2018 – Systems Analysis
Summary of Annual Merit Review of the Systems Analysis Sub-Program

Summary of Systems Analysis Sub-Program and Reviewer Comments:

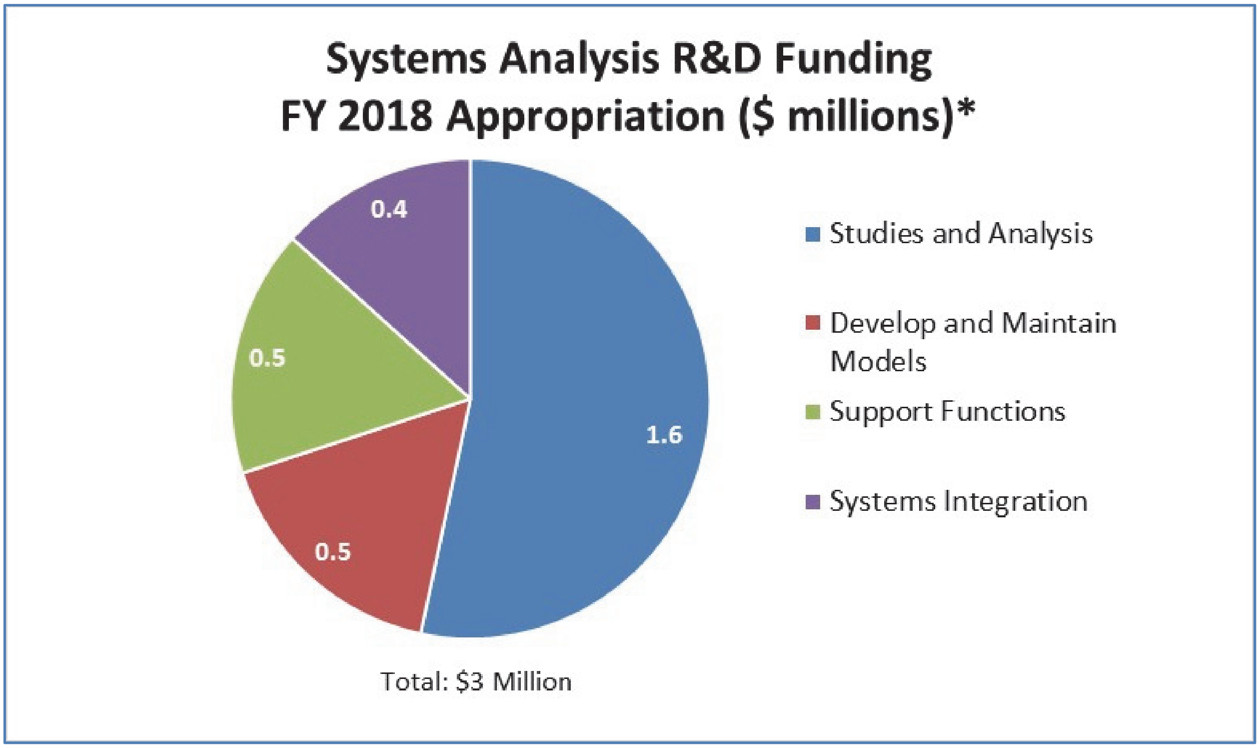
The Systems Analysis sub-program supports the decision-making of the Fuel Cell Technologies Office by providing a greater understanding of technology gaps, options, and risks for early-stage research and development (R&D). The sub-program's goal is to provide systems-level analysis to support hydrogen and fuel cell technology development and technology readiness by evaluating technologies and pathways, including resource requirements. The sub-program's analytical efforts focus on technoeconomic analysis of fuel production-to-utilization on a lifecycle basis for light-, medium-, and heavy-duty fuel cell electric vehicles (FCEVs) and the H2@Scale concept. The sub-program also conducts analysis to assess cross-cutting issues such as the integration of hydrogen and fuel cells with the electric grid for energy storage. The Systems Analysis sub-program aims to enable hydrogen technologies that support infrastructure development through innovative R&D. The results of Systems Analysis efforts help guide the selection of R&D projects and estimate the potential value of specific R&D efforts. The sub-program collaborates with industry and other federal offices and agencies (e.g., the DOE Offices of Fossil Energy and Nuclear Energy, U.S. Department of Defense, and U.S. Department of Transportation) to leverage outside activities, coordinate efforts, and build opportunities for new technology applications and input.

The Hydrogen and Fuel Cells Program (the Program) reviewers commended the Program's focus on H2@Scale and the prioritization of hydrogen production and infrastructure R&D. They identified the H2@Scale market assessment as a keystone analysis for the Program and recommended that it incorporate broader sensitivity analysis to increase credibility of the evaluations. The reviewers also considered the Systems Analysis work on hydrogen supply and demand interaction critical to H2@Scale, as well as the efforts to characterize hydrogen production across the United States. The comparative evaluation of FCEVs and plug-in electric vehicles on various vehicle platforms was also highlighted as a sub-program accomplishment.

The reviewers praised the Systems Analysis robust modeling toolkit but offered a cautionary suggestion to screen proposed analysis projects to avoid redundancy. It was recommended that the modeling project template incorporate industry/stakeholder review as a standard element to add value to the projects. Reviewers suggested that the sub-program evaluate the energy and environmental impacts of hydrogen liquefaction on a lifecycle basis to substantiate the benefits of the technology. Reviewers also suggested the sub-program initiate analytical projects aimed at better understanding the market and technology transition phase (versus the market launch phase) within the next 5–10 years.

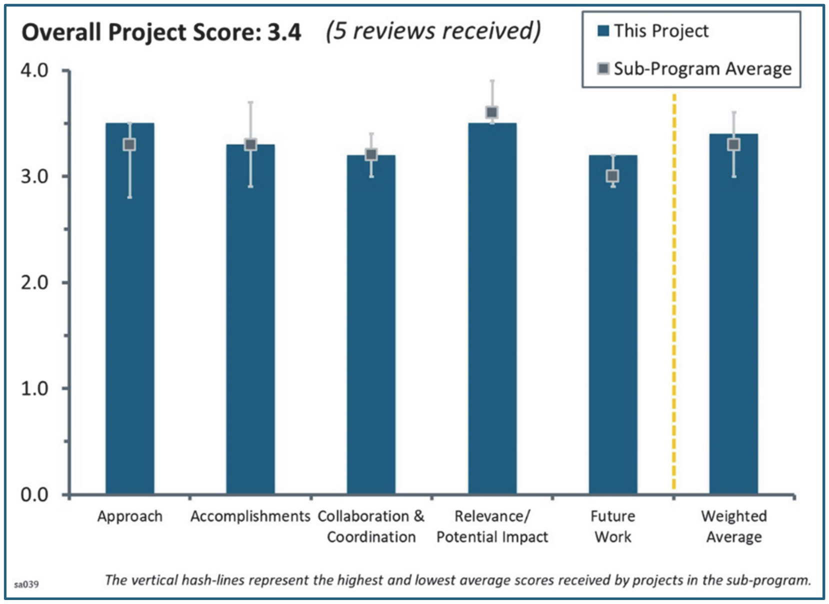
Systems Analysis Funding:

The fiscal year (FY) 2018 appropriation for the Systems Analysis sub-program was $3 million, allocated as indicated in the figure below. Funding continues to focus on conducting analysis using models developed by the sub-program. In particular, analysis projects are concentrated on the hydrogen value proposition for H2@Scale, the levelized cost of hydrogen from renewable hydrogen production pathways, the impacts of hydrogen delivery/onboard storage/fuel cells on early-stage R&D needs for onboard hydrogen storage options and associated costs, emissions from hydrogen pathways for fuel cell medium- and heavy-duty trucks, and hydrogen fueling station business assessments.


Systems Analysis R&D Funding
FY 2018 Appropriation ($ millions)*
0.4
0.5
1.6
0.5
Studies and Analysis
Develop and Maintain Models
Support Functions
Systems Integration
Total: $3 Million

Project #SA-039: Regional Water Stress Analysis with Hydrogen Production at Scale

Amgad Elgowainy; Argonne National Laboratory



Brief Summary of Project:

Argonne National Laboratory (ANL) has expanded the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET™) model to include water consumption. ANL has (1) identified major contributors 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 identifying and addressing barriers, project design, feasibility, and integration with other efforts.

- Data sources are appropriate, and the use of existing models to leverage existing pathways is a good use of laboratory resources. The impact analysis approach is appropriate; mapping water resources for freshwater and non-freshwater, as well as water consumption and scarcity, is useful in assessing how different forms of energy production affect water quantity/availability across regions.
- The approach ties together a complex set of variables including regional environmental aspects, power sources, and consumption. It would be good to also include access to water sources that are not freshwater.
- It is nice to see some focus on water consumption using a consistent analysis approach. It is necessary to ensure water consumption is taken into account, similar to CO_2. The Available WAter REmaining (AWARE)- and GREET-type analysis is a good approach.
- Overall, this is a valid and worthwhile evaluation. It is suggested that the project more clearly compare water requirements, including those for agriculture.

Question 2: Accomplishments and progress

This project was rated **3.3** for its accomplishments and progress toward overall project and U.S. Department of Energy (DOE) goals.

- Understanding groundwater recharge and human impact by region is not an easy task. ANL did a good job mapping this information. Also, understanding the impact of different electricity generation technologies located in either water-stressed or water-abundant areas provides a robust means to quantitatively evaluate the impact of thermoelectric and renewable electricity production. It is a plus that the team is integrating this project with H2@Scale to pair resource availability and demand with water availability.
- Given the basis of the study, an excellent job was performed. It is necessary only to consider overall water usage to put the results in perspective.
- The results of this study are very helpful for informing both national policy and production planning.
- This project contains a nice aggregation of water data from various sources.
- DOE has recently presented other analyses that seem to contradict the conclusion that water demand for fuel cell electric vehicles fueled by hydrogen from electrolysis is hugely higher than any other scenario analyzed. These cases should be reconciled.

Question 3: Collaboration and coordination

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

- A specific description of the roles of other collaborators was provided. There was good coordination with Pacific Northwest National Laboratory (PNNL) to incorporate higher resolution for regional water consumption. It would be valuable to have utility perspective on the team.
- With the variety of water data presented, it is evident that collaboration was necessary to aggregate and summarize.
- The list of partners and collaborators is appropriate, as it includes the U.S. Environmental Protection Agency, other national laboratories, the Army Corps of Engineers, and even academia.
- The collaboration was well done.
- It seems that the results of this study have not been thoroughly reviewed. There is evidence of this in the presentation. The presentation is mainly focused on the communication of data and results, and it lacks analysis and potential impacts. What this means for the production industry decision maker, or for the local or federal policy maker, is unanswered. The summary slide provides some of this information, but the bulk of the information is rather difficult to interpret. A review by project collaborators would ensure that the communication of information would provide a better interpretation and meaning for each level of information.

Question 4: Relevance/potential impact

This project was rated **3.5** for its relevance to/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.

- It is necessary to be sure all sustainability aspects are taken into account when evaluating technologies and alternative energies. This project brings in a critical resource analysis to ensure a sustainable future for all communities and regions is created.
- As the population grows and the climate changes, water quality and quantity issues have been exacerbated across the country. Understanding the impact on water from our energy sources will provide a map for future developments in grid infrastructure.
- An analysis of the full impact of energy technologies is highly important to understanding potential risks in implementation. Water is a key resource that needs to be understood as part of the analysis.
- This is a study that needed to be done, but the answer is perhaps relatively obvious: the overall impact on water is not great.

Question 5: Proposed future work

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

- The proposed future work is important in grounding the analysis. Understanding where the water is actually consumed in processes that are upstream from the hydrogen production could change some of the scarcity footprints.
- The proposed future work is appropriate.
- The proposed future should include possible water intensity reduction potential by looking at alternative water-handling and reuse options such as closed-loop water and reclamation systems.
- It is necessary to add water requirements for agriculture, in particular, to show how small the hydrogen generation effect is.

Project strengths:

- This project is highly relevant in the overall analysis of energy and water. The project represents high-fidelity modeling and interactions that are feasible only at a national laboratory.

- The methods used (i.e., AWARE and GREET) bring a consistent approach to analyzing water intensity data regionally and by production technology.
- This is a knowledgeable team, able to leverage the GREET model. The strong partnerships provide data and feedback, and the topic is relevant.
- The analysis is excellent; it is necessary only to put the results into an overall water-usage perspective.
- This project has relevance and adds improvements to the main life-cycle analysis.

Project weaknesses:

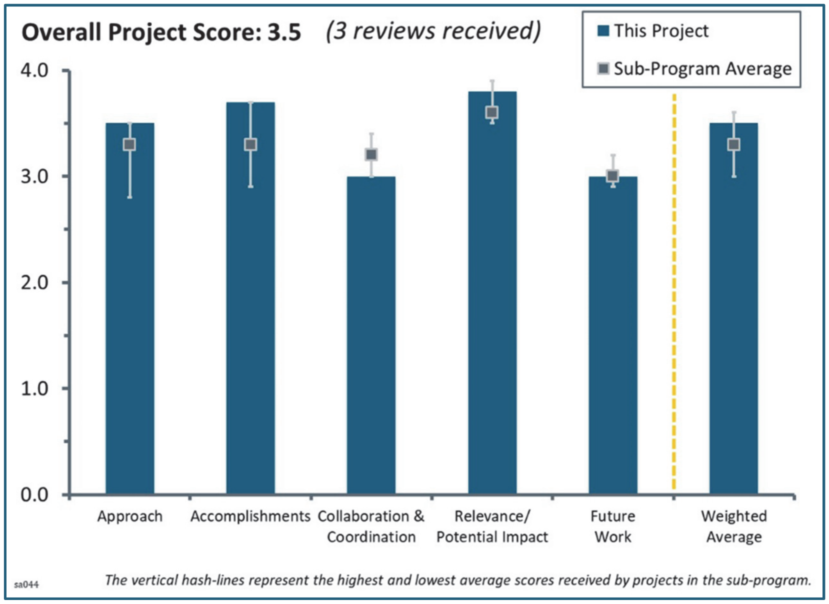
- While significant progress has been made, an analysis of this scale has to be done in phases. Completing the next layers of detail will be important to providing a balanced picture. Also, some of the output seems contradictory to other analyses within DOE.
- The project presenter had a hard time explaining the carbon fiber factor or stress factor. Perhaps it could be made clearer.
- Some stakeholders may not understand the importance of water in overall sustainability.
- It is necessary to compare usage for hydrogen generation to overall water usage.
- The project needs better communication of analysis and impact.

Recommendations for additions/deletions to project scope:

- The scope of the project is appropriate; future modeling work is well defined and contributes to the overall advancement of the body of knowledge.
- This is a recommendation on developing a regional water impact, based on the deployment of electric vehicles in a region. For example, as the California zero-emissions-vehicle mandate displaces gasoline and reduces oil refining, it would be good to know what the net impact of the water situation there will be in 2050. Also, a reduction factor for incorporating closed-loop or reclaim systems into the production processes for electrolysis could be useful.
- It is recommended that the project add an overall water usage perspective.

Project #SA-044: Cost–Benefit Analysis of Technology Improvement in Light-Duty Fuel Cell 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 **3.5** for identifying and addressing barriers, project design, feasibility, and integration with other efforts.

- Autonomie is a very robust and comprehensive model. Leveraging this tool to assess the impact of technological changes helps justify Fuel Cell Technologies Office (FCTO) programs. The vehicle technologies compared in the project are appropriate. The methodology to cost U.S. Department of Energy technical targets and the associated benefits is a smart way to figure out what the tipping point is where better technology does not translate into better economics.
- The project is using validated models in its analysis. The team provided a range for each analysis. It was unclear whether the team validated some of their assumptions and results concerning battery electric vehicles and plug-in hybrid electric vehicles (PHEVs) with the Vehicle Technologies Office.
- The project approach is reasonable and effective for evaluating target impacts on vehicles. It would be helpful to show more explicitly how Autonomie was used, the drive cycles, and other assumptions.

Question 2: Accomplishments and progress

This project was rated **3.7** for its accomplishments and progress toward overall project and U.S. Department of Energy (DOE) goals.

- The project is almost complete and is providing valuable information to guide DOE's future research and development (R&D) plans. The fuel cell peak efficiency versus dollars-per-kilowatt savings curve is an excellent representation of how more efficient fuel cells may not be worth the extra cost.
- The project's analysis was able to predict the impact not only of achieving the DOE targets but also of achieving close to the targets. The analysis does a fair job comparing the fuel cell vehicles with conventional vehicles, hybrid electric vehicles, and PHEVs. The analysis on hydrogen cost and benefits of higher system efficiency was very interesting. The team should vet the analysis and results with industry and with the Vehicle Technologies Office.
- Analysis results were generated in this project. Recommendations would have been expected in terms of which targets are more impactful. Even though this project is a benefits analysis, some relationship to technology progression rate or cost of improving technology could be applied to estimate which targets are lower-hanging fruit in the cost–benefit context.

Question 3: Collaboration and coordination

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

- U.S. DRIVE Partnership technology teams have worked with the project to validate the assumptions. It would be good to know whether results agree with original equipment manufacturers' (OEMs') views of future technology.
- More collaboration would have been expected, for example, with automotive OEMs (e.g., Honda, Toyota, General Motors).
- There was limited collaboration in this project. It is recommended that the project invite industry (OEMs) to an in-depth review of the approach and results.

Question 4: Relevance/potential impact

This project was rated **3.8** for its relevance to/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 type of analysis is essential to determining the impact of target-setting. It would be helpful to determine whether targets among other vehicle technologies are comparably aggressive. When subsequent analyses use targets, the program with most aggressive targets will appear to be "winning" the technological race. Thus, it is essential to have achievable and comparable target-setting among all vehicle drivetrains (e.g., electric vehicles).
- This project is important because it provides justification for the goals established by DOE. It answers the following questions: (1) what the benefits are of meeting the targets, (2) what the impact is of various components on weight, cost, and energy consumption up to the FCTO targets, and (3) what the point of diminishing returns is.
- This analysis helps inform the direction of FCTO.

Question 5: Proposed future work

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

- It would be helpful to do some validation testing on the model. As FCEVs are becoming available and the various OEMs have different energy storage density, stack efficiency, etc., it would be essential to validate the model.
- The project will not continue beyond August 2018.
- This is the final year of the project.

Project strengths:

- This project shows an in-depth knowledge of Autonomie. This is a strong team, knowledgeable and technically skilled. This project is of high importance.
- The team is using good models for their analysis. The approach is well-thought-out.
- The analysis leverages rigorous vehicle modeling models.

Project weaknesses:

- The principal investigator's presentation results seem biased by favoring FCEVs. For instance, slide 12 mentions at the top that FCEVs could reach life-cycle cost parity with PHEVs by 2025, but this is the most unlikely of cases. Furthermore, this would happen only when DOE's R&D targets are reached. In the other two cases, parity is reached either in 2030 or in 2045.
- The team should have industry OEMs review this project. They should look at medium- and heavy-duty applications.
- Validation of real-world vehicles will be necessary.

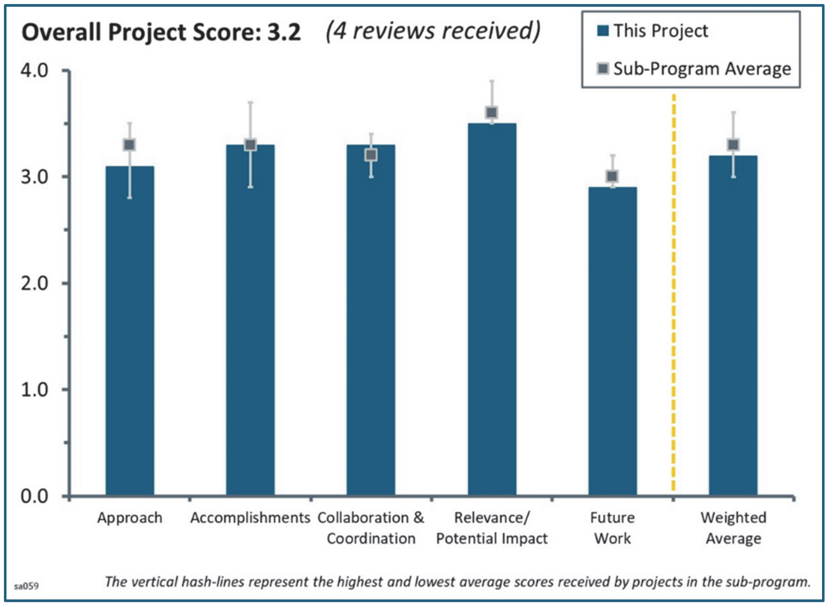
Recommendations for additions/deletions to project scope:

- It would be good to see the results discussed with OEMs to ensure that the results are accurate. It would also be good to see the “targets” referred as the “DOE R&D targets” to avoid confusion. These are ultimate targets that will allow technologies to compete with conventional internal combustion engine vehicles but are not likely to be achieved in the near term; this needs to be clarified. Other than that, the project is excellent.
- The team should include efforts for validation or, more practically, collaborate with vehicle testing-capable entities.
- The team should look at medium- and heavy-duty applications.

Project #SA-059: Sustainability Analysis: Hydrogen Regional Sustainability

Elizabeth Connelly; 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 identifying and addressing barriers, project design, feasibility, and integration with other efforts.

- The project represents a good application of different models to support results and analyze different scenarios. Incorporating all of these different analyses and tools with sensitivity analysis is a highly complex task.
- The objectives and barriers were identified, and the project supports the sustainable development of alternative fuel and vehicle technologies.
- The basis for study and the approach integrating models with input from other organizations were both excellent and very worthwhile.
- The HyReS analysis is a good idea. The modeling suite is mostly appropriate. It was not clear whether the project team had the U.S. Department of Energy's Vehicle Technology Office (VTO) and Bioenergy Technologies Office (BETO) validate the assumptions and results in their respective areas. Current hybrid electric vehicles (HEVs) have a much higher range than vehicles with internal combustion engines (ICE), yet the charts presented do not show the improvement—this should be investigated. It is not clear why Future Automotive Systems Technology Simulator (FASTSim) results were chosen over the GREET model data (see slide 11). It is not clear why the project team is not using Autonomie. Autonomie is validated by the industry and is the industry standard. It seems that Autonomie provides more information than FASTSim. FASTSim may have a faster processing speed, but if the information it provides is not as complete and is not validated, then the increased processing speed is not as useful. It is recommended that rather than updating FASTSim, the project team integrate Autonomie. It is good that the project is using BETO and VTO performance goals from the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan.

Question 2: Accomplishments and progress

This project was rated **3.3** for its accomplishments and progress toward overall project and U.S. Department of Energy (DOE) goals.

- To support DOE's planned direction, it is necessary to complete this type of analysis, with solid data and impact to health and economics, as well as energy sustainability.
- The project has made good progress toward attaining the stated goal.
- The researchers have made solid progress. The researchers should consider having representatives from BETO and VTO review the assumptions and outputs from the models. The researchers should include plug-in hybrid electric vehicles (PHEVs). Note that PHEVs are already included in Autonomie, as are plug-in hybrid fuel cell vehicles. This is another example of why the team should be using Autonomie. Current HEV miles per gallon is considerably higher than that of the ICE vehicles, yet the charts show very similar performance. This is surprising and should be explained.
- Some of the accomplishments produced results that have already been calculated by other teams. For instance, on slide 12, the life-cycle petroleum consumption of different fuel/vehicle alternatives were published in the cradle-to-grave study. Similarly, the results on slide 11 were calculated by the U.S. DRIVE Partnership Integrated Systems Analysis Tech Team two years ago. It is unclear why the calculations had to be redone using a different model instead of just updated.

Question 3: Collaboration and coordination

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

- Overall, this project has good coordination.
- The partnerships within this project seem adequate.
- The project leads are working with Argonne National Laboratory and have requested input from some external reviewers. It would be interesting to get reviews from General Motors, Toyota, Honda, and other original equipment manufacturers (OEMs) that make HEVs, PHEVs, and fuel cell electric vehicles.
- The collaborators were listed with model names, but there was not much description of how the collaborators interacted with each other or what the roles were.

Question 4: Relevance/potential impact

This project was rated **3.5** for its relevance to/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.

- There is good effort within this project to make sure that batteries and hydrogen are being compared on a common scale and that analyses are revisited when there are believed to be differences.
- There is a strong focus on integrating various models to develop an overall assessment.
- This information is very interesting and necessary to help with planning. The quality and completeness of the information may be improved by using Autonomie in place of FASTSim.
- The project contributes to a better understanding of the environmental effects of displacing conventional vehicles with hydrogen fuel cell technologies. However, the project would be more impactful if other aspects of sustainability and additional criteria air pollutants were included.

Question 5: Proposed future work

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

- The future work describes less concrete tasks than previous years, and it mainly seems to involve the refinement of existing results. While this is valuable, it would be good to describe how this refinement might improve the model conclusions more explicitly.

- In the reviewer response, the presenter discussed cost versus price—this was a good explanation. In slide 19, the presentation said that calculating price was a remaining challenge. It is recommended that the team call it “minimum selling price,” per the response in slide 16. One of the future work tasks was to “Implement Framework,” but it is not clear what this means. Finally, it is recommended that the project team use Autonomie.
- The project includes only NO_x and $PM_{2.5}$ (particulate matter – fine particle) emissions. Other criteria air pollutants such as sulfur and volatile organic compounds (VOCs) are not discussed. It is understood that these elements have not been included because these are the only pollutants with associated externality costs in the Estimating Air Pollution Social Impact Using Regression (EASIUR) model. Finding another source of externalities is recommended for a more comprehensive assessment. Other aspects of sustainability are not addressed; this analysis is purely environmental, and it does not integrate social or economic aspects.
- The project team will continue work as planned toward completion of the study.

Project strengths:

- This project looks at the societal costs of various vehicle technologies to better understand the implications of the research, development, and deployment plans. The team is very strong and is using a broad, powerful suite of modeling tools.
- This project has a thorough understanding of the available modeling tools and an impressive integration of the inputs and outputs.
- This project has made an excellent effort to integrate various models. This is very important.
- The project team possesses strong technical knowledge and partnerships.

Project weaknesses:

- It would be helpful to more clearly describe the benefits of additional refinement of the models.
- Only the environmental aspect of sustainability was tackled, and that too only partially. Some of these analyses have already been performed by other researchers.
- The project team needs to have more OEMs and perhaps have the VTO review the data and results. The team neglected to include PHEVs, and the HEV assumptions may not be accurate. It is not clear why the team used FASTSim over GREET. It could appear to a critic that this was done to make the fuel cell technology look better. To be clear, it seems acceptable to use FASTSim over GREET, but critics may raise this issue. It is recommended that the project team clearly justify their use of FASTSim.

Recommendations for additions/deletions to project scope:

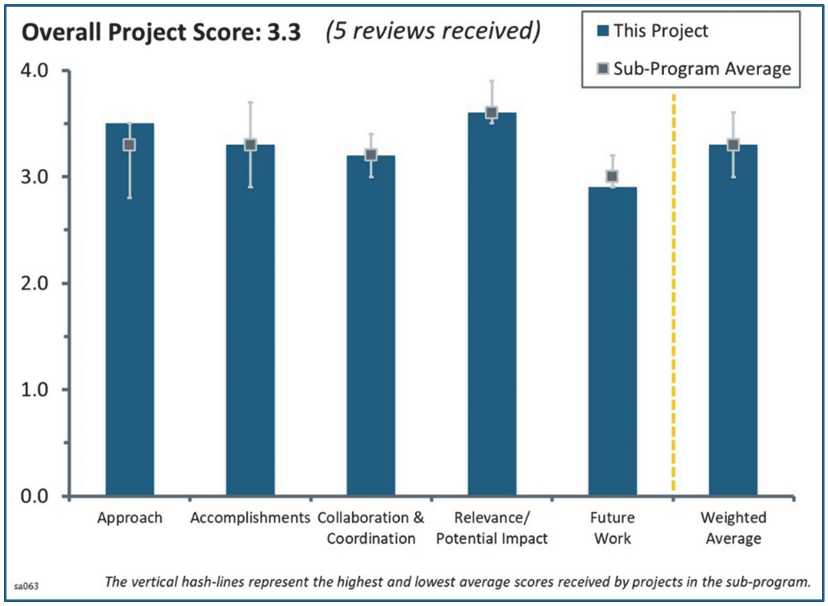
- This project is complete, as intended.
- It may be interesting for the team to do a sensitivity analysis to see how varying key metrics would change the output.
- It is recommended that the project team add other criteria air pollutants such as sulfur and VOCs. Once these results are completed, the team should include carbon dioxide and carbon monoxide from GREET. It is understood that these elements have not been included because these are the only pollutants with associated externality costs in EASIUR. It is recommended that the team find another source of externalities for a more comprehensive assessment. Also, the name of the project should be changed from “sustainability analysis” to “environmental analysis.”

Project #SA-063: Regional Supply of Hydrogen

Michael Penev; National Renewable Energy Laboratory

Brief Summary of Project:

This project aims to estimate existing hydrogen production assets and potential excess production capacity and provide enhanced forecasts for near- and long-term hydrogen supply chains. The analysis forecasts production capacity expansion requirements for the growing fuel cell electric vehicle (FCEV) market demand, simulates regional supply chain network dynamics, and incorporates market competition considerations.



Question 1: Approach to performing the work

This project was rated **3.5** for identifying and addressing barriers, project design, feasibility, and integration with other efforts.

- The project provides a thorough evaluation of a very important aspect of providing hydrogen where it is expected to be needed and estimating the cost of the hydrogen at the dispensation point.
- This project is conducting a very impressive and in-depth analysis of future scenarios for hydrogen fueling.
- The approach is realistic for achieving scale. The team should consider doing an optimization on centralized compression with final stage compression at or near the usage points.
- This project is looking to overcome the high cost of hydrogen delivered at the pump. However, the approach is rather simplistic since it assumes that land will be available when and where it is needed to lay down hydrogen pipelines. Right-of-way is a very real problem that would cost time and money. Also, it is not clear how hydrogen sources are estimated to compete economically against each other in the future, but coal and biomass gasification are currently expensive technologies that cannot compete with steam methane reforming (SMR). Furthermore, it is too simplistic to assume that 20% of all SMR is in overcapacity and will be available to the market.
- The dominance of the proposed concept, H2Grid, in the results suggests a bias and a lack of structure in the approach. This approach leads the results, and this presentation seem to endorse the idea of H2Grid.

Question 2: Accomplishments and progress

This project was rated **3.3** for its accomplishments and progress toward overall project and U.S. Department of Energy (DOE) goals.

- The modeling results are well described and supported. The time-based model shows how the mix of technologies changes as a function of vehicle deployment and infrastructure rollout.
- Given the complexity of the supply chain system, the team has done a good job laying out a framework to analyze and optimize.
- The project is making good progress to meet its objectives.
- This project meets all DOE Hydrogen and Fuel Cells Program goals established for this analysis project.
- This project has mixed results. The analysis tools developed for this work are impressive, but both the subjects selected for analysis and the results are underwhelming.

Question 3: Collaboration and coordination

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

- There is strong coordination with DOE laboratories, effectively using various models to develop an overall integrated assessment.
- The team includes appropriate representatives from industry, a utility, and other laboratories. The type of feedback was not described in detail.
- The project would benefit from collaboration and feedback with city planners and utilities that can talk about the likelihood of being able to install hydrogen pipelines near major urban centers, as defined in the scenarios. It remains to be seen whether the expansions and costs are realistic.
- This project should consider a more diverse group of collaborators to achieve a better diversity of future outcomes, particularly when assuming the scope of a nationwide assessment predicting results into the next 30 years.
- There could be value in bringing some large gas utilities into the project to validate pipeline assumptions and costs.

Question 4: Relevance/potential impact

This project was rated **3.6** for its relevance to/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.

- Understanding the potential scenarios for infrastructure rollout and distribution mechanisms is necessary to create an overall vision and get industry buy-in.
- This project is entirely relevant, focusing on a very important overall hydrogen distribution/cost assessment.
- This project addresses the fundamental issues in achieving scale.
- The relevance of this project is directly related to its accomplishments.
- The Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan states that “there is a high investment risk for developing a hydrogen delivery infrastructure, given the current absence of demand for hydrogen from the transportation sector.” This is still true today—the demand is too low to make these investments economically feasible. Given that the project forecasts that infrastructure development will commence in 2021 (only three years away), it is unlikely that the demand for hydrogen for transportation will be sufficient to justify the investment. However, it is promising as a delivery solution because it would considerably lower the cost for the station owner.

Question 5: Proposed future work

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

- The proposed future work considers the relevant factors affecting hydrogen generation/distribution and associated costs and challenges.
- It is a positive measure that electrolysis will be included in the hydrogen production options. Future work should also include potential cost, using all the hydrogen production sources listed in the presentation. It would also be important to calculate the cost of the hydrogen station under the semi-central delivery pathway.
- The team might consider other scenarios and the impact on hydrogen costs in various markets.
    - It is unclear what effect large FCEV deployments in a region would have on existing refinery hydrogen demand and whether this would accelerate depreciation of hydrogen plants. The average hydrogen cost in these markets, using the excess hydrogen in the various distribution channels, is unknown. Perhaps an oil company partner would be able to help with this.
    - Water transportation is excluded from the model. The team might consider the impact of shipping liquid hydrogen (LH2) from major production areas and having LH2 unloading terminals in large ports for use in ports and initial pipeline networks.

- The potential benefits of further refinement on the buildout algorithm are not really specified. Aligning the financial models to be more consistent with industry is very important since it affects Hydrogen Analysis (H2A) model costs, and current default assumptions are probably overstated.
- Unless this project is better scoped and titled as "H2Grid" analysis, future work should consider the potential for outcomes in which H2Grid is prohibited by circumstances cited in previous reviews, such as regulations or insufficient market investment.

Project strengths:

- The project is complex, but the team breaks down the major hydrogen costs and challenges and addresses large-scale hydrogen production with a rational approach. The team has been able to gather realistic data from collaboration with others on pipelines and hydrogen production costs.
- The model clearly represents a level of computing power that is accessible only at a national laboratory level. The evolution of various factors over time is highly informative and relevant.
- The project seeks to reduce the cost of delivered hydrogen and leverages existing modeling tools. The project team has engaged a number of technical experts.
- The excellent integration of models collaboratively with other DOE organizations helps in developing valuable estimates of future hydrogen pathways and their costs.
- This project's strength lies in its analysis model development.

Project weaknesses:

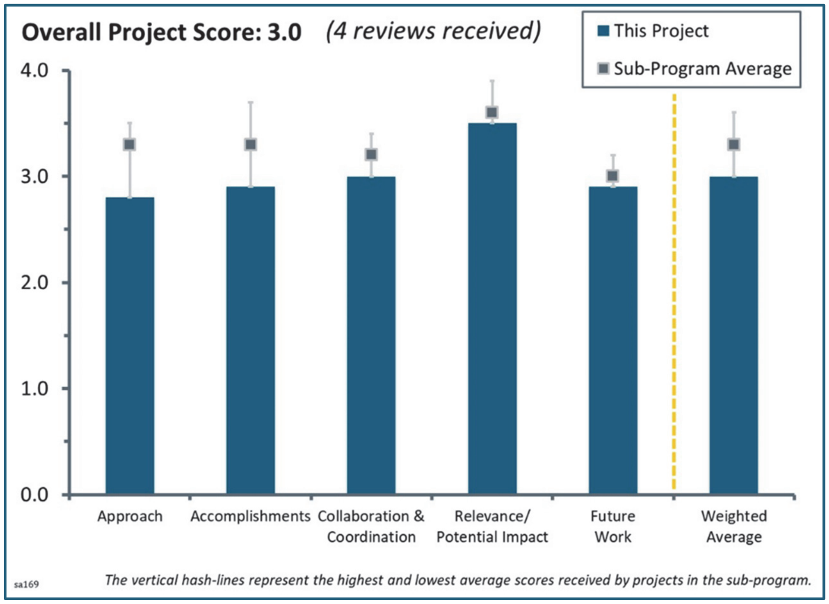
- There are no weaknesses evident.
- The project makes unrealistic assumptions about the availability of hydrogen supply and assumes that land will be available to lay hydrogen pipelines in and around urban areas. The idea of H2Grid is good, but it is unclear who would pay for the buildout.
- There is an immense amount of hydrogen produced for oil refining; this displaced hydrogen should not be ignored in the cost calculations as mass deployments of FCEV light- and heavy-duty vehicles emerge.
- The bias toward a single-solution future should be more distressful to the researchers; it points to a lack of diversity in collaborators.
- The type of feedback solicited from industry could be better described.

Recommendations for additions/deletions to project scope:

- The project team should increase collaboration with city planners and utilities that can provide feedback about the likelihood of installing hydrogen pipelines near major urban centers. The team should also estimate the cost of hydrogen refueling stations without production, compression, or on-site storage to assess the economic benefits for the station owner, compared to the stations that we have today. It is recommended the team understand the likelihood of having access to hydrogen overcapacity now and in the future, given the forecasted buildout. The team should also define who is expected to pay for future hydrogen pipeline buildout and expand collaborations to include potential investors (i.e., cities, utilities).
- The project scope is excellent as is, but it is suggested that the team check electrolyzer costs in the analysis—this seems higher compared to other available data.
- The team should consider adding water transportation of LH2 from large hydrogen production areas to unloading terminals into high-density FCEV regions.

Project SA-169: Market Segmentation Analysis of Medium- and Heavy-Duty Trucks with a Fuel Cell Emphasis

Chad Hunter; National Renewable Energy Laboratory



Brief Summary of Project:

This project provides stakeholders a broad assessment of medium-duty (MD) and heavy-duty (HD) fuel cell vehicle market opportunities and helps guide future U.S. Department of Energy investments in the area. As part of this effort, systems analysis models that assess cost and market barriers to fuel cell vehicle adoption will be enhanced and expanded. The tools and models used in analysis include Future Automotive Systems Technology Simulator (FASTSim) for vehicle optimization to obtain vehicle cost, fuel economy, and weight; and Scenario Evaluation, Regionalization, and Analysis (SERA) for stock modeling and modeling of direct costs, opportunity costs, and other value streams. The SERA model will be used to calculate total cost of ownership for each vehicle class and vocation by region.

Question 1: Approach to performing the work

This project was rated **2.8** for identifying and addressing barriers, project design, feasibility, and integration with other efforts.

- The use and combination of very robust and well-established models such as FASTSim and SERA are key for successfully achieving the main objectives of this work.
- The project team makes use of the excellent models available at National Renewable Energy Laboratory and other national laboratories in conducting a well-planned study.
- The SERA tool and Hydrogen Analysis (H2A) work are done well. It is unclear why the team is using FASTSim and not Autonomie. Autonomie is the industry standard, and it has already been developed and validated. The extra information, and the fact that it is validated and needs minimal development, makes Autonomie well worth the additional computational time required for its use. The team should have done ranges of performance or a sensitivity analysis. It is unclear why the team did not include plug-in hybrid electric vehicles (PHEVs) in their analysis. This is a significant gap, as PHEVs are gaining popularity even with MD and HD vehicle manufacturers. The data the team used in the SERA stock models needs to be updated.
- This project should be using Autonomie instead of FASTSim to carry out calculations. Autonomie is a more robust model with the ability to simulate the cost and performance of many different types of vehicles (including light-duty [LD], MD, and HD vehicles) and alternative fuels. This model has been around for more than 10 years, and Argonne National Laboratory (ANL) continuously updates the model with industry data. Furthermore, it is important that the project team include today's technology costs, in addition to the 2020 and 2040 targets, to understand the cost gap that needs to be bridged.

Question 2: Accomplishments and progress

This project was rated **2.9** for its accomplishments and progress toward overall project and U.S. Department of Energy (DOE) goals.

- As this project recently started, the accomplishments are somewhat limited. However, the current progress being presented (mainly on the FASTSim update and validation for optimizing MD and HD vehicles) shows that the project is on a good track to achieve its main objectives.
- There is excellent progress to date, considering the project started in January 2018. Accomplishments include the validation and enhancement of necessary models, such as SERA and FASTSim.
- The project team has made considerable progress toward the project goals. The initial results can be used to provide guidance to DOE development. However, it is disappointing that a sensitivity analysis was not done. This probably could have been done if the team had used Autonomie. Also, the team is missing PHEV vehicles. These are significant weaknesses in this project.
- The accomplishments are good, given that the project started in January of this year. However, the time that the team is spending updating FASTSim could be better used by running cases and analyzing results in Autonomie. Autonomie already includes MD and HD vehicles, and it is more comprehensive.

Question 3: Collaboration and coordination

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

- The input and feedback being provided by such strong players in the MD and HD vehicle space, such as Cummins, Inc., and Toyota Motor Corporation, are excellent for this project. The addition of Nikola Motor Company also provides great value from the fuel cell perspective.
- Vanderbilt University's Yuche Chen has good modeling capabilities in this field. The use of the VISION model as a benchmark is good because VISION emulates the U.S. Energy Information Administration's vehicle stock projections.
- The team had several industry partners as peer reviewers. It is recommended that the team review its approach, assumptions, and results with the DOE Vehicle Technologies Office (VTO).
- Additional modeling collaboration with ANL is essential to at least validate the results of this project using Autonomie. The team should involve VTO to provide feedback. The U.S. DRIVE Partnership should also be involved.

Question 4: Relevance/potential impact

This project was rated **3.5** for its relevance to/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.

- The MD and HD vehicle market is becoming more and more important in the transportation sector. Fleet refueling may be the initial deployment path for larger-scale hydrogen and fuel cell utilization.
- As the interest in hydrogen and fuel cells keeps growing beyond LD transportation to the MD and HD vehicle market, this analysis is extremely valuable to understand the potential of this transportation sector.
- Since the DOE Fuel Cell Technologies Office (FCTO) is moving in this direction, this analysis will be helpful. The project team could increase the potential impact by including PHEVs and a sensitivity analysis.
- Autonomie already has a series of papers on MD and HD trucks: https://www.autonomie.net/publications/papers_heavy_duty.html. Although none of these papers directly address market segmentation, it is easy to extract that necessary data to conduct market segmentation analysis using Autonomie.

Question 5: Proposed future work

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

- Although not on the slides, the presenter said that a large amount of sensitivity analysis will be done with FASTSim, which is an excellent idea. SERA needs data on truck travel over time to site location; the team will work on this. Also, idle versus driving time will be updated, and grade (slope of the road) effect will be added.
- The proposed future work presented was clearly defined and well aligned with the strategy and approach to obtain the main objectives of this project.
- It is good that the project team is planning on performing a sensitivity analysis. The team should continue to get their results validated by original equipment manufacturers, U.S. DRIVE, and VTO. The stock modeling must be updated, and PHEV vehicles are missing from the analysis.
- It is important that the project team not duplicate work. Autonomie could have been used from the beginning to produce faster and more accurate results. Furthermore, today's cost should also be included in the analysis, not just the 2020 and 2040 ultimate research and development (R&D) targets.

Project strengths:

- The project has excellent models and a current set of available data. There is excellent collaboration with appropriate experts. The project's focus is on major market segments relevant to the larger-scale deployment of fuel cells and hydrogen.
- The project team is examining an important new direction for fuel cells and has made solid progress in the project efforts.
- The objectives are clear and relevant.
- This project's strength includes its modeling capabilities.

Project weaknesses:

- There are no weaknesses in this project.
- The team needs to interact more with the California Air Resources Board because the board is doing a good deal of work in this area. Also, the project team needs to think about how the results will be presented. For example, it is unclear whether the results will look like the DOE FCTO low/medium/high results for LD vehicles in terms of cost per mile, based on ANL's Autonomie simulation.
- The team is spending money developing FASTSim when they could be using Autonomie. The funds could instead be used to update SERA. The team is not looking at PHEVs—this is a big weakness. From other presentations, PHEVs seem to already be part of Autonomie.
- The principal investigator is not familiar with the Autonomie model, which would provide more robust results. Furthermore, the project includes only DOE cost targets, not today's costs.

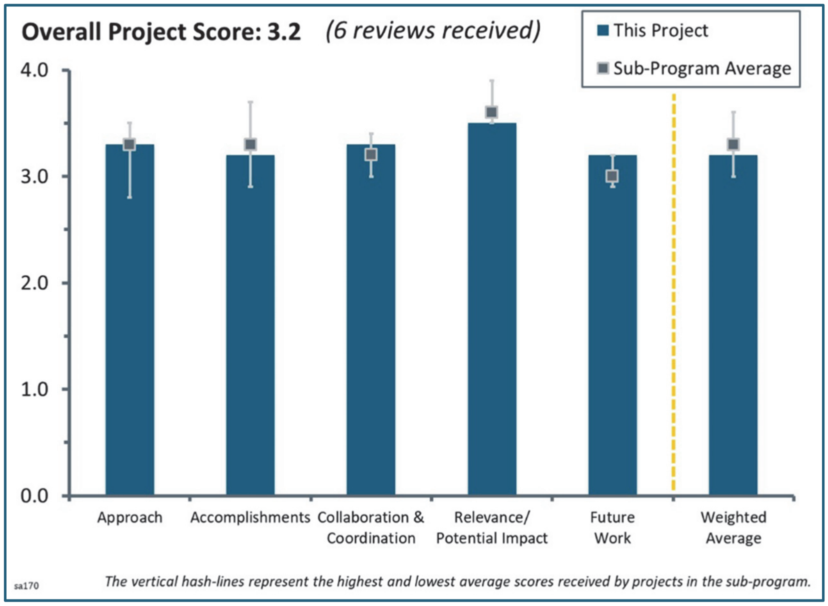
Recommendations for additions/deletions to project scope:

- The team should complete, or at least validate, the project with Autonomie results. It is recommended that the project team include current cost and compare with 2020 and 2040 R&D targets. The team should work with SERA to optimize the location of hydrogen refueling stations for these vehicle classes and include idling time.
- The team could possibly consider holding a brief discussion with Anheuser–Busch and get feedback on this work, since the company has recently placed an order for several hundred Nikola Motor Company hydrogen fuel cell trucks.
- The project team should replace FASTSim with Autonomie and include PHEVs. A sensitivity analysis should be performed. The team should vet the project assumptions and results for conventional vehicles with VTO and U.S. DRIVE.

Project SA-170: Analysis of Cost Impacts of Integrating Advanced Onboard Storage Systems with Hydrogen Delivery

Amgad Elgowainy; Argonne National Laboratory

Brief Summary of Project:



This project seeks to evaluate the impact of onboard hydrogen storage systems on delivery and refueling costs. Argonne National Laboratory, in collaboration with the U.S. DRIVE Partnership: Hydrogen Interface Taskforce, Lawrence Livermore National Laboratory, and Energy Technology Analysis, is addressing inconsistent data, assumptions, and guidelines by developing new delivery and refueling pathways in the Hydrogen Delivery Scenario Analysis Model (HDSAM) for onboard systems. By improving understanding regarding refueling pathways for onboard hydrogen storage and providing better models and tools to better evaluate relevant sustainability impacts, the project team aims to accelerate development and deployment of cost-effective refueling pathways.

Question 1: Approach to performing the work

This project was rated **3.3** for identifying and addressing barriers, project design, feasibility, and integration with other efforts.

- The project team evaluated three alternative storage concepts versus the baseline concept, compressed tank storage. The team focused on preliminary estimates of the key cost differences, with the proper emphasis on identifying overall trends and not the nitty-gritty details at this stage.
- The approach is to assess the cost impact of varying pressure and temperature conditions for a variety of onboard hydrogen storage temperatures. The team used modifications of existing Hydrogen Analysis (H2A) modeling/HDSAM tools and off-line modeling to assess the impact to refueling costs.
- This project appropriately identifies the approach necessary for the task.
- The approach is a good start, but it does not include key aspects (e.g., redesign of the dispensers and controls; onboard storage cost, volume, and mass impacts; or impacts on soft costs such as permitting, standoff distance, and site availability). Those areas should at least be acknowledged, even if they are not analyzed. If the principal investigator (PI) had discussed the approach in more detail, instead of using the first five minutes of his presentation to discuss challenges with 700 bar storage, this score would probably have been higher.
- The vehicle weight from added heat exchangers and metal hydrides would have an impact on weight. This needs to be evaluated with a vehicle model—perhaps through Autonomie or the Future Automotive Systems Technology Simulator (FASTSim). The metric of choice should cover the service envelope of miles traveled and not just dollars per kilogram of dispensed hydrogen.
- It would be good to understand key characteristics of materials-based storage, such as heat capacity.

Question 2: Accomplishments and progress

This project was rated **3.2** for its accomplishments and progress toward overall project and U.S. Department of Energy (DOE) goals.

- The team has demonstrated an objective and comprehensive assessment of the impacts of various proposed storage/refueling scenarios. The results are meant to be comprehensive in that they are not sub-optimizing, but rather are attempting to assess all impacts, positive and negative. Several systems were preliminarily examined: only the metal hydride system showed a pathway to significant net refueling cost reduction. The other pathways showed little to no improvement.
- The project team has done thorough analysis for the approach undertaken.
- The accomplishments align well with the stated goals of the analysis.
- The project started in October 2017, and progress to date is excellent in terms of concept definition and preliminary economics.
- The preliminary results were very interesting and suggested that metal–organic framework (MOF) systems may impose a large cost on the station. It was not clear whether the tank cooling was done for the MOF and cryogen-compressed tanks. The cryogen-compressed tanks can be cooled over repeated fills, but the MOF system does need additional cooling for each fill. This should be investigated if it is included.
- It was very difficult to identify the level of detail used for the analysis and how that level was selected, based on the slides provided. It appears that cost analysis was performed for only several primary components (the compressor and storage systems) and that the cooling system cost estimate was based only on the cost of energy. All other costs were assumed to be constant. Even the compressor and storage systems seem to have been analyzed using only a rough cost estimate. Those directions are probably acceptable; however, the reasoning and decisions behind them needed to be communicated.

Question 3: Collaboration and coordination

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

- The project team's has excellent collaboration with Ford Motor Company, U.S. DRIVE tech teams, Energy Technology Analysis, Lawrence Livermore National Laboratory, and three other national laboratories with the needed expertise, as a result of prompt and thorough input provided by the collaborators.
- Direct input from original equipment manufacturers with cars on the road is very important. Even if it is not the primary input, reviewer input and perspective would be useful. The project team has considered many design choices.
- The project collaborations have resulted in sufficient input and a critical review of the results. The accomplishments are well presented and provide a relevant analysis of the task objectives.
- The list of collaborators on the project is appropriate, and they function as excellent information resources.
- It is good to see that the project team reached out to many key researchers from the Hydrogen Storage Engineering Center of Excellence. Given that BMW was developing a cryogen-compressed hydrogen storage system, it is recommended that the researchers contact the company to see whether BMW considered the impacts on the filling station when deciding about the company's storage technology. Given that there are several companies that have installed hydrogen filling systems, the researchers could have reached out to them for any lessons learned or could have looked at their approaches and results as a check.
- The list of collaborators is useful, and the project team consists of a good group. However, the team does not include members that could provide insights into alternative compressor costs and other options. Including them would help.

Question 4: Relevance/potential impact

This project was rated **3.4** for its relevance to/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.

- The project aligns extremely well with the Multi-Year Research, Development, and Demonstration Plan objectives. This project has the potential to advance progress toward DOE goals and objectives because delivery cost for hydrogen fuel is still a major cost item for fuel cell electric vehicles.
- The project fundamentally seeks to better understand the potential for refueling cost reduction via enactment of various approaches. Gaining understanding is vital to achieving cost reduction.
- As infrastructure developers consider cost reduction strategies, this task, the analysis, and the results provide a straightforward summary of potential options.
- It is always good to reevaluate technology options as laboratory breakthroughs come to fruition.
- This was an analysis that was needed years ago. The results need to be vetted with industry and validated in some manner. The question is how DOE is going to use this information.
- It is not clear where DOE's priorities are regarding onboard storage beyond compressed gas. Focusing on only the off-board aspects of the storage costs makes it very difficult to understand how these technologies might fare when considering the full cost of driving. It would help to link this analysis effort with results from the Hydrogen Storage sub-program category projects that focus on onboard storage using these materials. Since the technical potential for these technologies was not presented, it is hard to understand why they were analyzed.

Question 5: Proposed future work

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

- Most results to date are marked as preliminary. Thus, future tasks will presumably finalize the estimates. Multiple narrow approach changes/expansions are listed, which together will ensure a comprehensive analysis when completed.
- The proposed activities are very logical continuations of this year's activities.
- The proposed future work continues the positive impacts of this project.
- The proposed future work looks like a good set of tasks to decrease the error bars around the analysis. The question is whether the current level of uncertainty encompasses competitive and promising technologies.
- The only recommendation is for the project team members to clarify how they plan to validate and vet their results.
- The combined cost and performance of delivery-dispensing onboard storage is more critical than the other proposed work. A major weakness of this analysis is that it does not include (or propose) any link to onboard storage analysis.

Project strengths:

- This is a much-needed analysis. The project team is looking at a key area that could influence the direction of onboard hydrogen storage projects at DOE. The team is very experienced, and the software modeling tools look to be appropriate.
- This is an outstanding analysis topic with a sound approach and a highly qualified PI and partners. There is excellent progress and collaboration with experts.
- The project has a well-experienced team that serves as an honest broker to comprehensively assess the refueling impact of various approaches.
- The researchers behind this analysis are very well versed in the topic and are well connected to industry.
- The project is well scoped, well executed, and well communicated.
- This is a good project, but it would be much better if it included some estimates of onboard storage and provided current status and future potential for each technology analyzed.

Project weaknesses:

- There is no overall weakness.
- The fundamental weakness of the project is that it has not identified significant pathways to refueling cost reduction. The cost breakdowns illustrated in the opening slide ($6–$8/kg for refueling cost) are for small-scale stations (only 200–300 kg/day). However, the costs shown later in the assessments of individual approaches are for 1000 kg/day stations.
- This project should include estimates of onboard storage and provide current status and future potential for each technology analyzed to help put the whole cost in context.
- Vehicles need to be considered to provide impact to the total cost of ownership for transportation.
- The project team needs to explain the plan to validate the results.

Recommendations for additions/deletions to project scope:

- The process for selecting technologies and identifying the level of analysis detail for each is not stated explicitly; this should be added to the project. If the technology selection process indicates that detailed analysis should be performed, then that should be within the scope. A rough estimate showing the impacts of delivery and refueling costs is necessary to understand whether they fit into the scope. Also, a rough estimate showing potential impacts of components (heat exchangers, liquid nitrogen storage and pump, etc.) is necessary to show the value of additional analysis on the components. All additional pathways should have a qualitative assessment of their potential value before detailed analysis is performed.
- The project team should consider adding a transportation analysis entity or develop in-house expertise with vehicle models.
- The cost of onboard storage must also be considered.