the current remaining life of the facility for new equipment is important. New equipment may provide an opportunity for a tri-generation system. Also, having information on whether the site flares the biogas or has engines to burn the biogas for energy will provide additional screening factors to determine the site suitability.
- The approach and results are susceptible to large uncertainties in technologies whose economics are unproven.
- The project team needs to focus more on the tri-generation aspect and value co-products appropriately.
- There is no input from a molten-carbonate fuel cell manufacturer.

Recommendations for additions/deletions to project scope:

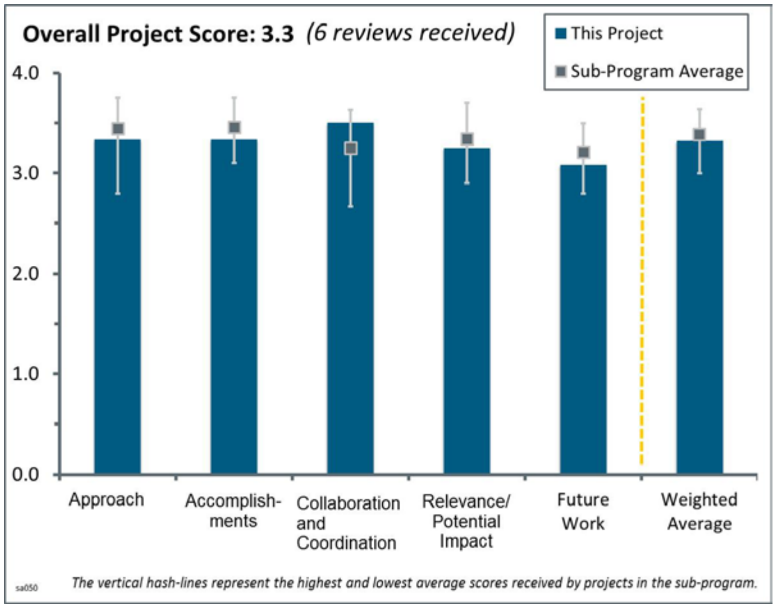
- It would be good for the project team to show an overall schematic with pricing, etc.; specifically, this could show the cost of hydrogen, the cost of electricity, and the capacity of both, as well as the use of heat (it works with the digester, but it may not be as viable in residential applications).
- The results should be shared with key stakeholders in the Northeast and used to develop a market transformation strategy. A compressed natural gas and hydrogen station together with electric vehicle charging for higher-value sites will be great to facilitate early market deployment.
- The project should expand to other regions of the United States.
- No additions need to be considered because the project is done.

Project # SA-050: Government Performance and Results Act Analysis: Impact of Program Targets on Vehicle Penetration and Benefits

Zhenhong Lin; Oak Ridge National Laboratory

Brief Summary of Project:

The objective of this project is to quantify the impacts of the Fuel Cell Technologies Office (FCTO) program targets on market penetrations and societal benefits of fuel cell vehicles. The goals are to (1) estimate fuel cell vehicle market share and the resulting reduction in petroleum use and greenhouse gas (GHG) emissions, (2) consider competition from all relevant powertrain technologies, and (3) collaborate on vehicle and infrastructure data.



Question 1: Approach to performing the work

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

- The work included an exhaustive comparison of fuel cell vehicles to all relevant powertrain technologies.
- The project uses the well-respected Market Acceptance of Advanced Automotive Technologies (MA^3T) consumer choice model to estimate the market share of fuel cell electric vehicles (FCEVs) and competing vehicle platforms. The approach of using a wide variety of alternative scenarios based on several choices each for key price, cost, and rollout parameters allows for a full understanding of the resulting range of potential FCEV vehicle market penetrations. Because estimates of petroleum use and GHG emission reductions are key outputs of this study, the project team should look at full fuel-cycle impacts using the Greenhouse Gas, Regulated Emissions, and Energy Use in Transportation (GREET) energy and emission model. This model is considered the standard model for understanding fuel- and vehicle-cycle energy and emissions, and it has been well vetted by industry and stakeholders.
- How the model is actually being vetted is of concern. The projections are useful but seem very ambitious, and from the perspective of the barrier "understanding future market behavior," the results should be more in line with reality. This is a fundamental issue with using targets, and the team needs to work with industry to use realistic projections for the future in order to understand the future market behavior.

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

This project was rated **3.3** for its accomplishments and progress.

- The project team has made excellent progress at assessing a wide variety of scenarios, as well as estimating FCEV vehicle purchases under these scenarios and the resulting reductions in petroleum use and GHG emissions.
- Particularly useful are the waterfall charts showing the petroleum reduction and GHG emission reduction impacts as targets for hydrogen cost, fuel cell system cost, and storage cost are met.
- The analysis provides projections in the areas of fuel cell vehicle market penetration, petroleum use, and GHG reductions, which is the objective of the project.
- The number of vehicles and pathways integrated into the model is quite impressive, particularly for a new project. However, it is difficult to see how the project addresses the overall objective of quantifying the impacts of FCTO program targets on market penetration and societal benefits. This assessment could be

done by equating DOE's research and development (R&D) investments with the results from those R&D efforts and their contribution to meeting the targets.
- It appears there has been a good amount of progress regarding building a model to determine future states. However, the inputs need more work—particularly inputs of a scenario where DOE targets are not completely met.

Question 3: Collaboration and coordination with other institutions

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

- This project benefits from excellent collaboration and coordination from stakeholders across national laboratories, academia, and industry. Additionally, the project makes excellent use of DOE-funded modeling and capabilities such as the National Renewable Energy Laboratory's (NREL's) Scenario Evaluation, Regionalization, and Analysis (SERA) model and Argonne National Laboratory's (ANL's) Autonomie model.
- The project features a good amount of collaboration with industry, academia, and national laboratories.
- The project involved widespread collaboration and coordination with academia and other government organizations. More widespread collaboration from automotive original equipment manufacturers (OEMs) is needed.
- The project could benefit from input from energy companies. Also, work from ANL for early markets (Elgowainy, Reddi, and Brown, project PD-014) shows early market hydrogen costs of $9.50–$14.60/kg of hydrogen. This analysis only goes as high as $8/kg of hydrogen. The principal investigators from ANL's project should provide input to Oak Ridge National Laboratory.

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

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

- This project provides a very good understanding of consumer acceptance of fuel cell vehicles in relation to achieving critical DOE targets for fuel cells and hydrogen.
- Outside of the notion that the results, in their current state, are not representative of reality, this project is conceptually impactful and important. Basically, an integrated model to understand how consumers will choose vehicles, and how that will result in market penetration, is needed for investors to understand when it makes sense to fund investments. This will help to overcome uncertainty in the hydrogen space.
- The results are interesting, but the analysis does not address the objective of quantifying the impact of FCTO targets on market penetration and societal benefits. It is not possible to demonstrate a direct correlation between FCTO targets and market penetration. It is possible, however, to quantify how technology advances due to government-funded R&D are getting closer to the targets established by DOE. The objective of this analysis does not have anything to do with DOE targets. The question that the analysis answers is how potential cost reductions can impact future FCEV sales. Also, it is unclear how "societal benefits" are measured. It is unclear whether societal benefits include petroleum use and/or lower FCEV cost.
- The project has obvious overlap with other FCTO system analysis activities.

Question 5: Proposed future work

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

- The proposed future work of completing the analysis of the full set of scenarios and completing Government Performance and Results Act (GPRA) reporting is both reasonable and expected. The proposed fiscal year (FY) 2016 project work appears to be a useful addition to this project, but it may be overly ambitious. Scaling down the proposed FY 2016 work may be necessary.

- The team should run FCEV cases with higher dollars/kilogram values based on ANL work. Regarding slide 8—it would help to understand how market penetration level results compare with rollout announcements from OEMs and other forecasts from organizations such as the California Fuel Cell Partnership. Also, the project could compare its vehicle penetration with numbers from the National Highway Traffic Safety Administration (NHTSA) and the U.S. Energy Information Administration (EIA).
- There is a considerable amount of proposed work for FY 2015 and FY 2016 that may impact the results presented to date.
- The team should add a line item to run scenarios with input from industry in place of DOE targets.

Project strengths:

- The project's strengths include the following: (1) the use of the well-respected MA^3T consumer choice model to estimate the market share of FCEVs and the approach of using a wide variety of alternative scenarios based on several key parameters; (2) the excellent collaboration with industry/academia/national laboratories; and (3) the reliance on key DOE modeling capabilities, such as Autonomie and NREL's SERA model.
- This project is a good attempt to address the future market behavior of consumers in their adoption of alternative fuel vehicles, which is complex.
- The project features a very comprehensive set of vehicle technologies, as well as strong modeling capabilities.
- The integrated modeling approach and long list of collaborators add strength to this project.

Project weaknesses:

- The project team uses its own estimates of petroleum and GHG emission reductions, rather than using the fuel-cycle energy and emission estimates from the GREET model, which is considered the standard for analyzing transportation-related energy use and emissions.
- The project's weakness is that it is unclear how the model inputs are being vetted. DOE targets should not be used simply because they are targets. This results in a circular argument or self-fulfilling prophecy. To understand future markets, realistic projections are needed, not targets.
- Consumer acceptance is not factored in. There are other projects looking at potential market penetration. The project should integrate/compare results.
- The work includes 44 scenarios; the analysis would be more effective and meaningful if there were a down-selection to a few.

Recommendations for additions/deletions to project scope:

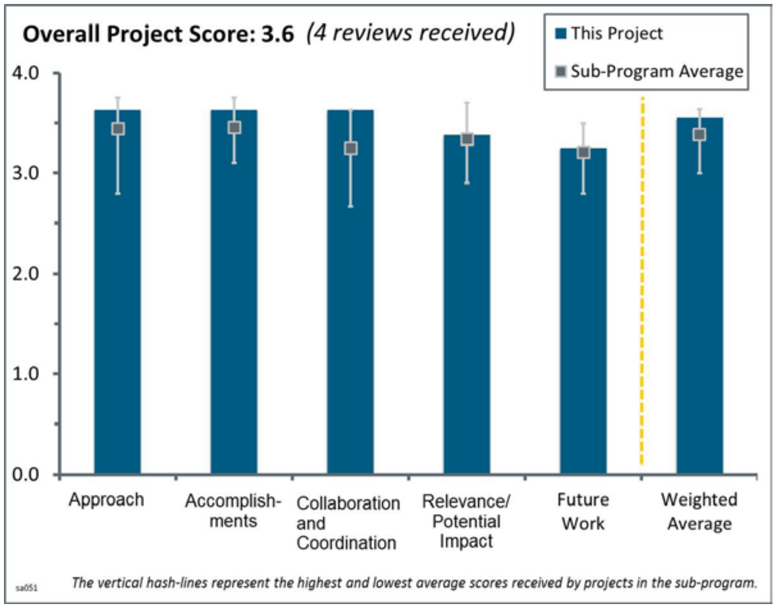
- The team should run FCEV cases with higher dollars/kilogram values based on ANL work. Regarding slide 8—it would help to understand how market penetration level results compare with rollout announcements from OEMs and other forecasts from organizations such as the California Fuel Cell Partnership. Also, the project could compare vehicle penetration with numbers from NHTSA and EIA.
- It would be interesting to benchmark the model's predictions against historical data on vehicle purchases by technology. It is unclear from the material in this presentation whether the model can have good predictive power.
- In presenting results, it would be helpful to provide the relative percent reduction in petroleum use and GHG emissions.

Project # SA-051: Infrastructure Investment and Finance Scenario Analysis

Marc Melaina; National Renewable Energy Laboratory

Brief Summary of Project:

The objective of this project is to provide a quick and convenient in-depth financial analysis (the Hydrogen Financial Analysis Scenario Tool, or H2FAST) for hydrogen station projects and investments. H2FAST builds on the Hydrogen Analysis (H2A) model's discounted cash flow framework and can be applied across the entire hydrogen supply chain system and a broad range of scenario parameters. The National Renewable Energy Laboratory (NREL) has fully integrated the hydrogen infrastructure cost model results from the Scenario Evaluation, Regionalization, and Analysis model with the finance framework. H2A cost details, infrastructure timing, and logistics information are integrated across all finance calculations.



Question 1: Approach to performing the work

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

- This project is well thought out, and the approach of making a user-friendly model to fill a gap in the area of communicating infrastructure costs and risks is good. The project definitely addresses a critical barrier in engaging the investment community.
- The approach is solid and helps provide a quick response to potential investors. The different versions of the tool are useful for different types of users. Further, adding a visualization tool to locate potential stations will add a lot of value if the market grows and there are many more players involved.
- An Internet-based spreadsheet model is an excellent addition to the Fuel Cell Technologies Office's (FCTO's) stable of analysis tools. The team has done a good job of leveraging existing models.
- The project team has a good grasp of a complex technical subject.

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

This project was rated **3.6** for its accomplishments and progress.

- The Internet- and Excel-based models represent significant accomplishments to date. This project has delivered something broadly useful to those seeking to understand implications of work in the hydrogen arena. In this way, it has addressed critical DOE needs.
- Data outputs seem to be providing just the right information the financial community needs for decision-making. The fact that the tool has the flexibility to accept inputs and change assumptions on the spot adds to the value of the tool for informing financial institutions in real time.
- The Internet-based model is easy to use and gives quick answers to basic investor questions.
- H2FAST is a good tool to do first-cut analysis for U.S.-based deployments.

Question 3: Collaboration and coordination with other institutions

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

- The number and types of collaborations are good; the collaboration appears to need no improvement. It is particularly valuable that an independent financial analyst reviewed the model.
- There are connections through H_2USA and the U.S. DRIVE Partnership, and subject expert reviewers are involved.
- The principal investigators have assembled a talented team to produce and vet the model.
- The project appears to have collaborated very closely with the appropriate institutions.

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

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

- The project is definitely relevant to the DOE goals, in particular for getting the venture capital community engaged. It would be useful to consider (when designing the tool) the policy and regulatory community as well, because that community includes stakeholders involved in understanding costs and risks of infrastructure deployment.
- A tool such as this is essential for potential investors and planners.
- The immediate impact of the H2FAST tool is clear from an investor’s perspective.
- Companies like to use their own models for financing, partly because most companies already have models with which they feel comfortable. This model can help as an instrument to double-check and validate assumptions.

Question 5: Proposed future work

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

- It would be interesting to fully develop the Business Case Scenario–Visualization (BCS-Vis) tool, but it would probably be more of an academic exercise than a useful tool, given that most station owners would either have an idea of where they want to locate their stations or hire a company such as Kalibrate to do the analysis. The rest of the proposed future work is good.
- The expansion of the model to include regional factors is a good addition. The team should consider incorporating outside firms such as Kalibrate to examine consumer acceptance issues.
- There is no apparent future involvement for federal regulators. There is clearly a lot of future work with state regulatory agencies (mainly California) but not much for federal agencies.
- It would be useful to look at interfacing with international databases (i.e., in Germany and Japan) to have a common tool for investors.

Project strengths:

- The product of this work is a user-friendly Excel model, as well as an Internet interface, which makes the product completely transportable and accessible by all. This is very appealing in terms of a product.
- The project is highly structured and has a strong focus on ease of use by the financial community.
- The team has created a comprehensive, easy-to-use tool for understanding station financing.
- Collaborations and validation of the model are good.

Project weaknesses:

- The fact that the model is being released in a protected manner is disappointing. Aside from transparency issues, there should be an option for an advanced user to unprotect the model and adapt it for his or her own use. After all, this is a publicly funded effort, so the product should be a public-domain tool. The project should consider opening up the H2FAST cells and code so that advanced users may modify the model for their purposes. To address concerns over making this too easy, the project could code a pop-up disclaimer stating that further modification may render the results invalid and requiring the user to acknowledge this fact.

- Potential stakeholders are not likely to use the tool for their primary financial analysis, given that companies tend to develop their own tools.
- The project is very U.S.-centric.

Recommendations for additions/deletions to project scope:

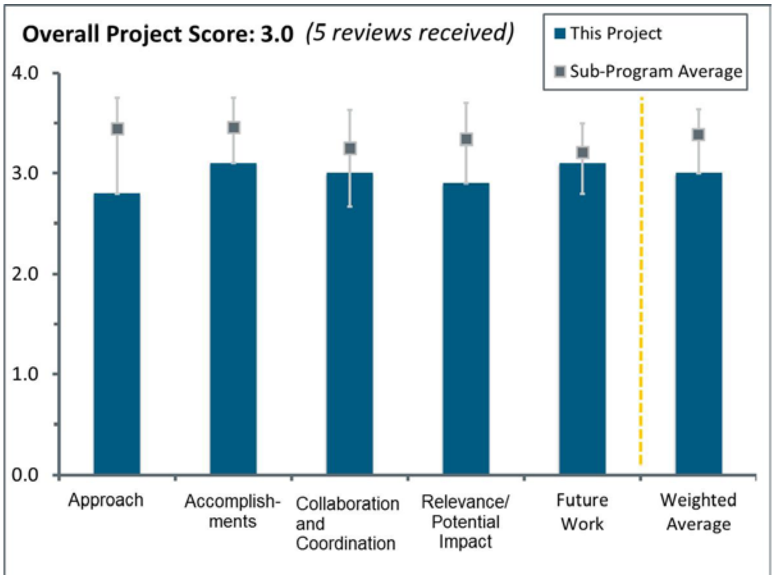
- The project should add international scope and add a module that follows the deployment of the Toyota Mirai in Europe, Japan, and the United States.
- A button could be added on the Internet model for user suggestions. The team may want to add a few “standard” cases to the model as a starting point for new users.
- FCTO has sponsored a number of very valuable tools, but these tools are not advertised appropriately, partly because the DOE website is so cumbersome to navigate. There should be a website on which all these tools are found, with easy explanations of their uses. In the next report-out, it would be good to read about the reaction of a financial institution to the outputs of the tool and find out whether the financial institution would find the information sufficient to make a decision.

Project # SA-052: The Business Case for Hydrogen-Powered Passenger Cars: Competition and Solving the Infrastructure Puzzle

Robert Rosner; University of Chicago

Brief Summary of Project:

The goal of this project is to support the development of a plausible business case for marketing hydrogen-powered fuel cell passenger vehicles and eventually including behavioral economic issues. Analysis will examine the competitive posture of hydrogen-powered fuel cell passenger vehicles in the marketplace and study the business case for a plausible hydrogen fuel distribution scheme.



The vertical hash-lines represent the highest and lowest average scores received by projects in the sub-program.

Question 1: Approach to performing the work

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

- The incorporation of uncertainty is an important and valuable piece of this work. It gives the project a rigor that many overlook. The plan to gather and vet data from stakeholders will also give the project credibility. The project should not rely on U.S. Department of Energy (DOE) targets for this modeling effort, as so many others have. The idea behind projects like this is to test whether targets are realistic. In the approach, it is important to consider that many of the potential collaborators will have vested interests in a result (one way or the other), and a variety of different perspectives needs to be used for any set of inputs.
- The project attempts to make the business case for investing in hydrogen production and takes the perspective of a potential venture capitalist. This thinking outside the rigidity of the existing models will provide valuable insight into how outside investment can be obtained. The team has a sound approach to this problem; after identifying the appropriate data, a first-cut model will be built and vetted.
- This project is just starting up and is still forming its framework.
- The concept of generating statements for venture capital (VC) investment is interesting, but it seems that all the data generated are repetitive. Other projects are already assessing costs and producing business cases. It is hard to understand what is new about this project, other than getting a third party to collect data and estimate uncertainties. This should be stated in future presentations. Also, it seems that there is a mismatch of vehicles being compared. The vehicles compared in the vehicle price table (slide 19 in the reviewer-only materials) have different attributes, so the side-by-side comparison does not present a fair representation of how vehicles would fare against one another.
- It is not clear what value this project adds, compared to the existing literature (e.g., the McKinsey 2012 study).

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.

- Much appears to have been accomplished in the first two months; this looks like a great start.
- The project has only been around for a couple of months, but it has already collected a fair amount of data. However, it is difficult to assess what exactly the final product will look like and how it will be different from other efforts/projects in existence. Regarding the results presented, total cost of ownership is not new. The U.S. DRIVE Partnership's Cradle-to-Grave (C2G) working group has produced much more

comprehensive results with as much uncertainty data as possible. DOE will produce a program record with the results.
- It is quite early in the project, but it is nonetheless hard to tell whether much work has been completed. It will be interesting to see the full results of this project at the next merit review. The plan for completion by the end of the year may be ambitious, given the current state of the project accomplishments.
- The provided accomplishments are in line with the phase of the project.
- It is hard to evaluate accomplishments and progress after only two months of work.

Question 3: Collaboration and coordination with other institutions

This project was rated **3.0** for its collaboration and coordination.

- The project appears to have started working with some original equipment manufacturers (OEMs); otherwise, coordination and collaboration are hard to evaluate after only two months of work.
- The project has good university and national laboratory collaboration, but it clearly needs much more industrial input. The project should involve more OEMs.
- It may be beneficial to cross-pollinate with other similar models—e.g., the Scenario Evaluation, Regionalization, Analysis (SERA) model. However, it would also be advantageous to have an independent thought process for evaluating business scenarios.
- The stakeholders involved seem adequate, but the VC community should be involved earlier to ensure that the outputs and deliverables meet their expectations.
- There appears to be a heavy reliance on national laboratories and DOE. Future work needs to include detailed review and analysis by key stakeholders in OEMs and industrial gas companies, as well as station owners.

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

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

- It is very valuable to inform the investment and policy communities about hydrogen's potential. Because modeling is involved, it is helpful to have multiple and independent efforts to provide a spread of predictions of possible future trends.
- The project clearly considers how the private sector will be investing in the technology—it is a much-needed study.
- This has the potential to be a very impactful project, but it needs to have critical input from industry stakeholders. It is critical that OEMs from different regions (the United States, Japan, and Europe) are involved to vet the data.
- It will be good to get cost data that do not assume "at-volume" levels for system components and high market penetration. However, this project feels repetitive. It is hard to assess how this information can be useful. Further, the vehicles compared have different attributes, and the side-by-side comparison is not done on a level playing field.
- The potential impact appears to be poor unless significantly new data, compared to what currently exists in the literature, will be produced.

Question 5: Proposed future work

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

- Examining whether learning-by-doing curves are appropriate based on actual data is a next step that will contribute to an understanding of the future states. Challenging and testing today's assumptions are the most valuable aspects of this project.
- The future work looks to complete this important project on a reasonable timeline.

- The project needs to show impact—for example, by predicting future Mirai sales based on one year's worth of data.
- The proposed future work does not present anything new. The project should add as objectives the development of learning curves and deep-dives on the impact of subsidies on the newest advanced vehicles and alternative fuels.

Project strengths:

- This is a strong team with good technical and business backgrounds. Collaboration with the National Renewable Energy Laboratory and OEMs is great.
- The strength of this project is the commitment to data validation. DOE learning curves and other targets have always appeared quite optimistic, and it would be good to see whether these can be backed up with both industry input and actual data.
- The project is highly structured, and the principal investigator is very competent.
- The project looks at funding hydrogen production from a VC perspective.

Project weaknesses:

- The project needs much more industrial input.
- Feedback from the VC community and industry is needed about the overall usefulness of the project.
- It is not clear what the value added is compared to existing literature.
- The main weakness of the project at this point is how early it is, and the fact that not much progress has been made on which to base a review.

Recommendations for additions/deletions to project scope:

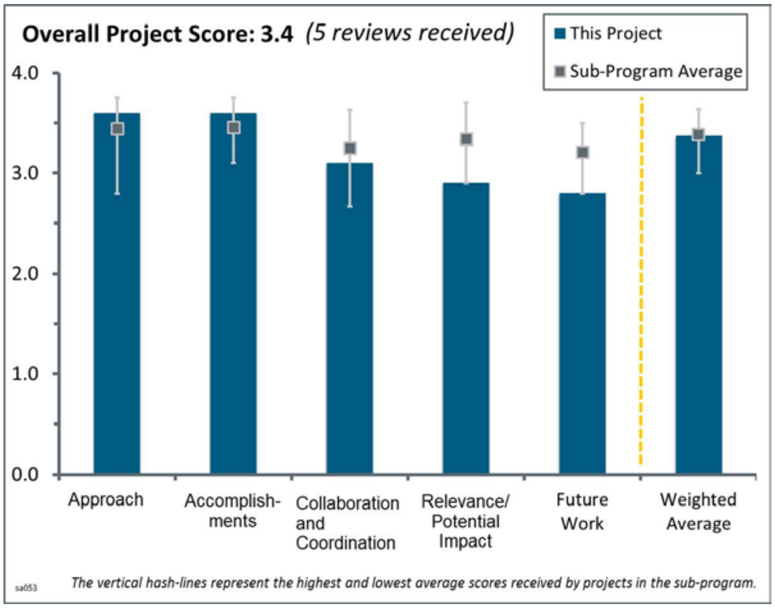
- Additional feedback from industry is needed about the overall usefulness of the project. The project team should discuss the project with the analysis Team Leaders in the DOE Fuel Cells and Vehicles Technologies Offices to ensure the work is not repetitive, considering what has already been done in these programs and by the C2G working group. The project should develop learning curves and deep-dives on the impact of subsidies on the newest advanced vehicles and alternative fuels.
- The project should consider emerging hydrogen production pathways.
- The project should make sure that detailed follow-up of the deployment of the Mirai in the United States is an integral part of this project.

Project # SA-053: Retail Marketing Analysis: Hydrogen Refueling Stations

Kent Schlesselman; Kalibrate

Brief Summary of Project:

The objective of this project is to develop an analytical approach to prioritizing and identifying the best locations for hydrogen refueling stations. Kalibrate will apply this framework to California to prioritize station network expansion beyond existing and planned locations.



Question 1: Approach to performing the work

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

- The approach reflects the many years of experience that Kalibrate has in siting refueling stations. The approach was appropriate, and the results pass the "laugh test," meaning that they make sense when they are looked at closely. However, it is difficult to understand why the distance to the hydrogen pipeline and other hydrogen delivery considerations were not in the list of independent variables considered. Perhaps these variables are embedded in some of the other independent variables.
- Kalibrate is clearly a leader in the field and approached the problem with standard methodologies adapted for hydrogen specifics.
- The project was conducted under an already proven approach based on the team's expertise in fuel retail network planning.
- The project is highly structured and focused.
- Kalibrate certainly understands what it is doing. The only suggestion would be to test whether the independent and dependent variables being used are the correct ones for hydrogen. Because the goal of most service stations is mainly to sell other items and not fuel, it is not clear that this would have any influence on station placement.

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

This project was rated **3.6** for its accomplishments and progress.

- Given the budget and timeline associated with this project, the results presented are of great value to the hydrogen industry in understanding the future market behavior in California.
- The project was completed, so the progress is good. The goals appear to have been completely met.
- The project has been completed with identification of the best potential locations for hydrogen stations.
- The project met expectations.
- The results were delivered on time and on budget, although it is difficult to see how this project can be further used without the accompanying software. Also, it would have been good to see hydrogen station developers commenting on the results and the general usefulness of the project, but perhaps that was outside of the scope.

Question 3: Collaboration and coordination with other institutions

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

- The project appears to have worked well with other institutions.
- There has been good work with relevant California entities.
- Collaborating with the team at the National Renewable Energy Laboratory (NREL) has been very valuable for this work. The project will also benefit if there are additional interactions with vehicle original equipment manufacturers (OEMs) that are already deploying fuel cell electric vehicles (FCEVs) to the California market.
- It seems odd that OEMs (e.g., Toyota, Honda, and Hyundai) are not listed as collaborators, because they would have a very good understanding of the market for hydrogen vehicles and therefore the target consumer for hydrogen. This seems to be a big gap in the approach of defining variables that one should examine.
- The team could have benefited from additional input from hydrogen station owners such as Air Products and Air Liquide, as well as gasoline station owners. It would be particularly interesting to find out whether these organizations would use the tool for planning purposes.

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

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

- The study provides a great starting point for siting future hydrogen stations.
- To some extent, this seems a bit outside the DOE goals in this area. It is nonetheless very interesting, and from a purely academic stance, it would be good to see the work continue. To make this more relevant, it would be nice to turn this into a publicly available model.
- The impact needs to be evaluated; the project needs to look at how potential investors would react to using this tool to determine where to place a hydrogen refilling station. It would be good to know the result in terms of traffic volume for a station once an investor follows Kalibrate’s recommendations.
- This project seems more of an academic exercise than something that is likely to be used by companies to site their next hydrogen stations. Companies use their own models and contractors. Further, because there is no user-friendly tool accompanying this project, it is even less likely that companies will adopt the results of the project.

Question 5: Proposed future work

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

- As proposed, one great addition to this work will be to analyze other regions in the United States where there are plans to introduce FCEVs.
- The project has been completed on time and on budget!
- Because this project is over, no future work was proposed; it would be interesting to show this in Germany and Japan.
- There is no proposed future work.
- While it is true that the project is finished, with no clear plan to continue, the proposed future work is nonetheless not well thought out.

Project strengths:

- Strong analysis and a long history of doing this sort of work gives confidence that it is being done well.
- The project is highly structured.
- Industry experience is a strength.

Project weaknesses:

- The results are not likely to be used by industry, and there is no user-friendly software tool.
- The model is not publicly available.
- The project is very California-centric.

Recommendations for additions/deletions to project scope:

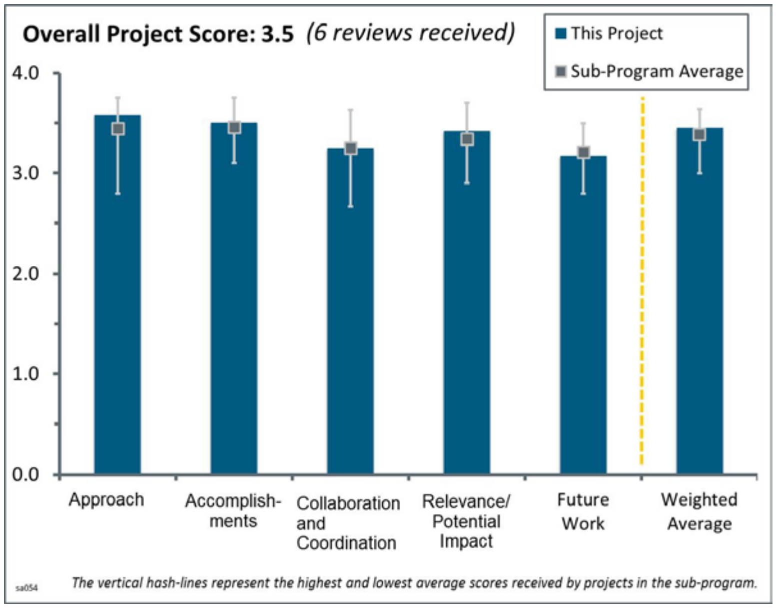
- This should be applied to the U.S. Northeast, Europe, and Japan.
- It is OK to stop the project and use the results to advance Marc Melaina's (NREL) visualization tool for future hydrogen stations.

Project # SA-054: Performance and Cost Analysis for a 300 kW Tri-Generation Molten Carbonate Fuel Cell System

Shabbir Ahmed; Argonne National Laboratory

Brief Summary of Project:

The objectives of this project are to (1) determine the performance and cost benefits of a molten carbonate fuel cell (MCFC) plant that can co-produce electric power, hydrogen, and heat; (2) develop meaningful definitions for cell, stack, electrical, and hydrogen production efficiencies in tri-generation modes; (3) explore scenarios in which the MCFC tri-generation system has particular cost benefits, including the scenario for charging electric vehicles (EVs); and (4) examine strategies for improving the performance and reducing the cost relative to the one-off Orange County Sanitation District tri-generation system.



Question 1: Approach to performing the work

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

- The project has a perfect approach to combine real costs of capital with real costs of electricity and hydrogen production. This project will produce real-world data for use going forward with tri-generation.
- The approach for this project is well thought-out and reasonable. The project develops an MCFC tri-generation performance model and uses the findings of that model as inputs to an MCFC cost model, which was also developed by the project team. The cost modeling appears reasonable, but comparisons to other stationary fuel cell cost modeling tools would have been beneficial, particularly the National Renewable Energy Laboratory's (NREL's) Fuel Cell Power Model, which was developed to model tri-generation systems.
- The bottom-up approach is quite effective. There has been a comprehensive evaluation of all parameters, including efficiency, economics, and components. Use of the Hydrogen Analysis (H2A) model provides data on a comparable basis. System model assumptions are relevant. The charging station add-on is a very good idea. It helps EV infrastructure and provides grid support.
- The approach is comprehensive and breaks the modeling effort appropriately into individual, transparent, and verifiable assumptions.
- This is a complex and important problem in terms of how to balance both outputs (power and electricity) and what the markets are. The researchers are looking at metrics and economics and developing meaningful efficiency definitions with multiple outputs. The project considers diurnal cycles. The model includes thermal integration, purification, compression/storage/dispensing (to 10 bar), and a five-stage ionic compressor.
- The system piping and instrumentation diagram shows pressure swing adsorption (PSA), yet feedback from FuelCell Energy is for electrochemical hydrogen purification.
    - Cost modeling should be done in a consistent manner with all other U.S. Department of Energy (DOE) production projects by using the H2A platform. One possibility would also be using the Fuel Cell Power Model or the Hydrogen Financial Analysis Scenario Tool (H2FAST).
    - Waste heat utilization is optimistic. Installation of combined heat and power (CHP) systems have shown ~12% to 20% utilization because of real-world impacts of hydronic system operation; for

example, heating is only necessary during a few months of the year, or the quality of heat is not adequate for steam generation (heat quality decreases when hydrogen production increases).
  - It is not clear whether this project is running a thermodynamic simulation of a tri-generation system. It is not absolutely necessary, but if the project team is doing so, the results would be interesting to publish.
  - In future reporting, the team should provide costs in a normalized fashion. For example, storage cost should be reported in dollars per kilogram, stack should be reported in dollars per kilowatt, etc. Stakeholders in this technology area use such normalized values and are calibrated to them.
  - The team should report performance in a normalized way. For example, hydrogen purification should be reported in kilowatt-hours per kilogram of hydrogen.
  - Normalizing numbers to the maximum alternating current (AC) output rating of the system (when it is not producing hydrogen) is suggested.

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

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

- The project has made excellent progress. Analysis results are consistent. Total combined heat, hydrogen, and power (CHHP) and hydrogen + power (H+P) efficiency should be included. Fuel cell performance improves because of lower utilization and improved reactant compositions. This needs to be added. The parametric analysis is done well.
- Clearly, a large amount of work has been performed, and some really nice insights into the costs of such a system are emerging.
- The project team has made very good progress, namely on the development of MCFC tri-generation system performance and cost models and the estimation of the cost of produced hydrogen for a system designed with and without EV charging.
- Progress to date represents the synthesis of substantial amounts of data into a single-system analysis. However, overall results could be summarized more clearly by providing a top-level summary of energy flows and costs. A steam-to-carbon ratio of two is assumed. This should be further justified. While assumptions are difficult to present for a project of this scope and in the limited DOE Hydrogen and Fuel Cells Program Annual Merit Review format, the presentation did not discuss assumptions on the cost analysis in enough detail for reviewers to fully assess their validity. A system thermodynamic and electrochemical model was done in GCTools, providing a ready-build platform for fuel cell analysis.
- The constant fuel assumption used in this analysis implies the system can adapt its output with some variation (hydrogen production can be increased with the same fuel amount inputs). The analysis shows 46% efficiency at 100% electrical output (no hydrogen production) to efficiencies in the 20s with hydrogen production—as stated in the review, this can be misleading to the general population. The project needs to come up with a total "effective" efficiency shown as a separate metric. Looking at sizing and the inflection point at 300 kW and the need to be greater than this to be competitive is very interesting. Hydrogen costs seem high relative to claims of other technologies; it is unclear how $6.50/kg–$9.20/kg is going to benefit the overall picture. Again, this may be a misleading picture because the project is also producing electricity, and it was not clear how these traded off.

Question 3: Collaboration and coordination with other institutions

This project was rated **3.3** for its collaboration and coordination.

- There is very good collaboration with national laboratories. The use of real data from appropriate industrial organizations was outstanding.
- The project has a good strategy to engage all stakeholders. Involving the University of California, Irvine (UCI), and Air Products and Chemicals International would be beneficial.
- The project suggests good coordination, but it could be improved by fuller vetting of modeling results rather than just collaboration on input parameters.

- This project appears to have been conducted mainly by the project team itself. There has been some interaction with industry stakeholders and fuel cell researchers, particularly in the area of component cost, but the project does not seem to have strong collaboration with a wider range of national laboratory, academic, and industry researchers.
- A body of past work was not referenced. For example, work by UCI would be relevant. FuelCell Energy is an excellent source, but it is also good to look at actual systems.
- The presenter did not really describe the collaborations in detail; it was just on a slide. Hence, it is unclear how iterative/interactive these discussions were.

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

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

- Tri-generation technology offers a great transition opportunity for multiuse infrastructure. It is timely to help fuel cell electric vehicle (FCEV) original equipment manufacturers. The grid, EVs, and FCEVs benefit from this study.
- The project provides a good assessment of MCFC tri-generation systems, which provides useful information on additional avenues for producing hydrogen for FCEVs. Such production leverages other needs (e.g., building heat and electricity) to help provide hydrogen fuel availability at reasonable cost, particularly during the hydrogen transition.
- Making the case for large, centralized tri-generation could be a really nice way to kick-start hydrogen production while leveling electricity production.
- It is good to see realistic and thorough costs of the compressor. The total installed capital cost for MCFC seems comparable to other technologies. The EV-charging model, including how it fits into the hydrogen-electricity picture, was unclear.
- The vision for CHHP systems is unclear. Specifically, it is not clear whether they are expected to be attractive to investors in the early market or only once hydrogen has already penetrated transportation to a significant extent.

Question 5: Proposed future work

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

- The future work to contrast CHP and CHHP and the plans of different sizes will be very important. It is nice to see electrochemical compression in the mix. The final report will be very valuable.
- Sharing with stakeholders is good.
- The proposed future activities appear to be useful and appropriate. One missing area is an investigation of the necessary system configuration of an MCFC tri-generation system during early market with low–Technology Readiness Level (TRL) designs compared with the system configurations of mature-market systems, and the resulting cost difference. Early market systems may be expected to have lower performance in terms of system efficiency, component reliability (leading to higher maintenance and replacement costs), etc. Fuel cell stack lifetime and compressor reliability/uptime are particular areas of concern.
- It is not really clear what comes next, if anything. The project needs recommendations even if it ends.
- The project ends this fiscal year.

Project strengths:

- The project provides a good assessment of MCFC tri-generation systems, which provides useful information on additional avenues for producing hydrogen for FCEVs. Such production leverages other needs (e.g., building heat and electricity) to help provide hydrogen fuel at reasonable cost, particularly during the hydrogen transition.
- The project provides a good survey of not only components, but also processes and equipment in the cost model. The sensitivity model for CHP-only mode and conclusions on key drivers and unknowns are other project strengths.
- This is a good collaborative project with real-world, realistic input into all costs.
- The project uses a good strategy that includes all relevant parameters. The cost model includes all major processes.

Project weaknesses:

- The project would benefit from an examination and comparison to other stationary fuel cell/tri-generation system cost modeling (e.g., NREL’s Fuel Cell Power Model) efforts.
- The system was not as well detailed as stack in terms of cost breakdown. It was stated to be similar, but the system cost breakdown was not shown. Collaborators were listed, but partnerships were not fully described.
- Results from the project are hard to understand/display because of the inherent trade-offs between electricity, hydrogen, and heat. Thought should be given to how these trade-offs can be better synthesized into a more readily conveyed format.
- The CHP and CHHP efficiency definitions are confusing. PSA efficiency gets better as compressors get larger. The team needs to further explain CHHP efficiency; it needs careful attention.

Recommendations for additions/deletions to project scope:

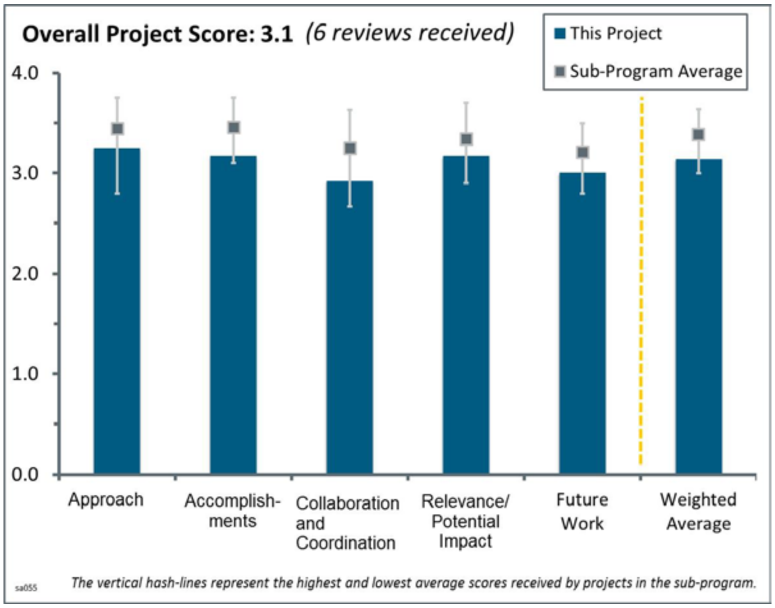
- The megawatt-scale analysis will be useful. Combining a compressed natural gas station with hydrogen can get better values.
- Based on the efficiency discussion, it would be good to discuss metrics with stakeholders from different technologies for consistency across the board. The metrics may need more than one number (fuel efficiency versus “effective”).

Project # SA-055: Hydrogen Analysis with the Sandia ParaChoice Model

Dawn Manley; Sandia National Laboratories

Brief Summary of Project:

The objective of this project is to capture the changes to the light-duty vehicle stock through 2050 and its dynamic, economic relationship to fuels and energy sources. ParaChoice occupies a system-level analysis layer with input from other U.S. Department of Energy (DOE) models to explore the uncertainty and trade space (with thousands of model runs) that are not accessible in the individual scenario-focused studies.



Question 1: Approach to performing the work

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

- The project has a great approach to predicting future light-duty markets. By considering all the possibilities and running thousands of parameters, the model gives a good indication of the future and has the ability to react to technology changes and look at the sensitivity of the analysis.
- The approach includes input from other DOE and Annual Energy Outlook models, and it explores trade space parameterizations. The project acknowledges that the results are projections, not predictions. The high-level feedback loop provides a good description of the supply and demand sides. The project addresses state-level variation that is based on natural gas pricing, electrolysis, incentives, etc. and considers one-time (i.e., upfront cost) versus multiyear (i.e., recurring cost) penalties.
- The approach to develop a methodology to assist in decision-making is sound, but the model is dependent on a number of variables that are subject to change.
- The ParaModel appears to apply Monte Carlo simulation to base DOE models and data parameters.
- Building off the existing ParaChoice Model is a project strength. However, the model is only as good as its inputs, and there are multiple parameters that are not clearly defined regarding how they are handled (or what their numerical assumptions are):
    - It is unclear what cost of delivery was added to the hydrogen prices. It is not clear whether it is based on the Hydrogen Analysis (H2A) model/Hydrogen Delivery Scenario Analysis Model.
    - The assumed cost of distributed steam methane reforming (SMR) was not stated. H2A estimates are based on more than 100 units per year of production. It is not clear whether the station capital cost was modified for production rate.
    - It is not clear how consumer vehicle buying preferences were affected by the distance to the dispensing station. It is not clear whether a “standard” method already exists in ParaChoice. It would seem that this factor would affect the hydrogen station quite a bit in the early years.
    - The assumptions regarding initial station density were not clear.
    - This is a national model, but there does not appear to be any discussion of geographic effects or city versus county variation.
- It is not clear how this approach is distinct from or adds value to other choice modeling projects and methods.

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 major accomplishments were inputting hydrogen production, refueling pathways, and fuel cell electric vehicle (FCEV) data into the ParaChoice model and aligning the ParaChoice model with the Macro-System Model. The ParaChoice model findings and results are consistent with similar DOE analysis efforts.
- A lot has been achieved, and certainly many scenarios have been examined. The analysis of the hydrogen price dropping in response to demand was particularly interesting and pertinent.
- The project provides a realistic picture of electrolysis, SMR, and other technologies on an equal basis. It is interesting that in the case of a world without FCEVs, internal combustion engine vehicles only had 4% greater sales share. It is not clear what impact this may have on policy. Electrolysis may not get there with market forces alone (or other product efforts); it may need incentives/compensation. Hydrogen becomes far more renewable with electrolysis.
- Implementation of hydrogen FCEVs into the model appears to have been accomplished well for a first-year project.
- The model seems broad and comprehensive in scope, but it is unclear how inputs translate to market share.
- The modeling tool was developed to project market penetration.

Question 3: Collaboration and coordination with other institutions

This project was rated **2.9** for its collaboration and coordination.

- There are nice collaborations with national laboratories, but the project needs real insights from vehicle original equipment manufacturers (OEMs) and industrial concerns that may produce hydrogen.
- Collaboration is satisfactory, but it might be improved with additional collaboration with market penetration models from others, including the National Renewable Energy Laboratory.
- Incorporation of existing data sets and parallel modeling efforts require close coordination with others. The project received support from two major automotive OEMs. It is assumed there was occasional collaboration with them as well.
- There were no other funded partners for this period; all collaboration was informal. This is because of the scope of the project, but perhaps there should be more industry/stakeholder engagement.
- Further peer review would strengthen the project.
- It is not clear that the model has been reviewed by any outside party.

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

This project was rated **3.2** for its relevance/potential impact.

- It is very helpful to see the requirements to get to low/no greenhouse gas (GHG) emissions and the incentives needed to push hydrogen production to a cleaner pathway. Also, the model showed the need for state "initiatives" such as California's "100 station" goal.
- The project allows DOE to explore the sensitivity of costs of FCEVs and hydrogen to predict behavior and identify where research and development should be implemented.
- The project's relevance is good, but it could potentially become quickly outdated and/or misleading due to changes in variable inputs, including vehicle costs, alternative vehicle costs, fuel and alternative fuel costs, and the regulatory environment (e.g., mandates and incentives). Nonetheless, the model will have a positive impact for the projection of the market and preparation for market entry.
- The topic is relevant, but considering other models in the DOE portfolio, it is not clear how ParaChoice reveals anything relevant that other models are not already addressing.
- This new project appears to provide a duplication of other DOE models and work involving the market penetration and mix of FCEVs and the resulting reduction in petroleum and GHGs.

Question 5: Proposed future work

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

- The proposed future work is important and focuses on parametric assessments. However, it should not necessarily emphasize conferences; there should be a few select forums that have high impact.
- The proposed future work represents a logical extension of the current analysis work.
- It is good to see more sensitivity analysis, and it will be interesting to get this team's perspective on the levers for FCEV adoption.
- Additional model refinement with refinement of variables is appropriate.
- The model does not seem ready in terms of capability and sophistication to address market levers. The model does not feature enough significant predictive capability or novel/realistic causal mechanisms.

Project strengths:

- ParaChoice explores the uncertainty around FCEVs and hydrogen infrastructure that other DOE models and analysis do not address.
- Project strengths include the neutral, powerful analysis tool that can look at thousands of scenarios and seems to have some very nice predictive capabilities.
- Project strengths include the objectivity for forward-looking projections to prepare for market entry with infrastructure.
- Project strengths include the use of an existing model that highly leverages past work.
- The production pathways seem appropriate for technical maturity.

Project weaknesses:

- Complex models such as this are difficult to analyze. Consequently, transparency of input assumptions is critical. Further description of inputs and selection basis would boost confidence in the model's output. The model outcome is quite sensitive to FCEV pricing assumptions, and the two versions of pricing considered would lead to significantly different results. This should be explored further.
- Creating another model to determine the effect of FCEVs and hydrogen adoption on petroleum use and GHG emissions is a project weakness. There are too many DOE models addressing this same subject matter.
- The model appears to need additional refinement of variables, including vehicle costs. There is possibly a need for a sensitivity analysis for variables related to fuel costs that are reliant on U.S. Energy Information Administration data.
- There is no direct input from industry.

Recommendations for additions/deletions to project scope:

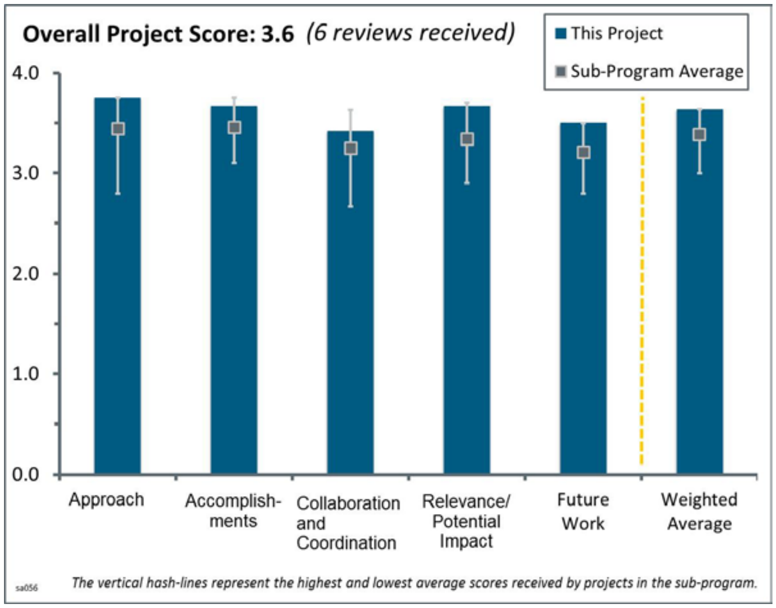
- The project should consider transformative technology breakthroughs in hydrogen production; i.e., a potential method to produce hydrogen for a lot less per kilogram delivered.
- Full disclosure of all variable data, an internal peer review of such variable data, and a sensitivity analysis for fuel and vehicle cost data for input into the model are recommended.
- DOE should consider reducing the number of models and analysis involving FCEV market penetration and the resulting reductions in petroleum use and GHG emissions.

Project # SA-056: Status and Prospects of the North American Non-Automotive Fuel Cell Industry: 2014 Update

David Greene; University of Tennessee

Brief Summary of Project:

The objective of this project is to contribute to the formulation of effective and efficient policies for deployment of fuel cell technologies and development of a sustainable fuel cell industry. The project will assess the impacts of American Recovery and Reinvestment Act (Recovery Act) deployments in the fuel cell backup power (BUP) and material handling equipment (MHE) industries, as well as reassess the effects of key policies on the sustainability of the non-automotive fuel cell industry in North America.



Question 1: Approach to performing the work

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

- The work represents a very pragmatic approach and demonstrates understanding of how market incentives can excite disruptive technology in new markets. The analysis is valuable in assessing the success of current and future policy in supporting the commercialization of new fuel cell technology and products.
- The project has a good strategy to provide feedback from key stakeholders and partners. Forklift and BUP are more near term than automotive application. The project provided great feedback on Recovery Act investments and the Recovery Act's impact, which includes the creation of new opportunities in the United States. Tax credit impacts and phase-out strategies are critical to commercial deployment of stationary fuel cells. This project builds on a previous study and updates it.
- The approach is outstanding. Appropriate tools were used, enabling adjustments to previous model estimates. Evaluations of money already spent are often the best way to assess future expenditures on similar projects.
    - This work applies to the non-automotive industry (MHE and BUP applications). It entails an update on a 2011 report. The report update addresses Recovery Act effects.
    - The work assessed Recovery Act effects on reducing technology costs and increasing technology deployment, and it considers reassessment policy goals concerning non-automotive applications.
    - The work considers the phase out of the investment tax credit.
    - The team looked at developments since 2011. Interviews with original equipment manufacturers (OEMs) were conducted.
    - It is not clear whether the cost predictions are for the future or current year.
    - It is not clear whether the sales data supports the fact that the Recovery Act helped sales.
    - It is not clear whether sales are going down. If sales are going down, it is not clear whether it is only those linked with the Recovery Act.
    - It is not clear whether there is a tax credit for electric vehicle (EV) forklifts.
    - Interviews with customers were conducted. EVs were covered in the work.
- The project goal is to assess the impact of Recovery Act funds to accelerate implementation of fuel cell power systems in BUP units and MHE. Specifically, it assesses whether Recovery Act-assisted purchases of fuel cells reduced costs through economies of scale and promoted additional sales above and beyond sales expectations without support from the Recovery Act. It is an interesting project; it is not addressing

any technical challenges, but more than likely it provides a methodology to judge the return on investment (ROI) of Recovery Act funds.
- Analyzing the effect of the Recovery Act stimulus on fuel cells for material handling and BUP was a really nice way to see whether government incentives work.
- The approach to isolate the impact of the investment tax credit (ITC) and incentive funding is of significant value to understanding the potential outcome for technology commercialization.

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.

- The project provides a good update on the status of stationary fuel cells. The results on the cost reduction due to market support are encouraging. The model results are very useful. Technology progress is better than predicted, demonstrating good results from DOE investments. MHE has done better than BUP. The gradual phase out of the ITC is a great strategy outcome. Uncertainty analysis results are quite relevant and useful to OEMs and stakeholders.
- The project showed that the Recovery Act incentives not only worked but also accelerated development by allowing developers to actually scale up system buildup. The analysis of the phase out of the tax break should drive policy to continue the jump-started progress.
- The results of this work provided good market research on the effect of market incentives on the adoption of new disruptive technology for two very large markets. Analysis outcomes provide good insight on the early market behavior of two diverse industries and the industry's acceptance of new technology that without market scale is relatively more expensive than the incumbent battery technology.
- This will help DOE assess future investments and help develop the non-automotive fuel cell industry.
- The model is appropriate and understandable. The model generally under-predicted the outcomes, but this conservative approach is reasonable.
- The model is simple; however, it is subject to large uncertainties in its projections.

Question 3: Collaboration and coordination with other institutions

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

- This small project was able to get accurate and honest data from the developers. The researchers talked to all the right people and were able to adjust their model accordingly.
- The project work involved a good deal of market research that required collaboration and persistence with most of the industry stakeholders.
- Outside experts were used in the assessment of this industry, adding to its value.
- Collaboration and partnerships appear appropriate, and there is adequate input of reliable data.
- The project had good collaborative efforts. Plug Power input would have been more valuable.

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

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

- This market research provides a valuable ground-level view of the market behavior of the material handling and BUP markets, their acceptance of fuel cells, and the impact of the Recovery Act market incentives. The work should be valuable to DOE because it provides an understanding of the commercial success for products resulting from previously funded research and development projects. Furthermore, the work provides an understanding of the effect of federal policy in jump-starting new fuel cell markets.
- Using the real-world experience of the Recovery Act incentives, it is now clear what the impact of future government intervention will be.

- This will help adjust policies, and it provides a compelling argument for phasing out funding rather than ending it abruptly.
- The project provides very important feedback for DOE to use in planning activities. The ITC and Recovery Act impact analysis is useful.
- This relevant work to project and predict pathways for commercialization with isolation of the impact of the ITC and incentive funding is very significant in understanding whether and how to provide incentives and in understanding the potential outcomes of technology commercialization with and without assistance.
- There is little value in projecting sales of fuel cell power units.

Question 5: Proposed future work

This project was rated **3.5** for its proposed future work.

- The future work recognizes the current level of market research, and the model can be further refined and developed through additional market research, market segmentation, and model development. It is great that this work is externally focused and involves a market survey and close contact with industry players.
- All proposed work is appropriate, including refinement of “learning curves” with data and calibration. Additional attention to supply chain, export markets, and market segmentation is appropriate.
- Future work, including conducting more customer surveys, is in line with the findings and project needs.
- Surveying customers is a great activity.
- No future work was presented.

Project strengths:

- The project provides a way to estimate the impact of the Recovery Act in accelerating fuel cell deployment and reducing costs. The project has a good approach to justify the ROI on the Recovery Act support.
- The project provides a valuable ground-level view of the market behavior of the material handling and BUP markets and the impact of Recovery Act market incentives.
- The project used a real-world case and excellent collaboration to determine Recovery Act outcomes.
- The project is built on experience and a previous study. The project uses the choice model very well.
- Evaluation of past policies and adjustments to assumptions are beneficial to good decision-making. Concrete recommendations on phasing out versus ending funding are useful.
- Project strengths include the use of an objective model to isolate the impact of the ITC and incentive funding to understand potential technology commercialization.

Project weaknesses:

- The project could incorporate the value proposition of EV forklifts. Hydrogen forklifts may be not as cost competitive as they once were. The drivers for past and future demand are not clear.
- The project could include all stationary fuel cell projects and their status. Other fuel cell groups and trade associations can provide synergistic data to make the study more useful.
- One project weakness is the inherent need to calibrate the model with new data.
- Plug Power was absent from the list of OEMs providing data and information supporting this work. Data from Plug Power, a major recipient of the Recovery Act funding of fuel cells for the material handling industry, should have been incorporated into this work.
- Large uncertainties in the predictions make the results of little value. Authors indicate that Recovery Act support reduced annualized costs by economies of scale effects and that, as a result of the support, sales of units deployed for MHE and BUP increased by 1,500 and 3,000 units, respectively. It would be interesting to compare the additional sales derived from the support to the actual amount of support and how this cost (per unit) compares with the reduction of costs incurred per unit.
- The project is not continuing.

Recommendations for additions/deletions to project scope:

- The project has done good work in assessing the further impact of current fuel cell investments. It would be beneficial to analyze the combined effect of the Self-Generation Incentive Program (SGIP) and the ITC. Adding renewable identification number credits from the U.S. Environmental Protection Agency would also be useful.
- The team should consider expanding the scope to include vehicle markets for fuel cell EVs and hydrogen infrastructure.
- The project scope should explore the effect of state market incentives associated with the material handling market, along with California SGIP and other funds related to the BUP market.
- The team should expand the project to assess potential future government incentive programs.
- The project should incorporate the competition: EV forklifts.