2016 — Systems Analysis
Summary of Annual Merit Review of the Systems Analysis Program

Summary of Reviewer Comments on the Systems Analysis Program:

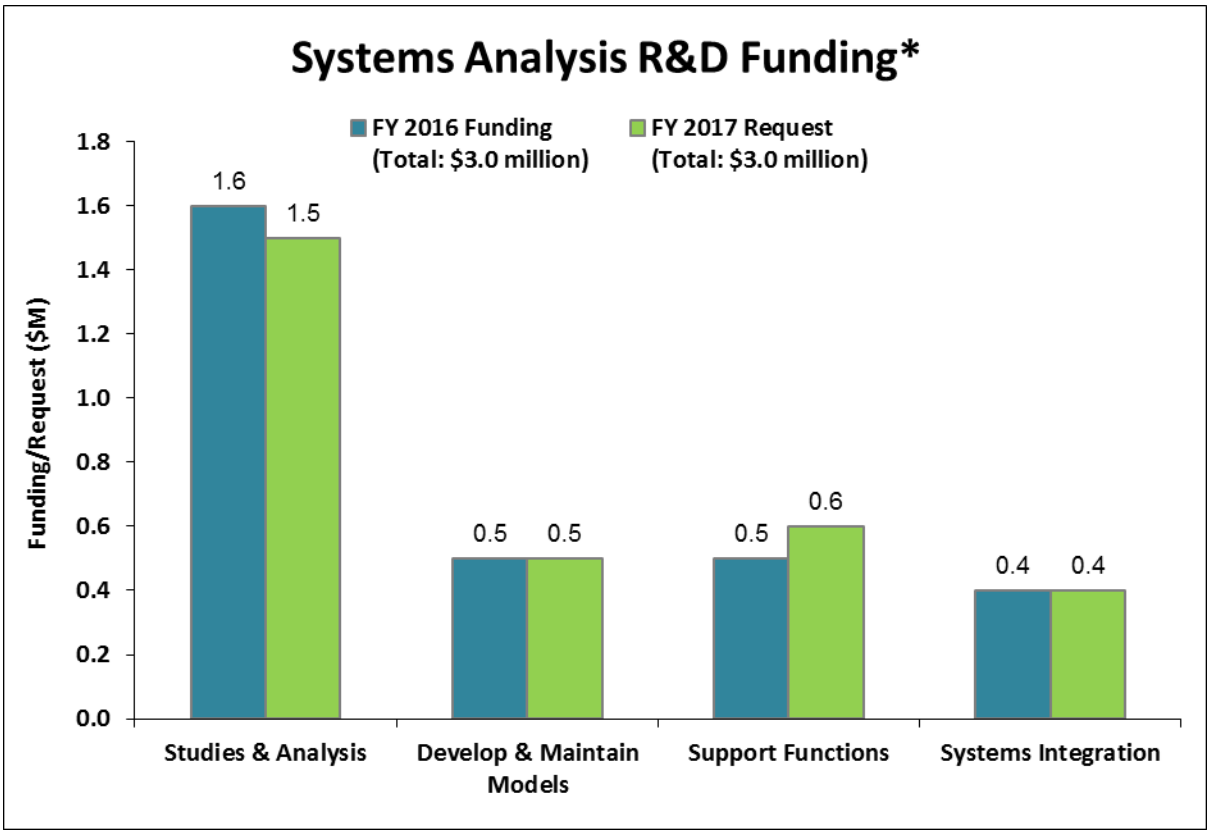
The reviewers considered the Systems Analysis program critical to the U.S. Department of Energy's (DOE) Fuel Cell Technologies Office's (FCTO's) mission and to be focused on the relevant issues that will enable cost-effective implementation of hydrogen fuel cell electric vehicles (FCEVs) in a way that addresses national needs. In general, they noted that the Systems Analysis program is well managed and the projects are diverse and focused on addressing technical barriers and meeting targets. Reviewers commended the program for the excellent mix of near-, mid-, and long-term analyses and the portfolios' focus on assessing progress to targets. They stated that the 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. Overall, the reviewers commented that the program's research and development (R&D) portfolio is appropriate and comprehensively addresses key technical aspects to achieve the ultimate program targets.

Some reviewers commented that the program is effective in providing analytical support and key insights and guidance for the Hydrogen and Fuel Cell Program's (the Program's) R&D efforts to address key barriers. They noted the Systems Analysis program is one of the strongest areas of the Program because of its extensive interaction and engagement with a broad set of key stakeholders. Reviewers identified the Cradle to Grave analysis and its resultant publication as an example of the program's value. Also, it was 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 technical targets. Reviewers praised the program for analyzing near-term issues, such as policies for infrastructure growth, and for focusing on mid-term evaluation of the costs with models such as the Hydrogen Financial Analysis Scenario Tool (H2FAST) and its benefit to states that are developing and evaluating infrastructure deployment.

Key reviewer recommendations for this program include the following: (1) to provide more details on the sustainability project to understand the benefits to the program; (2) to expand analysis to include a longer and wider view of greenhouse gas (GHG) reduction to be more inclusive of the transportation and electrical generation sectors; (3) to continue analysis of consumer behavior and explore further with stakeholders; (4) to incorporate cost analysis for low-volume production and market penetration; (5) to analyze scenarios with carbon taxes and incentives; and (6) to increase funding for the program so that it can continue to address a wide range of analytical topics.

Systems Analysis Funding:

The fiscal year (FY) 2016 appropriation for the Systems Analysis program was $3 million. Funding continues to focus on conducting analysis using the models developed by the program. In particular, analysis projects are concentrated on analysis of 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, employment impacts of hydrogen and fuel cell technologies, the impacts of consumer behavior, the cost of onboard hydrogen storage options and associated GHG emissions and petroleum use, and hydrogen fueling station business assessments. The FY 2017 request level of $3 million, subject to congressional appropriation, provides greater emphasis on analysis of large-scale deployment and utilization of hydrogen through the H2@Scale concept; the employment impacts of hydrogen and fuel cell technologies; sustainability; hydrogen fueling station business assessments; life cycle analysis of GHG emissions and petroleum use for future hydrogen production technology pathways, including solar thermochemical, photobiological, and photoelectrochemical; hydrogen production capacity at the national and regional levels; and the impacts of consumer behavior.



* 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.

Majority of Reviewer Comments and Recommendations:

The maximum, minimum, and average scores for the 11 Systems Analysis projects were 3.6, 2.9, and 3.2, respectively.

Infrastructure: The two projects reviewed in this topic area received an average score of 3.0 for assessing the costs of hydrogen infrastructure development and understanding the hydrogen infrastructure costs compared to other alternative vehicle infrastructure.

Reviewers commented that the National Fuel Cell Electric Vehicle and Hydrogen Fueling Station Scenarios project (SA-061) is relevant to assessing FCTO infrastructure goals; made good use of stakeholder experience; and utilized an effective strategy for the scenario analysis of key market parameters. The reviewers noted the project would be strengthened by engaging energy companies to validate their assumptions, especially for scenarios outside California. They recommended the project consider potential upgrades to potential fueling sites to increase capacity as a progression step for infrastructure development.

Reviewers noted that The Business Case for Hydrogen-Powered Passenger Cars: Competition and Solving the Infrastructure Puzzle project (SA-052) is relevant to the infrastructure buildout and informing the investment community. However, the project is in the early stages and does not yet fully evaluate the total program benefits, and it lacks collaboration with key stakeholders such as industrial gas suppliers, the investment community, and infrastructure developers.

Model Development and Systems Integration: Four projects involving model development were reviewed, receiving an average score of 3.4. These projects received favorable reviews and were regarded as well aligned with the current program goals and objectives.

Reviewers acknowledged that expanding the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model platform to include water-use life cycle assessment and emerging, renewable hydrogen production pathways to address critical and relevant program issues associated with hydrogen production was beneficial and that the comparative evaluation to conventional fuels was also beneficial. 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. Also, the GHG emissions information for the emerging hydrogen production pathways enables DOE to prioritize technology R&D that will be most effective in achieving the largest GHG emissions. 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. The emerging technology expansion for GREET would benefit from the inclusion of international participation and peer review.

Reviewers commented that the Expanded Capabilities for the Hydrogen Financial Analysis Scenario Tool (H2FAST) project (SA-062) aligns well with the program objectives of supporting infrastructure development by providing market and financial information relative to strategies for infrastructure development. They noted that the model is comprehensive with the addition of the stochastic risk analysis capabilities and takes into account the key cost variables required to evaluate a hydrogen station or network. The project made use of an excellent array of collaborators and validation of the model. The reviewers recommended that the ability to evaluate production and logistics options be added to the model.

Programmatic Benefits Analysis: Two projects were reviewed in this topic area, receiving an average score of 3.1 for the sustainability and employment impacts of the institution of hydrogen and fuel cell technologies.

Reviewers commented that the Employment Impacts of Hydrogen and Fuel Cell Technologies project (SA-035) is based on the use of a well-regarded employment model to understand job creation with the development of hydrogen infrastructure and production of fuel cell systems associated with automotive and stationary applications. They found the project to be relevant to understanding the economic benefits and job impacts and that it enables a framework to build in assumptions of the effects of various costs, geographic situations, and market perturbations. The reviewers recommended expanding the work to include competing technologies such as battery electric vehicles and consider the geographic and market implications attributable to displacement of gasoline and regional increases in hydrogen production capacity.

Reviewers commended the addition of the Sustainability Analysis project (SA-059) to the System Analysis program portfolio. They noted that the project takes a rational approach to assessing sustainability for hydrogen pathways by examining environmental and socio-economic aspects. Although the project is in the early stages, the reviewers acknowledged the use of a steering group to guide the project and vet the results and progress. Future work for the project should leverage data from multiple sources to ensure the results are consistent and transparent.

Studies and Analysis: Three analysis projects were reviewed, receiving an average score of 3.1. The projects covered a range of topics, including analysis of incentives and policy and fuel cell storage cost analysis.

Reviewers noted that the Impact of Fuel Cell and Hydrogen Storage Improvements on Fuel Cell Electric Vehicles project (SA-044) 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 and onboard storage. The reviewers acknowledged the project's benefits in assessing FCEV cost and performance resulting from these parameters and provides a useful understanding of the impacts of technology improvements. The reviewers recommended the results include analysis of lower volume fuel cell production, marginal benefits of technology-specific advances be assessed, and sensitivity analysis of market penetration be completed for understanding short-term and long-term effectiveness of FCEVs.

Reviewers stated that the Analysis of Incentives and Policy Impacts on the Market for Alternative Fuels and Vehicles project (SA-058) provides insight about cost drivers and policy impacts of transitioning to alternative fuel vehicles. The "lessons learned" information is informative for federal and state governments in designing effective policies and incentives for FCEVs. The reviewers recommended the information be used for policy development

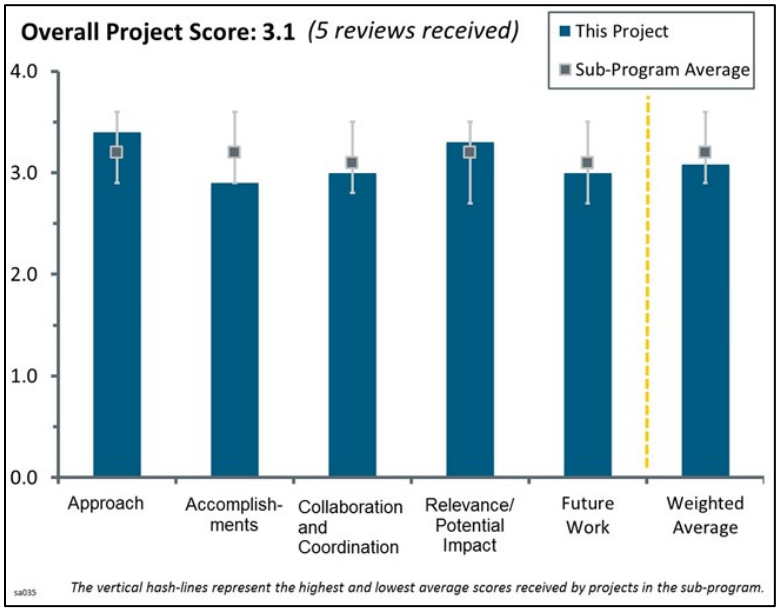
through economic impact analysis. The information search should be expanded to a global literature and information base and include 85% ethanol (E85) and natural gas transportation fueling infrastructure information.

Project #SA-035: Employment Impacts of 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 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 benefits of the FCTO.



Question 1: Approach to performing the work

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

- The approach seems to have the integrated flexibility to account for geographical and market impacts attributable to displacement of gasoline and regional increases in hydrogen production capacity that could result.
- It was a good approach to switch to the Regional Economic Models, Inc., (REMI) model and to coordinate with National Renewable Energy Laboratory scenario activities. The only drawback might be a lack of comparison with competing technologies, such as battery electric vehicles, or incumbent technologies, such as gasoline and diesel suppliers and vehicles.
- This project's approach is based on the use of a well-regarded employment model to understand job creation associated with development of hydrogen infrastructure and production of fuel cell systems. The analytic framework incorporates an integrated approach that combines economic input–output modeling and general equilibrium modeling to understand the full lifecycle and supply chain of fuel cell and hydrogen infrastructure development. Expanding the analysis to consider non-highway fuel cell applications makes sense, as the market for these fuel cell applications has greatly expanded in recent years.
- The overall approach is good. However, it was not clear how many original equipment manufacturers (OEMs) were engaged. It simply said 30 web-enabled attendees. A breakdown of the different types of attendees (academic, national laboratory, and, most important, industry—OEMs, fuel cells, suppliers, etc.) is needed. The project really needs to include representatives from automotive manufacturers, gas suppliers, and energy companies.
- Analysis is solely focused on hydrogen station construction and station operation, and an input–output model that converts hydrogen station placement to job creation has been developed. It is unclear whether job creation associated with upstream supply chains to stations and hydrogen production, distribution, and operations is included in the jobs growth valuation.

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

This project was rated **2.9** for its accomplishments and progress.

- The project has a well-developed approach and has acquired the models required for the analysis. A good project team has been assembled, and stakeholders have been engaged. A formal advisory group has been structured. It is too early in the project timeline for economic analysis results. Though it appears to be on schedule, development of baseline and alternative scenarios to be evaluated is crucial for project success.
- This project is progressing well, and the project has developed a good framework and roadmap for success. Outreach and solicitation of input through the workshop was an important accomplishment.
- The model framework to date attempts to capture the job categories created and skill sets for mass fuel cell deployment.
- The analysis establishes jobs growth associated with California and U.S. station development through 2021.
- The presentation should provide a breakdown of who the "webshop" attendees were by type of organization: OEMs, suppliers, fuel cell, academic, etc. This information is needed to better understand the results. The results in slide 14 are interesting. There is a very large range indicated (~0%–20%), and the upper limit seems very unrealistic. In 2015, there were approximately 12 million light-duty vehicles sold; assuming that this stays the same until 2025, 10% would be 1.5 million vehicles per year. This is a very large ramp-up in production that the supply chain would probably not be able to economically handle. It is not clear why the participants believed that growth rate would occur. Comparing fuel cell electric vehicle (FCEV) sales to historical hybrid vehicle sales is useful. From 2000 until 2015, sales went from <0.5% of the market to around ~2.8% (peaking at ~3.1%–3.25% in 2013). It would be interesting to know why the participants believed that the FCEV market would grow from <0.5% to 20% in 10 years (2015 to 2025) considering that new fueling infrastructure has to be installed and a new supply chain needs to be developed, especially when compared to the hybrid vehicle market, which did not achieve that growth, and hybrids needed relatively minimal infrastructure changes. On slide 15, it is not clear what FCEV sales were assumed. This is critical to know in order to determine the reliability of the projections. Growing out the FCEV fleet will require significant infrastructure. It is not clear why jobs in the infrastructure were not considered. This seems to be a major gap.

Question 3: Collaboration and coordination with other institutions

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

- This project makes excellent use of collaboration. The project taps on personnel and expertise from national laboratories, data analytics firms, and support firms. Use of an advisory group with stakeholders from public agencies, fuel cell and hydrogen infrastructure suppliers, and researchers to assist in data collection, scenario development, and research direction helps ensure necessary expertise is brought to the project.
- There was good engagement in obtaining data from the California Fuel Cell Partnership and California Air Resources Board on California jobs growth. It was also beneficial to engage RCF Economic and Financial Consulting and Northwestern University.
- The collaborations seemed to be California-centric and lacked OEMs and energy companies. The California market has different drivers compared to the rest of the United States. This may skew the results, or it at least assumes that the rest of the country will adopt California's policies, which may not be the case. The project did not have any respondents from automotive manufacturers, gas suppliers, or energy companies.
- Focus groups and input data need to have strong participation from the energy industry (oil and gas and electricity producers).

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 is very relevant, as it helps provide an understanding of the economic benefits and jobs impacts of investments in hydrogen infrastructure and production of fuel cell systems. This provides a necessary piece for policymakers as they consider continued public support of these technologies.
- A consistent way to measure and predict the resulting jobs impact from mass fuel cell deployment is needed. This project provides the initial framework to build in assumptions and study the causes and effects of various costs, geographic situations, and market perturbations.
- There is a need to recognize jobs growth and job cannibalizing of all alternative transportation fuels. Understanding should cover fuel cells and FCEV production growth too.
- The project addresses a key issue for the DOE Hydrogen and Fuel Cells Program.

Question 5: Proposed future work

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

- The work plan for this project is appropriate. The project plan for future work intends to compare jobs impacts for a baseline scenario to alternative scenarios. It is imperative that the yet-to-be-constructed alternative scenarios incorporate a range of assumptions for fuel cell system cost and performance, introduction of hydrogen infrastructure over time and across regions, and public investment (at the federal and state level) in both hydrogen infrastructure and fuel cell systems.
- The Jobs Model is being further expanded beyond the current 2021 forecast horizon. The analysis scope should include upstream supply chains supporting hydrogen infrastructure and FCEV manufacturing. An expanded view of job growth needs to encompass all facets of the overall industry.
- It might be an improvement to anticipate future policy drivers, such as Corporate Average Fuel Economy (CAFE) or carbon pricing policies, to see how those influence the relative benefits.
- It would have been good to see more detail on the future work. Some items to consider for future work include the effect of low oil prices on natural gas prices and the reduction of fracking capacity. If gas prices go up, it is not clear what impact the wind and solar centers play in centralized hydrogen production. It is not clear how reduction in gasoline consumption might affect and shift the large hydrogen production centers currently supplying refineries. It could create the need for pipelines and rail and truck transportation to fueling points. The impact of the Low Carbon Fuel Standard and Renewable Fuel Standard on deployment and hydrogen production hubs is also unclear. Technology shifts in how fuel is purchased and the venue for fueling—e.g., home fueling, mobile fueling, and fueling centers placed on non-traditional sites—should be considered.
- The researchers must get more input from stakeholders. Thirty participants is not sufficient. They must get participation from automotive manufacturers, gas suppliers, and energy companies.

Project strengths:

- The project provides a consistent approach to model and validate complex cause and effect relationships. It also provides motivation for a collaborative effort by all key stakeholders.
- The project proposes a thorough investigation of the jobs and economic impacts of hydrogen and fuel cell investment and deployment.
- Project strengths are the use of standard models (REMI) and good collaborations (Connecticut Center for Advanced Technology, Inc., and others).
- The project is based on actual station costs associated with California hydrogen infrastructure development.

Project weaknesses:

- Though not truly a weakness, as the project has not developed far enough to properly assess this, the development of the alternative scenarios and the breadth, range, and assumptions of these alternative scenarios are crucial to assessing the usefulness of this project and its results. The project has yet to progress to the point at which these alternative scenarios are constructed, but care must be made to ensure that the scenarios capture the range of technology cost and performance progression and public investment in these technologies. Additionally, though the results of the project are still forthcoming, it will be crucial to understand net jobs impacts to the economy, taking into account potential reductions from competing industries.
- Hydrogen and FCEVs are one option of interest for policymakers. Perhaps it would be an improvement to do the same analysis across other advanced vehicle and fuel options, or to at least compare hydrogen and FCEVs to an ongoing comparable analysis being done by others (if it exists).
- The current model does not appear to account for jobs growth in the upstream supply chains to stations and FCEV supply.
- More input and participation from industries most affected by the shift to fuel cells (energy companies) are needed.

Recommendations for additions/deletions to project scope:

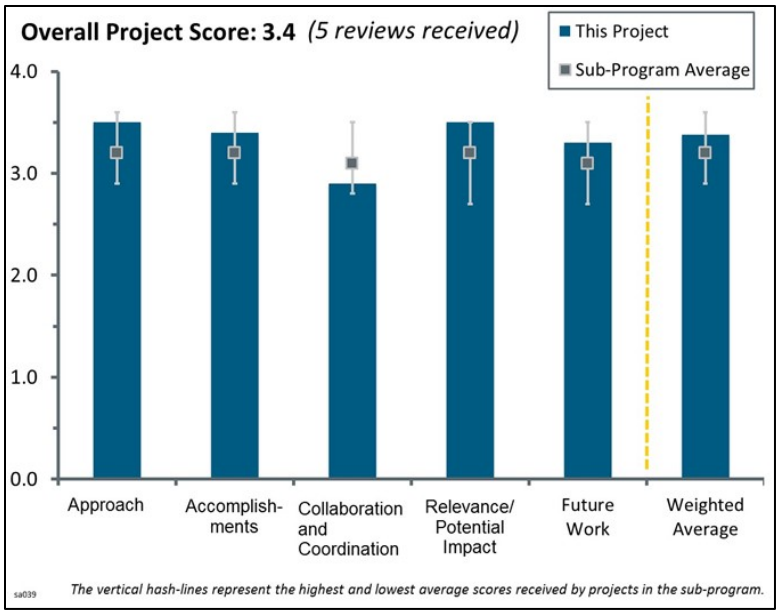
- Hydrogen and FCEVs are one option of interest for policymakers. Perhaps it would be an improvement to do the same analysis across other advanced vehicle and fuel options, or at least to compare hydrogen and FCEVs to an ongoing comparable analysis being done by others (if it exists).
- Perhaps the project could focus on those areas/market segments that present the greatest impact on jobs and wages.
- The full role of the advisory group is unclear, but the advisory group should review and approve data, assumptions, and proposed scenarios before the jobs and economic analysis is completed. The project team might also consider involvement of relevant U.S. DRIVE Partnership technical teams as part of its advisory group.
- It may be worthwhile to study the Japanese market because the Japanese government views hydrogen fuel cells and hydrogen infrastructure as a big opportunity for job creation and future economic growth.
- Growing out the FCEV fleet will require significant infrastructure, so it is not clear why jobs in the infrastructure were not considered. This seems to be a major gap. If the project team cannot get participation from automotive manufacturers, gas suppliers, and energy companies, this project should not continue.

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

Amgad Elgowainy; Argonne National Laboratory

Brief Summary of Project:

The 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 in the upstream supply chain to water consumption and (2) evaluated water consumption for the fuel production stage.



Question 1: Approach to performing the work

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

- The expansion of the well-regarded GREET life-cycle analysis model to include water consumption is an excellent approach to understanding water consumption associated with hydrogen fuels in comparison to other transportation fuels. The project team shows a very good understanding of water consumption aspects over the full fuel production and delivery chain. The project team appears to use a consistent approach to assess the various transportation fuels and develop water consumption factors for these fuels.
- This project continues in a no-stone-left-unturned approach to investigate all water sources and to strive to update input data continually. It is very impressive to see a complete life-cycle analysis of water.
- The latest work provides refinement and greater resolution to previous analysis of water consumption of fossil and renewable fuel pathways.
- The work was comprehensive and enabled detailed comparisons of water consumption for existing energy production approaches and emerging hydrogen production and utilization approaches. The analysis also included some regional data, which is important for providing context for the results. In fact, future work should include even more analysis based on regional data. For example, electrolysis appears to be the largest consumer of water of all hydrogen production approaches, whereas steam methane reforming (SMR) appears to be fairly competitive with respect to water consumption. The project should investigate how this impacts decisions about hydrogen production approaches in water-stressed versus water-rich regions. It is also not clear that the previous year's comment on the fate of evaporated water (either during production and use) was addressed in the analysis work.

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

This project was rated **3.4** for its accomplishments and progress.

- The project team has continued to examine and improve its modeling of life-cycle water consumption associated with transportation fuels and to incorporate this modeling into the GREET model. The team's further analysis of water consumption associated with cooling water and allocation of water use for hydro-electric facilities furthers understanding of these processes, and revisions of hydrogen fuel pathways and investigations into liquid petroleum products help enable useful comparisons across fuel types. The project team's analysis of water consumption on a per-mile basis across fuel types provides useful insights, though

it is unclear whether per-mile water consumption has been incorporated into GREET (which generally has examined different fuel pathways on an energy content basis, not a per-mile driven basis).

- The work provided by Jacobs® Consultancy provided a good update to the water consumption factors for products produced at a petroleum refinery. The updated information on cooling water consumption for thermoelectric power generation is valuable in understanding regional differences in waste consumption associated with hydrogen production. The work in understanding the viability of water consumption for hydropower is also an important factor in the analysis.
- This analysis work is critical for the Department of Energy (DOE) to make informed decisions on which hydrogen production approaches should be favored in the near term. With California entrenched as the earliest adopter for fuel cells and fuel cell electric vehicles, water usage during hydrogen production needs to be carefully considered. Concern about water availability is also likely to increase in the United States and the world in the future. Thus, this analysis is essential for DOE's decision making.
- It is very good to see a complete analysis of refinery processes and the conclusion that water consumption tracks with energy consumption. It is all very well saying that saline, brackish water, or treated wastewater can replace fresh water for cooling, but these all have corrosion issues that must be addressed (i.e., cost) before they can be fully utilized. It is very good to talk about the variability in water allocations from dams, but the national average may not be relevant, as allocation is something that is going to need to be done on a regional basis. There are great results from removing the wastewater treatment process out of SMR and electrolysis and showing that water consumption is dramatically reduced when using renewable electrolysis.
- Transparency of the work is lacking in parts where consultancies have been used (Jacobs Consultancy, etc.). It would be better to use completely open models.

Question 3: Collaboration and coordination with other institutions

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

- The external collaboration with Jacobs Consultancy was valuable in establishing the water consumption of petroleum products produced within a refinery.
- There is very good collaborations with industry consultants and government entities. This is getting good enough that the team may now need to be getting more detailed information about specific regions.
- The project team appears mainly to consist of the GREET team with additional help on refinery operations from Jacobs Consulting. However, the team has had appropriate interactions with government and industry researchers to understand water consumption associated with wastewater treatment plants, refineries, SMR plants, etc. Given the depth of data on water consumptions for various fuel pathways being incorporated into the GREET model, deeper peer review of the data and assumptions may be warranted.
- Given the nature of this project, the level of collaboration was reasonable. There would certainly be value in collaboration with European and Japanese institutions, although the modest budget for this project would make that somewhat difficult.
- Most of the "collaboration" is just reaching out to get data. It would be better to have stakeholders actively involved in the project. In particular, industrial stakeholders should be involved.

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.

- The project addresses barriers A, C, and D in the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan. This is outstanding; one cannot do any of this without considering water.
- There is continued interest in transportation sustainability. To further understand the environmental aspects of sustainability, continued life-cycle modeling of vehicle and fuel pathways is needed. This project helps expand life-cycle modeling to investigate water consumption associated with fuels, which will be critical in the future.

- The project addresses the importance of providing a solid understanding of water consumption for various hydrogen supply pathways at an early stage of hydrogen market development. Hydrogen production pathways that are grid- and energy-intensive should be avoided.
- Water use is highly relevant and is part of a broader view into sustainability.
- It is difficult to quantify the impact of this project, but it is essential for DOE to have this kind of information to support its program planning.

Question 5: Proposed future work

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

- It is important to understand the energy and cost penalty of alternative water production process like desalination.
- Generally, the future work is logical. It is important that the team arrive at a meaningful and consistent metric for water consumption.
- The project team should consider where the system boundary is and begin to think regionally while adding missing elements and updating data inputs and models.
- Proposed future activities are appropriate. Continued refinement of fuel pathways already incorporated in GREET and expansion of water consumption to other alternative fuel pathways will be needed to allow comparisons across pathways. Expansion of this type of modeling to the vehicle cycle in GREET2 is needed to provide a complete understanding of vehicle-fuel pathways. In particular, expanding the modeling to account for regional variability will be critically important to evaluating transportation fuel sustainability.
- The stated goals of future work are fine. It would be good to see a more regional flavor added to the analysis and an approach to assess relative impacts of the types of water consumption (i.e., true consumption versus evaporation back to the atmosphere).

Project strengths:

- This work further enhances the GREET model with water consumption data.
- Incorporation of water consumption into the GREET life-cycle model will aid in understanding transportation sustainability and enable comparisons across fuel pathways.
- Life-cycle analysis of water in energy production is a unique and very much needed project.
- A considerable amount of analysis has been performed with a relative modest investment. Comparison with baseline technology is important.

Project weaknesses:

- The project relies on a great deal of data and analyses of water consumption across regions and sectors. It is important that the data and GREET modeling of water consumption be peer reviewed, especially since comparability across fuel pathways is important for future sustainability analyses. Also, water consumption in particular needs to be understood on a regional basis.
- There is not enough analysis on the fate of evaporated water during production and utilization. There is not enough regional consideration.
- The project does not have a clear end date for completion.
- There is probably too much to do, considering the resources available.

Recommendations for additions/deletions to project scope:

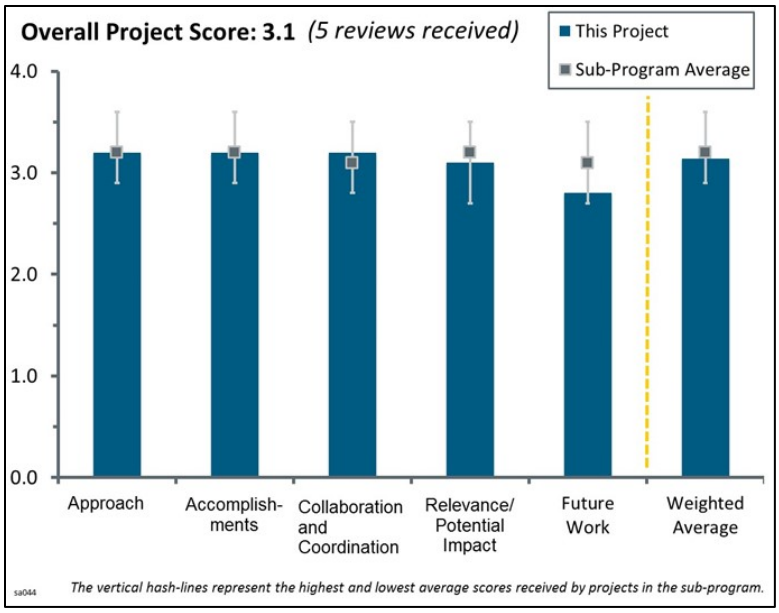
- Once GREET modeling is completed (GREET1 and GREET2) for average water consumption, further work should be conducted to understand regional variability.
- The project should consider adding scope to allow information sharing and collaboration with European and Japanese scientists (this may require an increase in budget).

Project #SA-044: Impact of Fuel Cell and Hydrogen Storage Improvements on Fuel Cell Electric Vehicles

Aymeric Rousseau; Argonne National Laboratory

Brief Summary of Project:

This project aims to quantify the impact of fuel cell system improvements on energy consumption and economic viability of fuel cell electric vehicles (FCEVs). The project will (1) analyze fuel cell stack, hydrogen storage, and fuel cell system improvements in terms of their impacts on the cost of driving FCEVs and (2) evaluate whether current fuel cell and storage technology targets are sufficient to make FCEVs viable.



Question 1: Approach to performing the work

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

- The study used the well-developed existing Autonomie model. Principal focus areas were fuel cell and vehicle hydrogen storage, which represent the largest improvement areas for FCEV performance improvement and cost reduction. The scope of work evaluated the design of fuel cell hybrid vehicles for mid-size class only, but it would be intriguing to understand relative performance of fuel cell hybrid vehicles in larger and smaller vehicle classes as illustrated on slide 5. The simulation results of this study support the long-term viability of fuel cell hybrid vehicles compared to conventional internal combustion engines at large-scale manufacturing of 500,000 fuel cell stacks. The large manufacturing volume represents scale in the distant future. Business planning environments are often short-term, so industry stakeholders also want to know the prospects for FCEVs for the next 10 years.
- The project uses the well-regarded and industry-vetted Autonomie model to assess vehicle cost based on various assumptions for fuel cell system efficiency and hydrogen storage system cost and gravimetric capacity.
- Autonomie is a good analytic tool for addressing the vehicle cost and performance questions. The market competitiveness question (last bullet on slide 3) is only partly addressed by this study.
- The approach is appropriate given that the project is based on Autonomie and U.S. Department of Energy (DOE) targets, which usually assume high volumes of production. However, it would be valuable to also assess cost at lower production volumes or at least compare low-volume to high-volume production to understand gaps. For the out years, the model could assume that production volumes increase over time. Adding that capability to Autonomie would be valuable. It is understandable that, in this case, the researchers wanted to understand the influence of improvements in the fuel cell stack and the hydrogen storage system on the overall levelized cost of driving (LCOD). However, the assumption of high volume is not realistic for the near term. The results slide (slide 19) shows a horizontal line for 2015 conventional vehicle costs. This line could be misinterpreted given that it extends all the way back to 2000 and forward to 2045. Perhaps this is just a matter of better labeling. The use of the word “accelerated” to represent the future cases is misleading, particularly when a National Renewable Energy Laboratory project (Evaluation of Technology Status Compared to Program Targets by Marc Melaina, et al.) uses the word “accelerated” for the cases where 2045 targets will be met in either 2035 or 2025. It is good to see that uncertainties were used to perform the analysis. However, it would be useful to know the uncertainty bands around the 3.5% result, although this is probably not a big deal given that the uncertainty band seems tiny. The uncertainty analysis would be more valuable in the LCOD results.

- The target-based approach is lacking. This project should use actual expected progress, rather than DOE targets. It might be good to leverage a third party consultant to provide this view if national laboratories are unable to project anything but DOE targets.

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 project team has done an excellent job evaluating FCEV configuration, cost, and performance based on various assumptions on the improvement in fuel cell system efficiency and hydrogen storage cost and performance.
- Progress toward completing the project is excellent; the project will be completed in less than a year thanks to the support of an excellent team of Argonne National Laboratory (ANL) researchers. The team did exactly what it was supposed to do, and the progress is good.
- The work provided validation that mid-sized fuel cell hybrid vehicles can realize a lower cost of driving over conventional vehicles in the long term, and performance improvements made in conventional vehicles can cost-effectively be applied to FCEVs. The scope of work only encompassed mid-sized vehicles, which is valuable to understand, but not ideal for understanding the broader market implications of fuel cells hybrid vehicles.
- Results are straightforward, but some additional sensitivity analyses would be interesting. Some discussion or analysis of the "other" relevant technology improvements, such as mass reduction, would also be interesting. This seems to be baked into the results on slide 19. It is hoped that if there are additional factors rolled into that result, they can be unbundled in the final report.
- This project seems very close to the similar study that was conducted in 2015, with a few tweaks on data inputs. It is puzzling why updating a study would require such a large budget.

Question 3: Collaboration and coordination with other institutions

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

- The collaboration is generally good. The team is working with the U.S. DRIVE Partnership and others in industry.
- Coordination is sufficient for a project of this size.
- The project team mainly consists of the Autonomie group and other researchers in ANL, though the team does team appears to have very good collaboration with and receives important inputs from U.S. DRIVE as well as DOE. The project team also notes collaboration with researchers conducting life-cycle cost, energy use, and emissions analyses, though it is not clear how formalized this interaction is or how Autonomie results are provided to other researchers.
- The Autonomie team engaged the correct stakeholders to acquire data and is collaborating with the appropriate DOE and national laboratories staff to provide results. The final results should be vetted by either the U.S. DRIVE Partnership's Cradle-to-Grave analysis team or the Fuel Pathway Integration Technical Team.
- The project covered analysis only, with no direct collaboration with the fuel cell and storage technology team. It is unclear whether the project lessons learned and results are being shared with these other DOE organizations, because the analysis shows no improvements in hydrogen storage after 2015. It is unclear whether the DOE storage team is aligned with the study results.

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 **3.1** for its relevance/potential impact.

- The project's assessment of FCEV cost and performance resulting from fuel cell system efficiency improvements and hydrogen storage system improvements provides a useful understanding of the impacts technology advancements will have. This analysis will aid DOE in its target-setting activities and evaluating its research priorities.
- This is a good and necessary basis for understanding future market competitiveness. Understanding contributions to strong market growth would require an expanded scope.
- The work confirms the challenges of achieving a big breakthrough in hydrogen storage but does not specifically address fuel cell durability.
- It is very interesting to understand that the potential improvement of vehicle power requirements from improvements to the fuel cell stack and the hydrogen storage system is only about 3.5%, but translated into dollars, that improvement can reduce overall fuel cell system cost by 50%. Of course, that is only valid if both systems are produced at scale, which is a big assumption that may not necessarily reflect future reality.
- This work does not need to be done on an annual basis, especially when the projected long-term changes are relatively small.

Question 5: Proposed future work

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

- The plan to conduct sensitivity analysis on market penetration is valuable for understanding short-term and mid-term cost effectiveness of fuel cell hybrid vehicles.
- The researcher did not address proposed future work during the presentation, presumably because the analysis has already been completed and is only in the review phase. However, he did talk about what he would like to do in the future, which is understand how much technologies should improve to meet targets and whether these improvements are cost-effective.
- The proposed future work was not included in slides but conveyed verbally during presentation: focus on marginal benefits of specific advances. This is acceptable and necessary for a limited set of research and development questions but not sufficient to understand the market potential for FCEVs more fully.
- The presentation did not describe any planned or potential future work activities. A milestone chart did indicate that analysis completion and reporting was expected in fiscal year 2016. It would be useful to better understand what type of reporting is envisioned for this project and how the project team expects to provide results and engage other researchers. The project might benefit from either further research into the impacts of fuel cell system and hydrogen storage system improvements or, more broadly, into other FCEV-related improvements.
- There is no future work. The project is finished.

Project strengths:

- The project's assessment of FCEV configuration and cost resulting from fuel cell system efficiency improvements and hydrogen storage system improvements will aid DOE in setting its research priorities and targets. The analysis is based on the well-regarded Autonomie model. In particular, the Autonomie modeling enables the project team to understand feedback loops that allow smaller fuel cell stack sizes (smaller mass per kilowatt output) and hydrogen storage systems that can reduce FCEV mass and enable lower cost and lower weight FCEV configurations.
- The simulation analysis further validated the long-term cost effectiveness of fuel cell hybrid vehicles and provided a better understanding of the impact of the projected development in fuel cell efficiency and hydrogen storage.
- Project strengths are the strong technical knowledge, strong team, experience with the model, robust model, and defensible data.

- The rigorous analytic approach is a project strength.

Project weaknesses:

- Considering the number of assumptions in the scenario analysis, it would have been valuable to provide more transparency on the key factors contributing to fuel cell and storage cost reductions over time. Also, transparency on the "other" technology contribution to base spark ignition vehicle performance and applicability of spark injection improvement to the FCEVs would be valuable.
- As part of its investigation, the project team conducted preliminary FCEV life-cycle cost evaluations. The Fuel Cell Technologies Office (FCTO) and U.S. DRIVE already are conducting various efforts to assess life-cycle cost and cost of driving. It would be more useful for this project team to work with other DOE and U.S. DRIVE researchers on this area so that multiple evaluations using multiple analysis frameworks can be avoided.
- The project lacks sensitivity analyses and only partially addresses the market competitiveness question.
- The assumed high production levels are a project weakness.

Recommendations for additions/deletions to project scope:

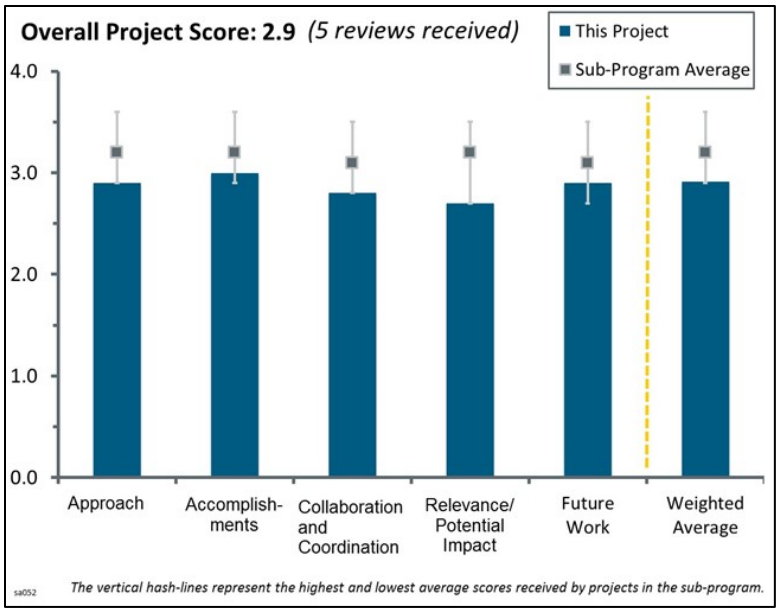
- The project conducts very valuable evaluations into FCEV configuration and cost based on important system parameters such as fuel cell system efficiency. It would be helpful for the project team to engage other FCTO and U.S. DRIVE researchers more formally to provide the results of these analyses to the community at large, to increase collaboration, and to avoid duplication of analysis efforts.
- A broader analysis that covers all vehicle classes and at lower fuel cell production volumes is recommended.
- The same analysis should be performed for business cases with lower volumes of production. The project should show uncertainty bands around LCOD results.

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 develop a plausible business case for marketing hydrogen-powered fuel cell passenger vehicles and building out the hydrogen fueling station network. Researchers will analyze 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.



Question 1: Approach to performing the work

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

- This is a great project that analyzes scenarios in which the hydrogen infrastructure is mature enough to be profitable to investors without any government subsides. The work uses and fits in very well with other U.S. Department of Energy (DOE) models.
- Although this project just recently started, from the material presented it seems the project leads are taking a good approach to this work. This was demonstrated by the proposed approach of utilizing two robust models, such as the Hydrogen Delivery Scenario Analysis Model (HDSAM) and Hydrogen Financial Analysis Scenario Tool (H2FAST) and collaborating with their main leads from Argonne National Laboratory (ANL) and the National Renewable Energy Laboratory (NREL). In addition, project leads stated they will also be interfacing with established hydrogen station equipment suppliers to gather additional data.
- The approach is good, but there is not a strong need for this report. The total cost of ownership comparisons have error bars that appear too small, particularly for future cases where technology breakthroughs (e.g., lower battery cost) could have a big impact on the competitiveness of the technology. The slides mention that "an optimal hydrogen production technology is not yet established." About 9 million metric tons of hydrogen are produced in the United States annually, mostly through steam methane reforming. DOE's reports confirm that natural gas reforming is an established industrial process that meets cost targets.
- This analysis hinges on which vehicles consumers will choose assuming different total cost of ownership. The vehicles chosen do not compete in the same market. The critical parameters for consumer purchase decisions are first vehicle size and body type (hatchback, sedan, sport utility vehicle [SUV], etc.). Once those are defined, then a consumer can do a cost-benefit analysis. The analysis needs to compare vehicles that represent the same size and body type. A better approach is a component-based buildup of vehicle costs, such as the one done by the Autonomie report or referenced in the cradle-to-grave report (both ANL publications).
- There are a number of questions about the approach: (1) Did the project have a break in 2015-2016?; (2) was venture capitalist (VC) input included in the study?; (3) what input database was used and how were the different modeling tools used? Also, the "101th of-a-kind" station is still a transition game, not full scale.

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

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

- Even though the project started only a couple months ago, some results and conclusions have already been reported, and these results are on track with the main goals of this project.
- The project is on track to be completed in a timely manner. The early conclusions appear realistic but not surprising.
- The project is making a great contribution by being able to predict the cost of ownership of a hydrogen fuel cell electric vehicle (FCEV). There is some risk in learning from the current FCEV implementation in California, because the circumstances there may not be applicable to other markets, and it is still such a small market that it may be a terrible test case for market validation. It also seems a little weird that the implication is that the 101st station is a standalone hydrogen station. The team should consider the costs and benefits of adding hydrogen to the portfolio of fuels at a regular filling station. Presumably there will be significant capital savings based on that scenario.
- It is not clear whether the project discussed the data with the VC community. It is not clear why the team did not contact Toyota and Hyundai directly. There is not adequate data to conduct a fair review. It is not clear how the team calculated the number of cars on the road and who is driving the vehicles. It is unclear what the owners' experience would be. It is unclear whether the Tesla Motors experience in cost reduction is relevant. The Toyota Mirai vehicle has fewer parts and much less maintenance cost. It is unclear what the main barrier is to the 101st station. The hydrogen price reduction strategy needs to be analyzed.
- It is too early in the sub-project to understand what was done. It appears to be mostly planning at this point.

Question 3: Collaboration and coordination with other institutions

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

- There is very good collaboration with both national laboratories. The project may also benefit by collaborating with industry stakeholders as well as with stakeholders in California where a lot of hydrogen and FCEVs efforts are underway. These could possibly include the California Fuel Cell Partnership, California Air Resources Board, and the California Energy Commission.
- ANL and NREL have been approached to provide feedback on the approach. Both institutions have highly knowledgeable staff familiar with the topic. Collaboration with industry and the VC community is needed to ensure that the assessment is material, the right assumptions have been made, and that the appropriate results are calculated.
- There are no hydrogen gas suppliers or vehicle manufacturers amongst the collaborators, yet the analysis uses hydrogen.
- The study needs much more input from original equipment manufacturers and suppliers of hydrogen fueling station hardware.
- The project needs to contact car companies directly, and the owners' experience needs to be analyzed. Input from the VC community is also needed.

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 **2.7** for its relevance/potential impact.

- The project addresses the relevant barriers of the Hydrogen and Fuel Cells Program Multi-Year Research, Development, and Demonstration Plan.
- This project will definitely inform the VC community about hydrogen and FCEV technology and whether there might be opportunities to invest in it.
- The study needs to go beyond ANL data and make more practical assessments. The study could investigate a battery-dominant FCEV as part of a transition strategy. The PI's comment on Tesla and fuel cells should

be put in terms of the opportunity for FCEVs to extend the range of Tesla vehicles. Performance is much better in battery-dominant FCEVs.
- A number of studies assessing future cost of hydrogen refueling stations have previously been conducted. A summary of such studies is in NREL's 2013 study "Hydrogen Station Cost Estimates Comparing Hydrogen Station Cost Calculator Results with other Recent Estimates" (http://www.nrel.gov/docs/fy13osti/56412.pdf). In addition, the H2FAST model is capable of generating cost data for potential VCs.
- This area of work does not seem to have clear relevance to DOE goals. A business case is something that should be investigated by the stakeholders who would develop the infrastructure, not DOE.

Question 5: Proposed future work

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

- Two aspects of the proposed future work are key: the vetting of input cost data and the market analysis of the rollout of first generation hydrogen stations.
- The proposed future work is adequate, but the materiality is lacking.
- Future work should include addressing the issue of the vehicle comparison.
- The project has a good approach to enter probability to the output rather than simple point output, but the quality of the input data is still in doubt.
- The project should focus on value proposition enhancement as related to the battery FCEVs. This study should consider how to enhance the value proposition, not just conduct analysis.

Project strengths:

- This project is another good attempt to predict future behavior of this exciting emerging market and begin the process of involving venture capitalists.
- Project strengths are the awareness of available tools and resources and access to experts from national laboratories.

Project weaknesses:

- It is still not clear whether the inevitable uncertainties are being correctly handled. It is not clear what the absolute worst- and best-case scenarios are and their true probabilities.
- The subsidy removal question is not practical. Sales of 60,000 hybrid cars made them successful. Analysis is needed for the first 1,000 and first 10,000 vehicles for the 101st station.
- The relevance of the report and the lack of engagement with industry and the VC community are project weaknesses.

Recommendations for additions/deletions to project scope:

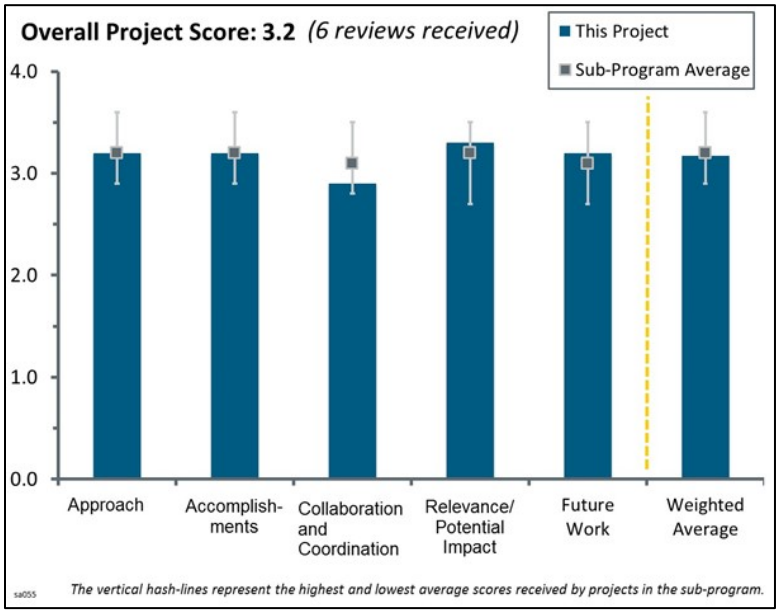
- Collaboration with industry and the VC community is needed to ensure that the assessment is material, the right assumptions have been made, and the appropriate results are calculated.
- The project should obtain more input from potential investors and stakeholders.
- VC funding for the FCEV and hydrogen market is critical. It is unclear how the study data will help the transition strategy.

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

Rebecca Levinson; Sandia National Laboratories

Brief Summary of Project:

The objective of this project is to understand changes to light-duty vehicle stock, fuel use, and emissions through analysis of the dynamic among vehicles, fuels, and infrastructure. ParaChoice parametric analysis will (1) identify trade spaces, tipping points, and sensitivities and (2) help researchers understand and mitigate uncertainty in data sources and assumptions.



Question 1: Approach to performing the work

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

- This is a great project that attempts to examine scenarios in 2050 and scale price with demand. The way hydrogen production is put into the model is really very good. Comparing drive trains, both established and emerging, is outstanding. The model is deliberately designed to explore uncertainties and tipping points; as it progresses, it will be exciting to see how accurate it is.
- The approach of using other previously developed models as input to the ParaChoice model is commendable. This addresses the barrier of "Inconsistent Data, Assumptions, and Guidelines." This provides credibility to the model. The project should ensure that the assumptions in these previously developed models are consistent with the assumptions throughout the ParaChoice model. The ParaChoice model may be limited by assuming that customer vehicle selection is based solely on cost when studies have shown that customers are not "economically rational."
- The ParaChoice model appears to apply a Monte Carlo simulation to the base U.S. Department of Energy (DOE) models and data parameters. The work explores the impacts of uncertainty around fuel cell electric vehicle (FCEV) cost and performance and hydrogen infrastructure that other DOE models and analysis do not currently address.
- The project has a nice combination of different aspects of other models. The FCEV penalties on slide 10 for battery electric vehicles (BEVs) and FCEVs need to be explained in greater detail for the reviewers to understand the unique contribution of ParaChoice compared to other models, or even to determine whether ParaChoice has correctly implemented approaches used in other models. Slide 6 states that the model has dynamic feedback with infrastructure resolved endogenously, but this is difficult to do, and there is little evidence in the slides (or in the presentation delivery) that there is a significant analytic contribution in characterizing this feedback. That being said, there is significant progress in the integrated economics of supply and market growth compared to last year's updates. The parameterization approach is valuable in general, but it is not necessarily a unique capability compared to other similar models, just a unique presentation of results.
- The model currently includes current and near-future policies. It would be good to start implementing potential future policies to assess their potential impact. The current process assumes that hydrogen production will be driven by vehicle demand. It would be nice to implement a methodology to include fuel availability as a parameter influencing vehicle sales. It would be nice to show one example of how Monte Carlo Latin hypercube sampling is used from generating inputs to market penetration analysis; the current presentation included only a "brute force" parametric study.
- The team said it used input from the Hydrogen Analysis (H2A) model and Hydrogen Delivery Scenario Analysis Model as price data. These tools do not calculate price; they calculate cost. In addition, H2A was

never intended to be used to project price. It was intended to allow for an apples-to-apples comparison of different technologies and/or the progress made on a single technology. If the team is using H2A for hydrogen price projections, it is misusing the model. The principal investigator stated that the team used price and cost interchangeably (see slides 5–8). However, price and cost are not the same. Cost is what it takes to manufacture. Price is what a product is sold for. The team needs to be very clear on its terminology. The assumption that federal and state incentives will not change between now and 2050 does not seem reasonable. To this reviewer's knowledge, most businesses do not include incentives if trying to project more than five years out since there are too many unknowns. In addition, the technologies need to be able to succeed without the incentives and policies (carbon tax). Also, it seems that if the difference between industrial hydrogen and central steam methane reforming (SMR) is the delivery cost (which is included in industrial hydrogen), then central SMR, central electrolysis, and central coal and sequestration would also have delivery costs. The project needs to clarify this issue. The assumptions on how the multipliers (slide 14) are developed need to be made transparent. Without understanding how they were developed, their accuracy cannot be evaluated.

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.

- Excellent progress has been made based on the funding the project was provided. It was great to see that the project has made efforts to validate the model based on history and performed a sensitivity analysis with the model.
- The work was able to parameterize base input assumptions to existing DOE models and apply market segmentation and market assumptions to establish market penetration rates of FCEV adoption and emissions reduction. Accomplishments or conclusions derived from the ParaChoice analysis confirm the importance of initial FCEV cost and efficiency along with hydrogen costs and emissions.
- The business-as-usual projection was possibly the most important result. It was in the analysis talks, and it will be incredibly useful moving forward. Also, the result that SMR needed to be displaced for hydrogen-fueled vehicles to make a real impact was important.
- The presenter showed which of the seven hydrogen fuel pathways was selected and how the selection evolved over time. It would have been nice to show the impact of assumption uncertainties on the fuel pathway selection, if any.
- The result that "FCEVs displace compressed natural gas vehicles disproportionately to other alternative fuel vehicles" is interesting; it is not clear why this happens. The need to move towards renewable hydrogen production is supported by the finding that the "Prevalence of distributed SMR hydrogen makes FCEVs a GHG neutral addition to the stock." The other findings are not very surprising. For example, if the FCEV cost is lowered, the finding that you will sell more FCEVs should not be a surprise. Likewise, it is not surprising that at lower hydrogen costs more FCEVs are sold. The need to go to cleaner fuels is also not a surprise, as this has been shown in other analyses.
- There are very interesting results. There are some concerns. First, slide 10 has the sales fraction in 2050 being very unresponsive to fuel cost, even near zero. This should be revisited. It could be that the vehicle is so efficient that fuel costs are very small, but either way, the team needs to unbundle this issue more to make that claim convincing. Also, FCEV sales fraction as a function of efficiency seems to contradict results on slide 15. It is hard to see that fuel economy improvements would improve the sales fraction but the cost of fuel does not. Fuel economy is only valuable to the consumer because it reduces fuel costs. This seems like an error unless there are some other correlations that are not being revealed, in which case the presentation is misleading.

Question 3: Collaboration and coordination with other institutions

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

- The project exercised existing analysis models and included frequent collaboration of the ParaChoice modeling team and the DOE model stakeholders from other laboratories. The work received technical feedback from two automotive manufacturers.
- There is good leveraging with the Vehicle Technologies Office (VTO). Collaborations with other stakeholders are unclear. It seems the team talked with one original equipment manufacturer (OEM), General Electric, and the American Gas Association at conferences ("and other conference engagements," slide 18). It is not clear how the energy producers were involved. From the slide, it seems the technical critiques were only from conference engagements. This is not a sufficient review by stakeholders to give confidence in the approach and results.
- It is not clear what benefits have been gleaned from the collaboration that has been claimed. It may be beneficial to highlight what assumptions have been changed or model improvements that have been made based on this collaboration. It is good to see that this work is funded by the VTO and the Fuel Cell Technologies Office (FCTO). This allows cross-pollination between the offices, resulting in a better product.
- It is not expected that funding will be given to other entities, but this work needs to be shared and commented on by a much bigger range of interested parties, multiple OEMs, government, and other agencies.
- The presenter should include collaborations with other agencies that perform similar work. Collaborations with other national laboratories are mentioned, but it is not clear what they are.
- Stronger collaboration is needed. It is not clear what "conference engagements" are. The project should be more explicit about its relationship to these entities and the type and quality of feedback received.

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.

- The model provides insight into the relationship between FCEV cost and efficiency and the resultant sales and GHG emission reduction. This information supports the FCTO objectives. Sensitivity analyses on anticipated improvements in hydrogen production pathways and energy efficiency of the FCEV could help guide the research, development, and demonstration priorities of the FCTO.
- This project addresses A, C, and D of the FCTO Multi-Year Research, Development, and Demonstration Plan.
- The analysis provides a projection of a variety of light-duty alternative vehicle platforms that are competing for the same customers.
- This has potential to be important, but there are several weaknesses that need to be fixed.

Question 5: Proposed future work

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

- It is great to see the deeper dive exercises and the attempts to begin to understand hydrogen fueling station growth.
- Conducting a deeper dive into consumer market segmentation and FCEV adoption will be valuable to understand.
- The model needs additional evaluation of the hydrogen refueling station growth scenarios, which could be very different from one state to another. Regulations and possible market drivers could be different in the different regions of the country. Addressing market niches will assist in understanding the non-cost-related issues in customers' purchase decisions (urban vs. suburban, vehicle class, etc.). The team might consider evaluating people's acceptance of new early adopters vs. late majority distribution.

- The work is fine, but the milestones are not specific, measurable, achievable, relevant, and timely (SMART). A SMART milestone is recommended.
- It is not clear how to do a deep dive into niche markets if the model treats all urban areas equivalently. The project has to take into account heterogeneity of urban markets, and it is unclear whether this is happening. Parametric analysis of station growth is not what is needed. First, a clear and meaningful articulation of the feedback mechanisms is needed.

Project strengths:

- The analysis was dependent on existing DOE models from other laboratories, and there was good collaboration between the Argonne National Laboratory project team and the other laboratories.
- Leveraging a Monte Carlo analysis to assess the uncertainties is a strength.
- Projections are needed to understand where the FCTO should focus its limited resources.
- The project really tries to understand uncertainties.

Project weaknesses:

- There could have been better transparency on the range of values assigned to the key variable in the model that were parameterized.
- There needs to be more input from outside entities.
- Lack of collaboration/coordination with other institutions developing similar tools is a weakness.

Recommendations for additions/deletions to project scope:

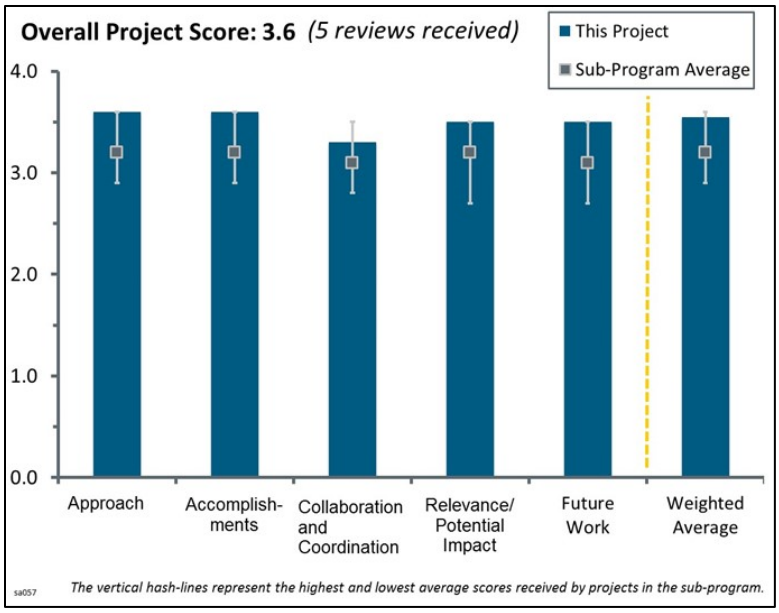
- It may be beneficial to allow the model to adjust the number of years that it forecasts out for switching between distributed and centralized production based on the past year's market growth. This could be another possible sensitivity analysis.
- The hydrogen supply pathway should be expanded to include biomethane supply to the steam methane reformer.
- The project team needs to be consistent with the FCTO on "cost" vs. "price." A SMART milestone needs to be added. So far, the results are not surprising. They are very consistent with results that the Systems Analysis program has done in the past. The team should add error bars on its findings.
- It appears that several national laboratories are developing similar models in parallel with little to no coordination. This appears to lead to duplication of efforts.

Project #SA-057: Life-Cycle Analysis of Emerging Hydrogen Production Technologies

Amgad Elgowainy; Argonne National Laboratory

Brief Summary of Project:

This project is expanding the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET™) model to include life-cycle analysis (LCA) of emerging hydrogen production pathways. Investigators will acquire material and energy balance information for emerging hydrogen production technologies from modeling efforts developed by partner laboratories, use GREET to conduct well-to-wheels (WTW) analysis of new pathways, and compare WTW greenhouse gas (GHG) emissions of new hydrogen production pathways with baseline pathways.



Question 1: Approach to performing the work

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

- A considerable amount of analysis was completed within a short time and with minimal investment. This was enabled by leveraging existing tools that already have been established. At this early stage of the project, it is difficult to find any faults with the technical approach.
- This project expands the number of hydrogen production pathways to include emerging production technologies based on fermentation, high-temperature solid oxide electrolyzer cells (SOECs), and bio-derived liquids. Developing new pathways as part of the GREET model is an excellent approach because it builds on the existing GREET model framework, which is the standard for LCA of transportation fuels. The project team is well versed in GREET modeling and has worked with the appropriate researchers from consulting firms and national laboratories to understand these emerging hydrogen production pathways.
- The project expanded the current GREET model to address three new hydrogen production technologies. This project appears to have addressed the three barriers that were claimed in the presentation. Modification of a thoroughly vetted model for this analysis is much better than development of a new model. The three technologies are at a relatively low technology readiness level (TRL) and, as a result, are subject to significant changes and improvements. Assumptions for these models should be well documented and then updated as changes occur.
- This is a great project to see attempts made to try to understand a full LCA of emerging hydrogen production technologies. However, the input to the model is data from one developer of each of the approaches; where possible, an effort should be made to include as much data from multiple developers as possible to increase the usefulness of the model. The project team needs to think very carefully about where the system boundaries are drawn; WTW here seems to mean feed-to-process-to-wheels. Many of these feeds have significant carbon dioxide and energy footprints before this model inputs them. Some of this information is known, e.g., for corn stover or the wood that is fed into the pyrolysis oil. The totals for producing and processing the biomass into fuel feedstock should be included in the complete analysis.
- Work included fundamental heat and material balance to support LCA of the three new emerging hydrogen supply pathways.

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 team has successfully developed new GREET pathways for dark fermentation, high-temperature SOECs, and hydrogen from bio-derived liquids (pyrolysis oils) by incorporating production process data and information on feedstocks and process energy. This work enables WTW comparisons to be made of these processes (including process variations) and other hydrogen fuel pathways, such as natural gas steam methane reforming and water electrolysis (wind- and grid-based).
- The project has made great progress starting this work and getting early numbers for how these technologies might pan out. It is great to see the new technologies already being compared to the more established ones.
- This kind of analysis is essential for DOE to make informed decisions on investments.
- The results of the analysis should be provided to those that are developing these technologies and could be used to help direct future research, development, and deployment. Cost, air toxic emissions, and land and water usage should be included in the analysis and, if possible, presented together to show a more complete picture of each alternative and help direct future work. It is not clear whether heat is required for biomass-derived liquid reforming and how much and the source (internal vs. natural gas addition). The other hydrogen paths are also not clear. It was not clear from the presentation whether the hydrogen transportation cost was reduced for the distributed hydrogen generation technologies relative to those that were centralized.
- An LCA was completed for three new emerging hydrogen supply pathways, and GHG emissions were estimated for different power grids.

Question 3: Collaboration and coordination with other institutions

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

- This project was conducted by members of Argonne National Laboratory's (ANL's) experienced GREET team, with appropriate input from national laboratory and consulting firm researchers on the various hydrogen production processes.
- The project could not have been conducted without critical input and collaboration with the National Renewable Energy Laboratory (NREL), Pacific Northwest National Laboratory (PNNL), and Strategic Analysis, Inc.
- The level of collaboration is commensurate with this type of work and the project budget. It would be useful to establish dialogues and collaborations with European and Japanese scientists in this field, although this could be problematic without an increased budget.
- It is good to see involvement from others in the development of the hydrogen production pathways. It is not clear whether the results of the project were fed back to the collaborators to allow them to modify their approach or at least be aware of the issues that should be addressed going forward.
- It is a good start to find one research group at an individual laboratory to get initial data. This project needs input from all developers of these technologies. It will be especially important to be watching for breakthroughs and technology improvements as the work progresses. Also, the project needs collaboration with feed producers.

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.

- The project addresses barriers C, D, and E in the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan. The project is needed to make proper and useful assessments of emerging technologies.

- The project directly addresses the LCA of emerging hydrogen pathways that is important to understand at the very early stage of technology development. The intention of this work is to identify future hydrogen supply technologies that hold promise, first environmentally and then economically.
- There is continued interest in transportation sustainability in general and, in particular, in hydrogen fuel cell electric vehicles (FCEVs) on the life-cycle GHG emissions associated with FCEVs and hydrogen fuel pathways. This project helps expand life-cycle modeling of hydrogen fuels to include emerging hydrogen production techniques and renewable feedstocks. Understanding these emerging production pathways, which have the potential to be low-carbon transportation pathways, is critical to advancing FCEVs.
- This LCA to determine reductions in GHG emissions and its comparison to currently available technologies aligns well with the Hydrogen and Fuel Cells Program and its objectives. It is not groundbreaking work, but it demonstrates an expanded ability for the GREET model.
- Understanding and quantifying WTW GHG emissions associated with various hydrogen production technologies is essential for DOE to make informed investment decisions.

Question 5: Proposed future work

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

- Adding photobiological, photoelectrochemical (PEC), solar thermochemical hydrogen (STCH), and others will be extremely useful. It is very good to add water consumption and other pollutants. This needs to be done for all pathways, so it may be ambitious for the current level of funding. It will be essential to update GREET and get peer-reviewed publications based on the analyses.
- The proposed future activities are appropriate. Continuing to develop modeling for new hydrogen fuel pathways (including those based on renewable feedstocks such as photobiological production, PEC, and STCH) will be important for advancing FCEVs and assisting DOE in understanding the potential of the technologies under its research portfolio. In addition to the new work cited, the project team should continue to modify the pathways investigated in this project, as improvements in these emerging pathways are likely as research progresses.
- The proposed future work appears to be appropriate. The proposed inclusion of water consumption in the analysis (perhaps leveraging ANL's parallel project) is especially important. It is also suggested that the project consider adding land use as a metric for each of the hydrogen production processes. Analysis of regional considerations might also be included in future work.
- Evaluating new hydrogen production pathways would be the next step with this project. It would be good to see a firm basis for the selection of the pathways selected. The selection could be based on technologies with the lowest cost, best chance of commercial success, or the widest range of possible alternatives. DOE should be involved with the selection. Probability distribution functions would be a nice addition to the GREET model. This would better represent the results of any analysis.
- The future work does not address cost analysis of the emerging hydrogen supply pathways. It would be helpful to understand how all new hydrogen pathways provide a balance in regard to life-cycle emissions, energy efficiency, and cost.

Project strengths:

- The strengths are the comprehensive approach to assessing GHG emissions for various hydrogen production processes and the effective use of existing tools to support the analysis.
- The expansion of the GREET modeling of hydrogen production pathways, particularly emerging low-carbon pathways, is important to furthering the market for FCEVs.
- The LCA of new hydrogen production pathways is a strength.
- The project built off previous work conducted at PNNL and NREL.

Project weaknesses:

- There are none at this stage.
- The project needs more resources to include everything, i.e., processes outside system boundaries and more input from the developers of these technologies.

- Though not the fault of the project team, the hydrogen production processes investigated represent emerging technologies at a low TRL. As such, understanding of these processes is preliminary, and the resulting GREET analysis and findings are likely to change. Development of uncertainty modeling and probability distributions will help in this regard.
- It is not clear how the three new hydrogen supply pathways were selected for LCA and whether the new pathways were down-selected from a larger list of future hydrogen supply pathways. The comparative WTW analysis of the new pathways to existing steam methane reforming and water electrolysis is incomplete without the listing of biomethane feedstock to steam methane reforming hydrogen supply.

Recommendations for additions/deletions to project scope:

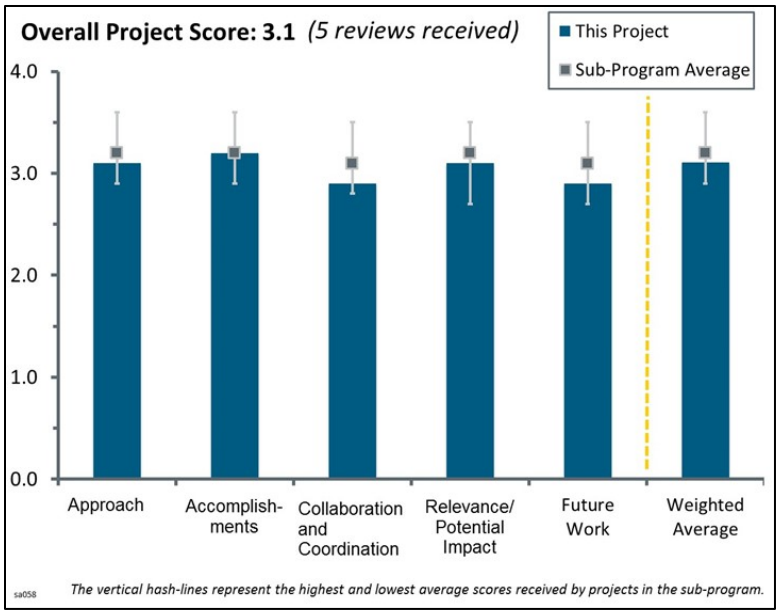
- The LCA should be expanded to include the biomethane supply to steam methane reforming hydrogen supply.
- The project should continue investigations of other emerging pathways (photobiological, PEC, STCH); revision and refinement of the current work on dark fermentation, SOECs, and bio-derived liquids; and the uncertainty analysis, including probability functions.
- The project should consider land use and regional considerations within the analysis. The project should consider expanding the scope to facilitate collaboration with European and Japanese scientists.

Project #SA-058: Analysis of Incentives and Policy Impacts on the Market for Alternative Fuels and Vehicles

David Greene; University of Tennessee

Brief Summary of Project:

This project supports analyses of future markets for hydrogen and fuel cell technologies. Investigators will develop and publish reports that increase understanding of the transition to low-greenhouse-gas (GHG) energy for motor vehicles, the role of public policies in the transition, impacts of policies on the early markets for non-automotive fuel cells, and effectiveness and efficiency of policies for promoting low-GHG energy vehicles and fuels.



Question 1: Approach to performing the work

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

- The collection of these data has been carried out effectively, and the findings are significant.
- Given the small size of the project, the focus and approach are very valuable.
- The project employs a review of relevant literature to understand cost drivers and policy impacts of transitioning to alternative fuel vehicles in general, and hydrogen fuel cell electric vehicles (FCEVs) in particular. This approach is reasonable, but data on FCEVs are limited, requiring greater emphasis on other alternative fuel vehicles. While much can be learned from this literature, recent experiences with hybrid electric vehicles (HEVs) and plug-in/battery electric vehicles (BEVs) are somewhat limited in regard to fueling infrastructure because infrastructure hurdles for these alternative vehicles are much lower compared to hydrogen infrastructure for FCEVs. Investigation of 85% ethanol (E85) and natural gas transportation fueling infrastructure might be informative.
- Barriers are not taken from the Systems Analysis section of the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan. The barrier should be "Future Market Behavior." This is a good literature review of the customers' behavior in terms of new technology and specifically FCEVs. These results should be used to help direct public policy and the manufacturer's approach to vehicle development.
- The project is a literature review of policies to promote alternative fuels and vehicles. So far, only U.S. policies have been reviewed, which may not offer a complete view.

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 project has made excellent progress at uncovering important learnings from the available literature on deploying alternative fuel vehicles generally and on economic and non-financial incentives for vehicle uptake. The lessons learned provide good information for the deployment of FCEVs and will help federal and state governments better understand how to craft policies to incentivize FCEV deployment. The project discussed findings regarding the extent of hydrogen infrastructure that will be needed to support FCEV deployment; however, more work is needed in this area, as recent alternative vehicle markets have not relied as heavily on new and expanded infrastructure as FCEVs will.

- The project has done a great job of sorting through the literature and summarizing it. The report is publicly available.
- It is great to have these topics all reviewed in one presentation. Fairly limited original work was presented, but the review and distillation are valuable.
- A good review of the literature has been completed, but as the presenter mentioned, nothing unexpected was found. It is, however, good to have the summary in a single location.
- While the information provided is informative and relevant, it would be beneficial to go a step further and lay out the results in a coherent and prioritized approach that could be used by DOE for policy development and by researchers to implement into their models to evaluate the economic impact on fuel cell sales and hydrogen infrastructure development.

Question 3: Collaboration and coordination with other institutions

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

- Given the scope of the work as a literature review, the level of collaboration for this initial literature review was good. Going forward, it would be beneficial to work with owners of the currently developed models to implement some of these findings into their models and determine the impact.
- This project was conducted primarily by the principal investigator. However, the project did gain valuable feedback in the form of peer review by several knowledgeable researchers.
- Given the nature of this project, collaboration was not critical.

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 **3.1** for its relevance/potential impact.

- Understanding the impact of costs, benefits, and incentives on customer behavior is a challenging yet important piece to the FCEV puzzle. This study and the information it gathered do an excellent job addressing these issues.
- This work is an important contribution to the Hydrogen and Fuel Cells Program (the Program). Having a single summary of all these studies simplifies analysis for other researchers.
- This project helps bridge the gap between deployment of FCEVs and deployment of other alternative fuel vehicles. Understanding what has facilitated the deployment of alternative fuel vehicles will aid policymakers in better understanding how policies and incentives can be structured to support deployment of FCEVs and hydrogen infrastructure.
- The policy issues reviewed are very relevant given the commercialization status of vehicles.
- No major new findings were uncovered.

Question 5: Proposed future work

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

- Comparative infrastructure cost data are a valuable addition.
- Proposed future work activities are somewhat vague. Beyond publishing this work and broadly supporting DOE in its deployment of FCEVs, this project should attempt to bridge the gap between what has been learned from the literature and what DOE should do to support deployment of FCEVs. The principal investigator should provide advice on research gaps, discuss what future research should be done in this space, and investigate the requirements for deployment of hydrogen infrastructure, which differs from HEV and BEV deployment needs.
- The author should look at impactful policies in other countries (e.g., revenue-neutral fee-based in France). It is also unclear how much can be learned from HEVs and plug-in hybrid electric vehicles (PHEVs) related to FCEVs since HEVs and PHEVs do not have infrastructure issues. The project should learn from other countries that have successfully implemented new fuels (e.g., E85).

- Other than publishing the results of the literature review, there are no concrete future work plans. It would be better if the team specified what models it is going to assist in developing and how it will assist. It is not clear whether there is additional research that could be done on compressed natural gas or biofuels in other countries that could be used to augment the current literature review.

Project strengths:

- This project takes a very broad search of the available literature on deployment of alternative fuel vehicles to understand the deployment of FCEVs better.
- This is a comprehensive review of literature by a capable investigator.
- The results of this work are interesting and relevant to the Program.
- This is a good literature review.

Project weaknesses:

- How the project addressed last year's Annual Merit Review comments should be delineated in "Responses to Previous Year's Reviewers' Comments."
- The focus on only U.S. policies is a weakness.
- The lessons learned from other alternate fuel vehicles are limited in regard to the need for hydrogen fueling infrastructure for FCEVs. Research areas such as revealed preferences, in which much of the literature is devoted to HEVs, are limited in application to FCEVs because of the differences in infrastructure needs.

Recommendations for additions/deletions to project scope:

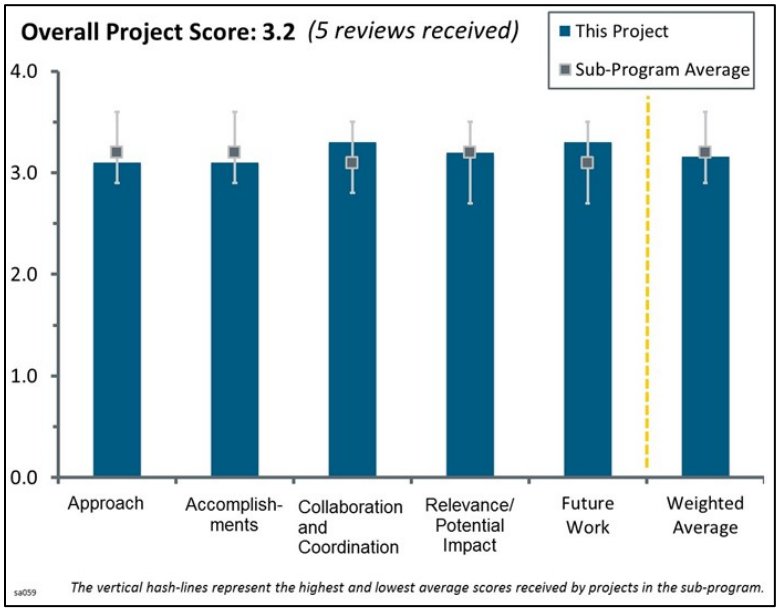
- The project should make some of the cited articles available on the DOE or Baker Institute website if copyright restrictions allow.
- Because hydrogen infrastructure needs are different from HEV and BEV infrastructure needs, the project should investigate this space further. A review of literature on E85 and natural gas transportation fueling infrastructure may be informative.
- The project should review policies, success stories, and failures related to fuel infrastructure worldwide.

Project #SA-059: Sustainability Analysis

Marc Melaina; National Renewable Energy Laboratory

Brief Summary of Project:

This project is conducting a sustainability analysis of hydrogen supply and stationary fuel cell systems using the Hydrogen Regional Sustainability (HyReS) framework. Investigators will develop regional metrics around upstream hydrogen supply chains, ensuring consistency with existing frameworks and tools used by engineering firms, the sustainable business community, and green investors. The project will leverage the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET™) model with the spatial detail of the Scenario Evaluation, Regionalization, and Analysis (SERA) model. Outcomes will include pathway cases, a beta framework, and a final public framework.



Question 1: Approach to performing the work

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

- The scope of these projects continues to be very impressive. Understanding sustainability is a totally brilliant addition to the analysis portfolio. The team is developing sustainability indicators, understanding the target audience, and reducing this analysis to regional-level data.
- The project takes a rational approach to assessing sustainability of fuel pathways. Regional production of hydrogen is desirable due to difficulties in transportation. The concept of sustainability is complex enough that it is difficult to derive a single "sustainability index." The project should continue to calculate and report numerous aspects of sustainability and allow users to do their own weighting of desired outcomes. The open approach should promote wide use and acceptance.
- The project involves life-cycle analysis of hydrogen supply network for fuel cell applications. A unique aspect of the analysis is that it includes environmental impact and sustainability metrics.
- The project title includes stationary fuel cell systems, but project work to date and future work do not address stationary fuel cells.
- The interpretation of "sustainability" does not seem to capture well the social and economic aspects of sustainability. It is more focused on the environmental aspects, which is too narrow a focus. While the categories are captured (slide 4), the economic and social aspects were not emphasized on slides 12–15. If the researchers are endeavoring to extend life-cycle analysis (environmental) to a sustainability analysis, those are the two areas that need to be emphasized.

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.

- Starting with a roundtable of experts was excellent and generated collaborative ideas and ranked users and use characteristics. It is true that system-level indicators are the most important here, but using the DOE

suite of models, it should always be possible to drill down and figure out what the most important drivers are.
- Since the project is just starting, most accomplishments are related to planning. The framework structure and goals seem to have been defined well.
- The project appears to be in the very early stage of development and just recently obtained stakeholder input at the roundtable meeting. Sustainability covers a very broad area, and the project appears to be seeking direction.
- Engaging stakeholders is useful. This is a very difficult subject to capture adequately, and the steps taken so far have been useful for informing the effort. It does not appear there is a very clear definition of the metrics that will be used yet, other than a few examples.
- This is a new project (started in September 2015), so there is little progress to report (as of the March date on the slide decks). Much of what is reported deals with the set-up of the project: establishing partners, pulling together models, and hosting workshops to obtain stakeholder input.

Question 3: Collaboration and coordination with other institutions

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

- The HyReS workshop made an effort to gather input from stakeholders. The project has assembled a strong team of partners. The work will access data from other entities to merge into an overall sustainability framework.
- The roundtable meeting held at the National Renewable Energy Laboratory provided a good forum for obtaining stakeholder input and expectations from the project.
- Collaboration is excellent, bringing in partners from national laboratories and industrial leaders.
- Having industry involved on a steering team is an excellent way to encourage collaboration. It is not clear whether there was an effort to get steering team members to contribute resources to the project.
- With this sort of project, there can always be more collaborators and sources of data.

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.

- The project totally addresses barriers A, B, and D of the Fuel Cell Technology Office Multi-Year Research, Development, and Demonstration Plan.
- Assuming hydrogen will be a fuel for the future, it is critical to understand its cost and impact on the environment and society. This project tries to develop a framework to quantify these metrics—a very daunting challenge. Knowing what challenges will need to be addressed is critical if hydrogen is ever expected to be a serious energy contender.
- This project is necessary to understand broad implications of different technologies.
- Sustainability is clearly relevant to all hydrogen supply pathways and stationary power generation, but this project appears to be having difficulty in establishing direction and focusing on the plan.
- These metrics are important, but it remains to be seen whether they will have a significant impact on implementation of hydrogen and fuel cells.

Question 5: Proposed future work

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

- The project has a good plan for assembling data and merging them into a rational sustainability framework.
- The project is just six months into its three-year life. There is no need to reframe future plans.
- If the team can bring in more experts and databases, this will be outstanding.

- Future work should cover a broader mix of hydrogen supply pathways such as liquid hydrogen, distributed steam methane reforming, and central water electrolysis. It is not clear whether and how stationary power generation is being addressed in the project.

Project strengths:

- A face-to-face roundtable meeting was conducted to obtain stakeholder input to the project.
- A project strength is understanding the sustainability of energy systems.
- Project strengths are its strong analysis capability and leveraging of data from multiple sources.
- The integration of a broad range of models is a project strength.

Project weaknesses:

- It is difficult to quantify results. There is a lot of subjective input and interpretation.
- The project needs to consider legal and ownership issues. If water is an input, it does not matter where it is; it matters who owns it, etc.
- The overall goal of the project is not clearly defined.

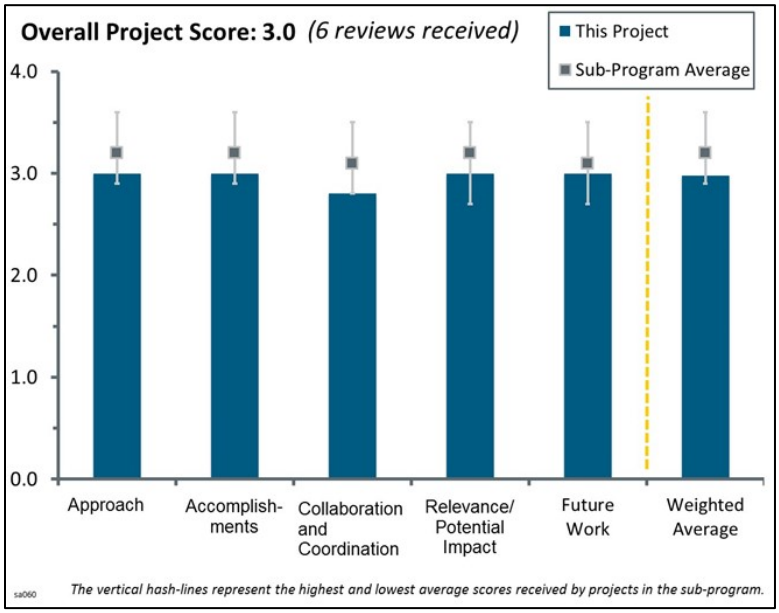
Recommendations for additions/deletions to project scope:

- If stationary power generation is included in the project scope, the work should include proton exchange membrane fuel cells, solid oxide fuel cells, and molten carbonate fuel cells.

Project #SA-060: Evaluation of Technology Status Compared to Program Targets

Marc Melaina; National Renewable Energy Laboratory

Brief Summary of Project:



This analysis is establishing the link between Fuel Cell Technology Office (FCTO) targets and future market dynamics, including explicit policy drivers. Objectives are to understand the influence of meeting, exceeding, or falling short of FCTO goals on future market adoption of fuel cell electric vehicles (FCEVs); consider a wide range of uncertainties around future technology progress; and combine techno-economic and consumer choice analysis of FCEVs in an integrated framework. Investigators will integrate techno-economic (Future Automotive Systems Technology Simulator [FASTSim]) and market potential (Automotive Deployment Options Projection Tool [ADOPT]) modeling capabilities developed within the Vehicle Technologies Office (VTO) analysis framework.

Question 1: Approach to performing the work

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

- The project generally has a good approach to using empirical data to break costs down to components. FASTSim and ADOPT seem like robust models and a good platform on which to base the project.
- This project is developing an analytical approach that integrates vehicle simulation with market adoption potential to create long-term scenarios extending to year 2035. It is using and modifying FASTSim and ADOPT to analyze FCEVs and other vehicle techno-economics and simulate future market share.
- The approach to the analysis project recognizes consumer choice in vehicle purchases and the impact of end-market incentives required to initiate and create market demand for new vehicle platforms. The analysis was focused on the two variables of government incentives for FCEV purchase and U.S. Energy Information Administration oil price that impact initial vehicle purchase and fuel operating costs. The analysis methodology included an update to two previous VTO models and the use of empirical data to support an understanding of FCEV market penetration rate.
- The difficulty of predicting consumer behavior is significant. The ADOPT model is a good effort to address consumer choice, but it may not be adequate for accurate prediction.
- It seems that the goal of the project was to find scenarios under which FCEVs can have a significant level of market penetration, instead of just modeling realistic scenarios to assess the potential future penetration of FCEVs. For instance, an accelerated scenario in which 2045 targets are met in 2035 is very aggressive and highly unlikely. A super-accelerated scenario in which 2045 targets are met in 2025 is even more unlikely. The issue with FASTSim is that the different vehicles evaluated do not have the same characteristics, unlike in Autonomie, which places all vehicle technologies on a more level playing field. The simplicity of FASTSim compared to Autonomie is appreciated though, and the fact that it reflects current vehicle models available commercially is also appreciated. A number of considerations need to be included to make the results more material, but not all of these issues are addressed in the proposed future work slide. These additional considerations need to be included in the analysis to ensure the validity of the model. These considerations should include consumer adoption where incentives are available vs. no incentives or fewer incentives, convenience of refueling, the effect of zero emission vehicles (ZEVs), low

and medium oil price cases, and mass reduction. It should also compare sales scenarios with planned hydrogen refueling station (HRS) deployment.
- The work is tautological. The targets were previously set on the basis of making fuel cells competitive with conventional vehicles, and now this study shows (not surprisingly) that if the goals are met, FCEVs will be competitive.

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

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

- The preliminary outcome of the project is encouraging for FCEVs since all analysis scenarios show the lifetime cost of FCEV is lower than for conventional vehicles and on par with hybrid electric vehicles (HEVs). A considerable amount of future work has been identified that covers many factors that can influence FCEV adoption and future analysis results.
- The National Renewable Energy Laboratory (NREL) analyzed several scenarios to determine the lifetime cost of FCEVs relative to conventional vehicles (CVs) and HEVs to identify technological improvements needed for reducing the cost and increasing adoption of FCEVs, and to assess the impact of policies that would support consumer adoption of FCEVs. It is unclear how the DOE used these results in developing policies and plans.
- Simulations have been carried out, and the model calibrated to total vehicle sales. The project should consider using the model to test HEVs, plug-in hybrid electric vehicles (PHEVs), or battery electric vehicles (BEVs) to look at other technology adoption barriers. This may have been done, but results were not shown.
- The analysis is very detailed, thorough, and carefully carried out. A scenario in which technology development falls short of technical targets should have been included. The blanket statement that “mass reduction has a greater effect than fuel cell cost reduction” on total cost does not seem to be accurate. It depends on the magnitude of the assumptions made for the two types of reductions. If one assumes huge mass reduction (38%–45%) but small fuel cell cost reduction (17%), then the project’s conclusion is accurate, but other sets of mass and cost reduction will result in different conclusions. As a result, the analysis, based on its assumptions, may not be guiding the FCTO in the right direction.
- More work needs to be done to ensure the validity of the results. It is important to ensure that the reader understands that the likelihood of the scenarios in which FCEVs can have significant market penetration are very unlikely. It would be valuable to see the sales and relative penalty results for BEVs compared to the other vehicle platforms. It is unclear why BEVs are predicted to have such a small sliver of the market in the future, particularly in the high-oil, extended-incentives scenario, when both of these characteristics benefit BEVs in theory.

Question 3: Collaboration and coordination with other institutions

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

- This project does not lend itself to collaboration very well, but at least the models used have been reviewed by original equipment manufacturers (OEMs) and hydrogen stakeholders.
- External peer reviewers, H2USA automotive OEM members, and the Fuel Pathway Integration Tech Team were listed as partners, but there were no specific interactions apparent in fiscal year 2016.
- Project collaboration included engagement in H2USA automotive members. It would be valuable to list the OEMs that were involved in providing input, review, and feedback to this work.
- Collaborations should be increased to include more marketing expertise and consumer-oriented researchers.
- It would be helpful to have the U.S. DRIVE Partnership’s Cradle-to-Grave working group peer review the results of the study. It would also be helpful to be transparent about comments received at the Program Annual Merit Review and other venues, and discuss how these comments were addressed.
- Just having partners review the work is not really collaboration. It would be more “collaborative” if others were actually involved in the work itself, such as development of parts of the model.

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 **3.0** for its relevance/potential impact.

- The project recognizes the importance of policy, technology improvement, and energy costs on the market competitiveness of FCEV.
- Having an understanding of consumer choices and ultimately adoption is useful to many stakeholders who may want to use the information to feed into business case models.
- This project provides a tool for the FCTO (and VTO) to establish the relationship between program targets and future market dynamics, including explicit policy drivers. The tool is primarily for use by the DOE policymakers.
- Studies like these are very detailed and are carried out by smart people, but at the end of the day, the reality is that they do not actually advance the technology. The study may help guide the Program, but the impact could be greater if the funds were invested in research and development instead.
- The model attempts to predict consumer behavior and does a good job within its constraints, but it is unclear how relevant the results are to such a disruptive technology as FCEVs, for which refueling and other consumer concerns are different than other automotive technologies.
- In its current form, the project is not relevant. However, market penetration scenarios for vehicle technologies are important, and an updated model that reflects the latest knowledge using strong scenarios and robust models is needed.

Question 5: Proposed future work

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

- The proposed future work is important and in alignment with considerations that are currently missing from the assessment. The following considerations should be addressed: consumer adoption where incentives are available vs. no incentives or fewer incentives, convenience of refueling, and sales scenarios compared with planned HRS deployment.
- NREL discussed the proposed future work on modeling vehicle systems, better representation of policy drivers, and the effects of consumer choice and fueling availability. It was not clear whether the project has FCTO support to continue.
- The project team should understand the differences and similarities between FASTSim and Autonomie models.
- It is not clear how this work is related to or different from similar work done in Autonomie. Part of the future work should be to delineate clearly when models such as Autonomie should be used instead of FASTSim.
- The project is almost finished.

Project strengths:

- The expertise of NREL researchers, access to third-party stakeholders for review, and existence of models that the project can leverage are project strengths.
- The project scope of analysis was narrowed down to two key variables.
- The ADOPT model is well developed and rigorous.

Project weaknesses:

- The project introduced the FASTSim model to provide techno-economic simulation of vehicle powertrain platforms. FASTSim appears more limited than Autonomie.
- ADOPT does not appear to look at the impacts of infrastructure availability.
- There are a number of considerations that need to be included in the model to make it valid.

Recommendations for additions/deletions to project scope:

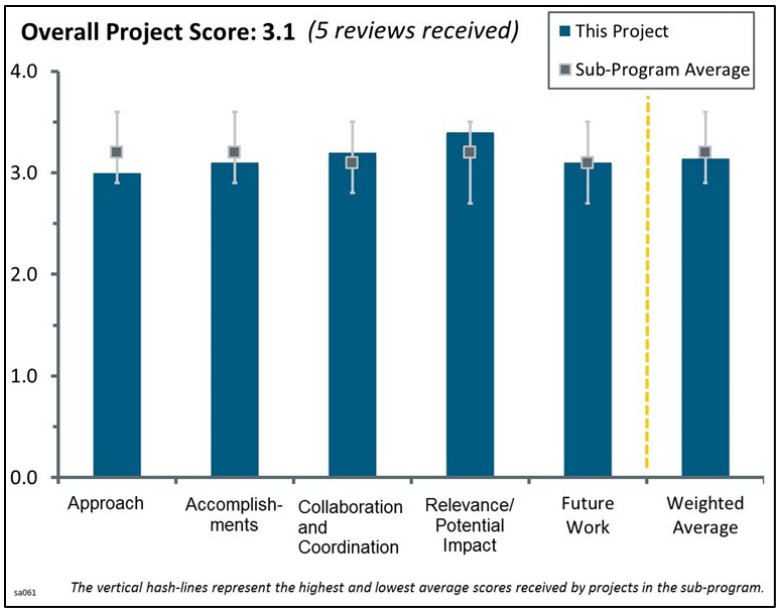
- The current analysis is based on the vehicle purchased by the consumer, and it would be valuable to understand whether a vehicle-leasing model would result in a faster rate of FCEV market adoption.
- The project should consider the use of agent-based models to predict consumer behavior. The project should test the ADOPT model on the market penetration of HEVs, PHEVs, and BEVs.
- The project should add analyses of the regionality effect, consumer adoption where incentives are available versus no incentives or fewer incentives, convenience of refueling, the effect of ZEVs, low and medium oil price cases, and mass reduction. The project should compare sales scenarios with planned HRS deployment.

Project #SA-061: National Fuel Cell Electric Vehicle and Hydrogen Fueling Station Scenarios

Marc Melaina; National Renewable Energy Laboratory

Brief Summary of Project:

This project is conducting integrated scenario analysis to assess interactions between fuel cell electric vehicle (FCEV) adoption, infrastructure requirements, and investment. Investigators will work with industry and other stakeholders to develop and analyze self-consistent national FCEV scenarios, examining early market trends and exploring long-term possibilities for FCEV adoption. The scenarios will be grounded in empirical data, early market plans, and technical analysis.



Question 1: Approach to performing the work

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

- There is good use of stakeholder experience and focus areas, as well as models at national laboratories. The project has a very effective strategy of scenario analysis of key market parameters. There is good focus on California market data, which is very important for useful results to apply to ROC. Scenarios based on historical data and near-term plans make very good sense. Using three time zones for introduction is very valid to get a better understanding of FCEV and station deployments.
- The technical approach is solid.
- The approach seems reasonable. The project is using many existing models. The researchers are trying to examine by region and focus on the most likely areas. For the station siting, they are not taking into consideration zoning laws, accessibility for the delivery, or electrical power accessibility, and they are using land costs that are not realistic (Hydrogen Analysis [H2A] model defaults at $50,000/acre do not reflect urban land prices). Of course, many people will lease their land, and this is also not considered. Some (or even most) of these considerations may not be reasonable, but the land costs definitely need to be changed. Almost every station will require an upgrade in electrical power, and it is not clear whether that is included in the cost estimates. These costs are important for the business case scenarios reported in the presentation.
- It is difficult to assess the validity of this study without understanding how other vehicle technologies would fare under similar scenarios and what the likelihood of the cases is. Current sensitivity analysis in the model has identified key parameters and market penetration bottlenecks. Further, regional economic considerations do not appear to be factored in; regional levels of economic well-being affect the adoption of alternative vehicle technologies. Another factor that does not appear to be considered is the price of alternative fuels and vehicles and how that will affect market penetration. Differences in land availability and cost in urban vs. suburban areas are not considered. Incentives beyond zero-emissions vehicles (ZEVs) (e.g., access to high-occupancy vehicle [HOV] lanes, rebates) have not been considered in the analysis. Also, replicating the California financing structure in other states is not ideal. It would be useful to vet the results against other market penetration scenarios and assess the differences.
- There seem to be very bullish assumptions on adoption of technologies. This is a critical assumption and appears to influence the results significantly. A better approach would be to consider historical adoption rates of alternative technologies. Perhaps the project team could do a look-back analysis on adoption expectations versus reality for some of those technologies and temper the current assumptions.

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.

- FCEV market share growth predictions are supported with realistic assumptions. There are good correlations with stations and daily hydrogen use. Station utilization factor is the key to success; stranded assets must be managed and minimized. The interactive scenario analysis tool is very neat. It has great potential to help in planning future hydrogen vehicles and stations. The Hydrogen Financial Analysis Scenario Tool (H2FAST) use is very well done.
- The project has done interesting work and made good progress.
- Given the complexity of the approach, the team has done a very good job at integrating the different models. Additional modeling of market penetration of the rest of the vehicle fleet would provide a more complete picture of the validity of the model and would address Barrier 4.5 A: Future Market Behavior. The results visualization tool is a very informative addition to the project.
- The project has made good progress, given the budgets. The utilization scenarios are very useful and interesting. Some of the findings are not very significant or surprising (e.g., on slide 12, "The more aggressive scenarios have substantially greater numbers of stations"). Some of the cost assumptions are not very robust and will need to be updated to improve the financial metrics. For example, the land cost of $50,000/acre in an urban setting is unrealistic. In addition, some station owners in urban areas may choose to lease the land. This option should be examined. The project needs to report the hydrogen cost and price assumptions for the business case scenarios.
- Generally, progress is good, but the project needs to have more realistic assumptions to be credible.

Question 3: Collaboration and coordination with other institutions

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

- There are very good interactions with California stakeholders.
- Given the number/type of partners listed in the overview, collaboration with third parties seems adequate. It would be advisable to include additional interactions with states other than California to get feedback on the assumptions and promote the use of the model.
- The collaboration seems California-centric. For this to be a national study, the project needs to recognize that other parts of the nation have different drivers from those in California. In addition to using H_2USA to provide comments on the project's refueling station assumptions, the team should engage energy companies to validate its assumptions, especially for the scenarios outside of California.
- This project would benefit from collaboration outside of the hydrogen space so that historical introduction of technologies can be understood. More challenges to the assumptions are needed, which includes those with viewpoints that hydrogen may not undergo rapid adoption.

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

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

- This is interesting work with good potential to inform hydrogen infrastructure development.
- This has some important work in understanding how the market will develop.
- This project has good potential to be used by states to guide funding decisions.
- This is very useful work toward DOE goals.

Question 5: Proposed future work

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

- It is an excellent idea to incorporate municipal- and state-level plans; this will require many hours of work, but it will make the model much more useful for communicating with policymakers.
- The work plan is very relevant and timely. It would be good to know how the project will share its results with stakeholders.
- The future work seems to be engaging California about deployment activities. This makes the work very California-specific. The project needs to engage other entities as well to make this a true forward-looking document.

Project strengths:

- The analysis seems well done; useful information is being generated.
- The team's expertise with robust models is a project strength.

Project weaknesses:

- The project does not consider the potential to upgrade sites to higher capacity as a progression. This could be a path for potential future improvement.
- The magnitude of the assessment is huge, which makes it difficult for the team to integrate data at the appropriate scale to reflect national trends.

Recommendations for additions/deletions to project scope:

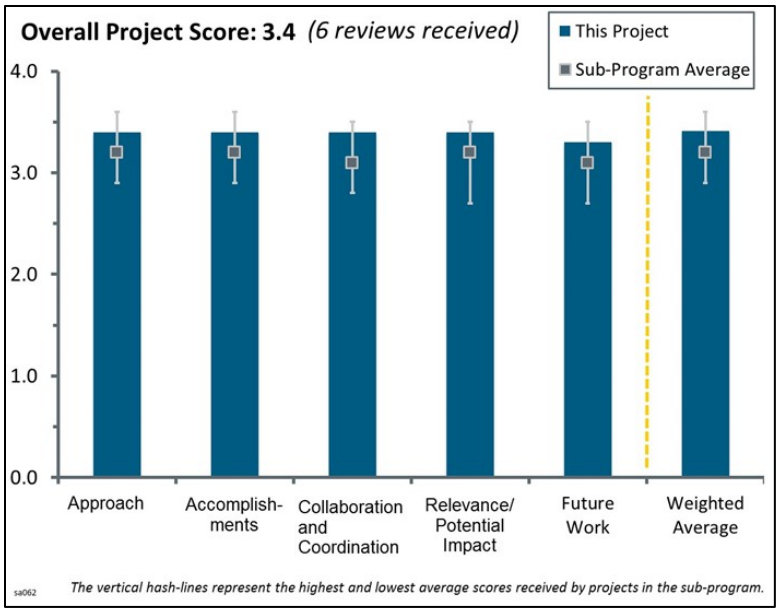
- The project seems well scoped.
- Regional economic considerations should be included; regional levels of economic well-being affect the adoption of alternative vehicle technologies. The price of alternative fuels and vehicles should be considered, as should how that will affect market penetration. The project should also consider differences in land availability and cost in urban vs. suburban areas, as well as incentives beyond ZEVs (e.g., access to HOV lanes, rebates). The project should validate the results against other studies and understand the differences.
- Having financing stakeholders review the results will be beneficial.

Project #SA-062: Expanded Capabilities for the Hydrogen Financial Analysis Scenario Tool

Marc Melaina; National Renewable Energy Laboratory

Brief Summary of Project:

The Hydrogen Financial Analysis Scenario Tool (H2FAST) enables detailed financial analysis for hydrogen infrastructure. This project is enhancing this tool with new capabilities to facilitate investments in hydrogen refueling stations and improve policy design decisions to support early hydrogen station and fuel cell electric vehicle market development. Examples of enhancements include improvements to usability, risk analysis for any input parameter, multiproduct configurations, multiple feedstock considerations, and expanded concurrent analysis of up to 300 hydrogen stations.



Question 1: Approach to performing the work

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

- This project aligns well with the Hydrogen and Fuel Cells Program (the Program) objectives of supporting infrastructure development by providing market and financial information relative to strategies for infrastructure development. Relevance and potential impact will really be measured by the utility of the tool for stakeholders. It would be useful to continue to gather feedback from potential future users as to the utility of the software. This information can be used to promote the tool as well as to evaluate the acceptability of the inputs and format.
- This is a comprehensive financial model taking into account the many cost variables that one would use to evaluate a hydrogen station or a network of stations.
- Improvements to H2FAST are useful and make the model more relevant. The model is comprehensive and flexible, allowing for a meaningful comparison of options.
- It is great to see H2FAST being completely enhanced with a variety of users and outputs in mind.
- The project is in Year 2 of a two-year effort to develop H2FAST financial analysis code for hydrogen infrastructure.

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

This project was rated **3.4** for its accomplishments and progress.

- The list of additions to the model is very impressive. The model looks relatively easy to use, with great graphical output allowing a large number of scenarios to be investigated.
- The additions made this year to the H2FAST project are significant. The stochastic risk analysis tool is an important part of making the tool more useful in estimating the economics of refueling stations. Many of the other additions seem like excellent model improvements. One area to consider is maintenance and repair of equipment at the filling station. With the frequency of compressor failures, this should be taken into account. It would be useful to consider the use of other hydrogen storage materials, such as chemical hydrogen storage materials and cryo-adsorbents. The change in infrastructure required for these materials

may require user-defined feedstocks (liquid nitrogen for example) and materials returning to be reprocessed.
- The enhancements made to include residual values help make this more realistic and allow for reuse and redeployment of equipment, which is critical in early build-out and station expansions. It would be useful to include upstream capital expenditures for trailers and central distribution centers to complete the network.
- The National Renewable Energy Laboratory (NREL) has taken note of reviewers' comments, addressed them, and implemented changes.
- Added features in the model appear to add flexibility.
- The model is a solid foundation to assess potential scenarios of hydrogen refueling station deployment in the United States, but it is unlikely that venture capitalists and/or investors will use models other than their own to make investment decisions. Although the approach is good, it contributes little to meeting infrastructure deployment goals. As part of the approach, NREL should assess whether this model has resulted in any investment decisions or is used purely for academic purposes.

Question 3: Collaboration and coordination with other institutions

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

- There is a good level of collaboration with (including meaningful contributions from) a wide variety of industry and government stakeholders.
- The team seems to have engaged a very comprehensive list of folks representing most expected stakeholders and has used many of them for direct input into the model.
- The project has engagement with the right financial institutions, investment community, and advisors.
- There is a good mix of collaborators representing industry, state, academia, and laboratory stakeholders.
- Collaboration with all the potential users of this software is critical to its success: policy and government decision makers, station operators, equity investors, strategic investors, and lenders. The success of the software requires that they buy into the approach and how the input and output are presented. It would be useful to the reviewers to understand what suggestions the collaborators have made and how those suggestions have been addressed in the project.

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 has made an excellent effort to develop information using standard accounting practices and producing results in a form that could be useful for investors and lenders to understand the results. The challenging part of using the H2FAST tool would be determining the inputs. Efforts should be made to facilitate coupling information from the H2A Refueling Station Analysis Model (HRSAM) and other modeling tool outputs to the H2FAST inputs. The types of scenarios and their assumptions should be similar. If the data from other models do not easily feed H2FAST, it may require changes to the H2FAST tool itself.
- The work addresses barriers A and E of the Program Multi-Year Research, Development, and Demonstration Plan.
- It is good that the investigators have expanded the scope to include policymakers and regulators. This is the community for which DOE should be promoting the development of economic analysis tools.
- The industry needs a common tool that varies in complexity based on the level of financial and technical expertise. This tool accomplishes this.
- Information on the total costs of hydrogen as a fuel is needed, and this project addresses that need.
- Although the model appears very robust, it is unlikely that it will result in investment decisions. Investors have their own financial models and are not likely to use financial models developed elsewhere. Further, at this stage, market entrants are mostly technology manufacturers and gas producers that are already familiar with the economics of hydrogen refueling stations.

Question 5: Proposed future work

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

- Even more great additions are planned for the model. It is especially nice to see the plan for customization for a variety of stakeholders.
- Allowing analysis of non-simultaneous projects seems to be a very important aspect of the model that should be included. Emissions calculations could be useful but only if they can be tied to the costs, such as through application of Low Carbon Fuel Standard Program or Renewable Identification Number (RIN) credits.
- Including central source and compression options for large-scale electrolyzers and medium-scale steam methane reformers would be valuable. Perhaps another sheet could be created for central/regional sources and distribution centers that includes the above production sources with capital and operational expenditures and calculations. It is not clear whether incremental capital could be added to existing stations for capacity expansions and enhancements.
- Proposed future work seems appropriate. After the model is completed, the team should focus on outreach, model demonstrations, and assessing whether the model is being used to make investment decisions.
- This project is wrapping up and transitioning to a new project (SA-059).
- It is not clear whether the emissions calculations would be leveraging an existing model. One hopes that this will not be a duplication of work.

Project strengths:

- Increased capabilities are being added to an already useful modeling tool. Analysis is enabled by a large number of diverse stakeholders.
- Project strengths include a common platform for evaluating station projects, the project being fairly comprehensive, and the varying degrees of complexity based on needs.
- Strengths include the knowledge of the strong team and good subject matter expert engagement. In addition, H2FAST is comprehensive.

Project weaknesses:

- Since station profitability depends highly on hydrogen source and distribution methods, having the ability to evaluate production and logistics options would be a great enhancement. This would be most effective if the project partners could collaborate with electrolyzer and steam methane reformer manufacturers.
- A business case is needed to develop the model and determine who is using it and whether there is a need for this type of model by venture capitalists/investors/lenders.

Recommendations for additions/deletions to project scope:

- No responses provided.