2017 – Systems Analysis
Summary of Annual Merit Review of the Systems Analysis Sub-Program

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

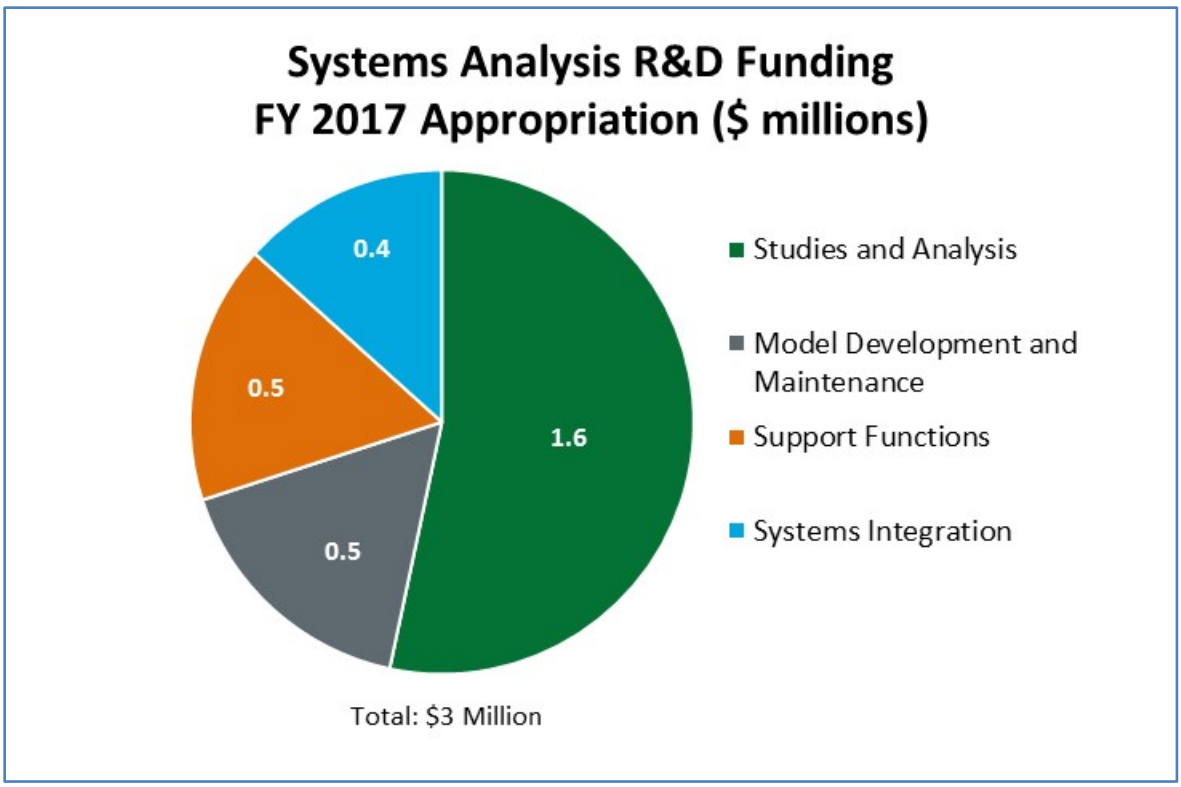
The reviewers considered the Systems Analysis sub-program to be critical to the U.S. Department of Energy (DOE) Hydrogen and Fuel Cells Program's (the Program's) mission and focused on the relevant issues that will enable cost-effective implementation of hydrogen fuel cell vehicles in a way that addresses national needs. In general, the reviewers noted that the Systems Analysis sub-program is well managed and the sub-program projects are diverse and focused on addressing technical barriers and meeting targets. Reviewers commended the sub-program for the excellent mix of near-, mid-, and long-term analyses as demonstrated by the assessment of hydrogen cost at low volumes for the current market, early-market infrastructure costs for the near term, and relevant activities to support H2@ Scale and assessment of medium-/heavy-duty transport and regional resources for the longer term. They said that one of the strengths of the sub-program was the extensive collaboration with industry, national laboratories, and academia to gather information from the entire value chain to conduct analysis. Overall, the reviewers commented that the sub-program's research and development (R&D) portfolio is appropriate and comprehensively addresses key technical aspects required to achieve the sub-program targets.

Some reviewers commented that the sub-program's broad portfolio of models and tools are adequate to address the issues and barriers facing the Program. They noted that the Systems Analysis sub-program links the results for all the pathways and technologies and adds a technoeconomic macro-level assessment of status and needs. Reviewers identified analytical activities as crucial in assessing the relevance of the technical progress. It was also noted that the analysis and model portfolio is balanced and enables the Systems Analysis sub-program to quickly respond to high-level assessments. In particular, when H2@ Scale was announced, the team was able to complete analysis tasks to assess market potential and economics using the current model portfolio.

Key reviewer recommendations for this sub-program include the following: (1) highlight the job impact assessment; (2) extend the analysis timeframe for the total cost of ownership assessment to 2040; (3) provide analysis of consumer behavior; and (4) provide risk analysis of sub-program targets to understand the impacts of meeting the overall objectives.

Systems Analysis Funding:

The fiscal year (FY) 2017 appropriation for the Systems Analysis sub-program was $3 million. FY 2017 funding focused on conducting analysis using the models developed by the sub-program. In particular, analysis projects 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 greenhouse gas emissions and petroleum use, criteria emissions from hydrogen pathways, greenhouse gas emissions from fuel cell medium- and heavy-duty trucks, and hydrogen fueling station business assessments.



Majority of Reviewer Comments and Recommendations:

The maximum, minimum, and average scores for the 12 Systems Analysis projects reviewed in the 2017 Annual Merit Review were 3.5, 3.1, and 3.4, respectively.

Infrastructure: The one analysis project reviewed in this topic area received an average score of 3.5 and focused on assessing hydrogen infrastructure development costs and understanding the hydrogen infrastructure costs.

Reviewers commented that the ***Hydrogen Financial Analysis Scenario Tool (H2FAST) Updates with Analysis of 101st Station*** project aligns well with the Program objectives of supporting infrastructure by providing options to focus effective research on cost reductions and insights to station network development. They noted that the model is comprehensive with the addition of the stochastic risk analysis capabilities for deployment of hydrogen infrastructure and incorporates excellent collaboration with stakeholders, including government agencies. The reviewers noted that the model would benefit from additional outreach and engagement with stakeholders to solicit customer feedback.

Model Development and Systems Integration: Five 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 sub-program goals and objectives.

Reviewers commended the ***Greenhouse Gas Emissions and Petroleum Use of Medium- and Heavy-Duty Trucks*** project for expanding the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model platform to include fuel cell applications for medium- and heavy-duty truck sectors. They agreed that the project is critical in emphasizing the benefits of hydrogen fuel cell applications for medium- and heavy-duty trucks, especially in communities that are disproportionally affected by heavy industrial activity. They commended the work for its effort to accurately assess engine and fuel cell performance in these truck sectors (including during idle engine operation) and for having excellent collaboration with stakeholders. Suggestions include validating the power assumptions, providing additional funding to continue this critical work, and adding health benefits from emission reduction.

Reviewers acknowledged the ***Life-Cycle Analysis of Air Pollutants for Refinery and Hydrogen Production from Steam Methane Reforming*** project for updating the GREET model platform to improve the model's accuracy and provide life-cycle data on criteria pollutants. They agreed that the project is addressing a sub-program gap and will enable critical evaluations of conventional internal combustion engine vehicles compared to zero-emission vehicles such as fuel cell vehicles in non-attainment areas. Suggestions include increasing collaboration with state agencies such as the California Air Resources Board (CARB) and California Energy Commission (CEC) to ensure the model has the most recent data and includes regional analyses to assess impacts on non-attainment areas.

Reviewers acknowledged that expanding the GREET model platform to include water-use life-cycle assessment and renewable hydrogen production pathways will address critical Program issues associated with hydrogen production and the comparative evaluation to conventional fuels. They agreed that the project has established a good fundamental understanding of water consumption associated with hydrogen pathways, which is essential for comparing multiple vehicle platforms, fuel pathways, and resource analysis. They commended the work for expanding the capabilities of existing modeling tools and for including county- and regional-level analysis of water consumption and potential for water stress. Suggestions include quantifying the net water impacts of fuel substitution or displacement, providing more context on water usage overall, considering the impacts of varying regional policies or economics affecting water use/cost, and increasing collaboration with/peer review by western state water authorities. Reviewers agreed with continuing the emphasis on completing and expanding regional analysis, especially in areas of the country where water limitations may be an issue.

Programmatic Benefits Analysis: Three projects were reviewed in the topic area of sustainability and employment impacts of hydrogen and fuel cell technologies, receiving an average score of 3.3.

Reviewers observed that the ***Benefit Analysis of Multi-Fuel/Vehicle Platforms with a Focus on Hydrogen Fuel Cell Electric Vehicles*** project's approach is good and uses well-regarded, industry-vetted models to generate results. They recognized the importance of estimating the benefits of DOE R&D but questioned the attribution of benefits to federal programs versus industry and others. They suggested that the model use an estimated market price of hydrogen versus the Hydrogen Analysis model (H2A)-calculated production cost, and criticized the five-year ownership period as being too short. Other suggestions included quantifying air pollutant reductions; adding medium- and heavy-duty trucks; conducting sensitivity analysis around vehicle ownership, vehicle resale value, and discount rate; evaluating the effects of different policy drivers; and increasing industry review and vetting of the work, possibly by adding an industry advisory or steering committee.

Reviewers commented that the ***Employment Impacts of Hydrogen and Fuel Cell Technologies*** project is based on the use of the well-regarded Regional Economic Model Inc. (REMI) model to understand job creation associated with the development of hydrogen infrastructure and production of fuel cell systems associated with automotive and stationary applications. They found the project to be very relevant and critical to examining the economic benefits and job impacts of an expanding fuel cell market, and useful in assessing complex scenarios of employment for a developing fuel cell market. The reviewers recommended expanding the work to include international competitiveness and medium- and heavy-duty fuel cell truck markets, although one reviewer was unclear about the value of the multimarket analysis and suggested that it be better articulated.

Reviewers emphasized the importance of a sustainability analysis tool to support technology evaluation and program decision making and noted the value of such a tool to the broader stakeholder community, including technology developers and end users. They appreciated the ***Sustainability Analysis: Hydrogen Regional Sustainability*** project's efforts to integrate existing data sets and models, noting that this increases the utility and capabilities of models already developed. Reviewers recommended that the project eliminate duplicative work being done by other projects (e.g., water use analysis and regional hydrogen supply analysis), provide additional clarification of input and output metrics, and engage a broader audience (through increased industry collaboration and education/ outreach). They also made some specific suggestions about the model's assumptions regarding technology selections and hydrogen cost.

Studies and Analysis: Four analysis projects were reviewed, receiving an average score of 3.3. The projects covered a range of topics, including analysis of incentives and policy, and fuel cell storage cost analysis.

Reviewers generally agreed that the ***Cost–Benefit Analysis of Technology Improvement in Light-Duty Fuel Cell Vehicles*** project is extremely relevant in that it evaluates the value of future fuel cell and hydrogen storage technology improvements to consumers, which will help support R&D target setting and strategic planning. They praised the use of an established and well-respected modeling tool, and the use of assumptions that enable comparisons across component sizing options and vehicle platforms. Suggestions included adding an industry partner or gathering more outside feedback from industry and conducting analysis to evaluate the impacts of reaching various performance goals on total cost of ownership (e.g., fuel cell efficiency, platinum loading, etc.). They supported plans to conduct sensitivity analysis on hydrogen cost and to evaluate possible tradeoffs between cost and efficiency.

Reviewers noted that the ***Resource Availability for Hydrogen Production*** project's approach is technically strong and thorough and properly integrates new efforts with existing models and data. They agreed that updated estimates of regional hydrogen production potential are needed, given the availability of new resource data and technology improvements. They commended the plans to integrate the results into tools such as the Hydrogen Demand and Resource Analysis tool (HyDRA) and the Scenario Evaluation, Regionalization and Analysis model (SERA), which can be used to understand how supply chains may develop in different regions. Suggestions included adding uncertainty analysis for resource potential and production efficiencies; conducting analysis of relative cost, land use, and carbon dioxide emissions of various options; and increasing industry collaboration to vet key assumptions (such as hydrogen production efficiencies and ranges) and increase industry uptake and use of the results.

Reviewers commented that the ***Regional Supply of Hydrogen*** project provides data that is key to understanding infrastructure challenges and real costs, and commended its integration with other related analytical efforts. They agreed that the analysis is relevant and addresses options to provide hydrogen to various regions and accelerate the introduction of additional hydrogen refueling stations. Reviewers suggested that the project engage in more collaboration with state agencies such as CARB and CEC, vehicle manufacturers, and other industrial stakeholders. Other suggestions included comparing semi-central gaseous hydrogen with liquid hydrogen delivery and assessing costs for pipelines in urban areas.

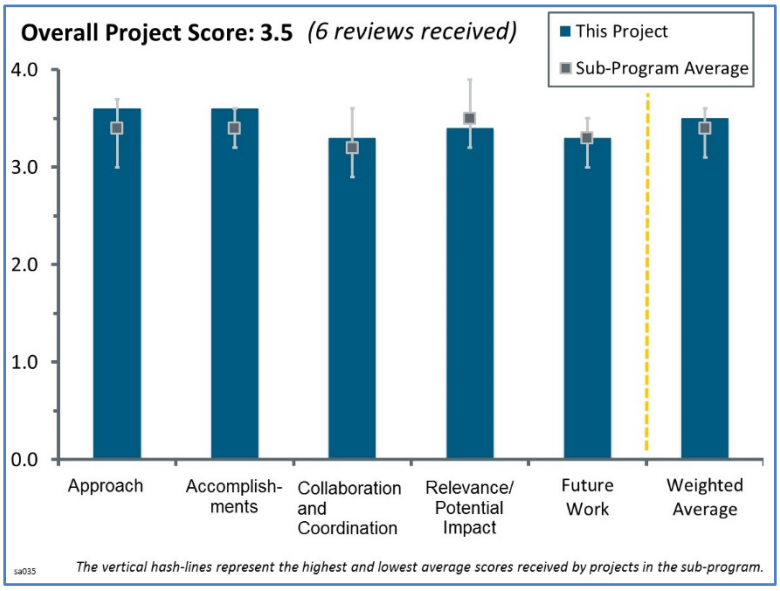
Reviewers commented that the ***Hydrogen Analysis with the Sandia ParaChoice Model*** project has a good approach to using previously developed models as input and exploring uncertainties and tipping points. They noted that the project enables market segmentation and market assumption inputs to explore fuel cell vehicle market penetration. Reviewers suggested that the project be reviewed by a larger audience, including OEMs, and expand its collaboration with stakeholders, particularly additional collaboration with industry stakeholders and coordination with other models to minimize redundancy. In addition, the range of values assigned to key variables was unclear, and reviewers suggested these be articulated for transparency.

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 (RD&D) 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 **3.6** for its approach.

- The project made use of the Hydrogen Delivery Scenario Analysis Model, H2USA, and several other FCTO capabilities and activities in developing an industry scenario. The RCF Economic & Financial Consulting (RCF) employment modeling work is very well suited to the objective.
- The comprehensive framework was successfully used in 2008. The project makes good use of existing data sets, models, and projections.
- The approach is very impressive.
- The approach seems logical and thorough.
- It is encouraging to see that this work is seeking to avoid siloed modeling efforts and is making a concerted effort to incorporate and/or match several other models that provide key inputs. While the new Regional Economic Models Inc. (REMI) model discussed appears to have provided needed internal consistency, it is unclear what effect the model switch had on the final results, especially considering this appears to have occurred so late in the project's total timeline. It is also good to see that several of the fundamental assumptions are being updated with today's understanding and outlook of the fuel cell electric vehicle (FCEV) market, especially the expected rollout of FCEVs. This is important for the project to continue to provide realistic insights and expectations.
- The project uses models across multiple sources (the U.S. Department of Energy, U.S. Department of Commerce, regional sources, etc.), which lends credibility to the approach. The multi-market scenario does not really cover the major demand sectors for hydrogen outside of fuel cell connections; hydrogen generation via the pathways covered in the FCTO portfolio could generate additional employment as well. It should be clarified that these are or are not included in the presentation. The assumptions do consider the most recent and extrapolated oil prices as a single data point, which can shift the projections substantially from year to year. Doing a sensitivity analysis across a few scenarios would be helpful.

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 so far has answered several questions about the potential employment impact of hydrogen and fuel cell industries. The complexity of all the inputs involved makes this not a simple task, and the completion of such detailed modeling, especially with regional specificity, is a major accomplishment.
- The project represents analysis of a large number of data from various sources and synthesizes it into an understandable format. The dependence on geographic area is also an important element and could be compared to other manufacturing efforts in the United States to develop a strategy for states.
- There are very interesting results. The degree to which material flows are modeled explicitly is not clear. It is very good to be able to draw out distribution and sales jobs.
- The updating of the 2008 employment impacts study made good progress, including completing the development of the Base Case and Core Multi-Market Scenario, 75% completion of the REMI work, and economic analysis work.
- Progress appears to be good. A lot of work is planned for a relatively minimal budget.
- The project seems on track to deliver intended results.

Question 3: Collaboration and coordination with other institutions

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

- The project made use of extensive collaboration through the advisory group, which includes industry members and others.
- It is good to see that the project is actively working with advisors and has a stakeholder workshop, given that the results are highly dependent on assumptions and projections. Industry validation and buy-in will also be important if policy decisions are ultimately based on project results.
- There are partners that have contributed to the project in the past, and it is planned that they will come back in future years for specific analyses. The project does discuss interaction with H2USA as an advisory group, but it was not extremely specific in terms of the review provided.
- Multiple parties have been effectively engaged in conducting this analysis work.
- The list of collaborators appears to be appropriate and thorough for the project scope.
- The project could use more industry participation, or academic expertise, in the automotive industry sector.

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 project is absolutely relevant and critical to justifying and advancing the DOE Hydrogen and Fuel Cells Program goals by directly showing the effects on the U.S. job market. Recurring updates are, and will continue to be, critical because of the nature of the underlying projections, market changes, fuel cell technology evolution, and highly variable oil costs.
- The project directly addresses one of the objectives of Systems Analysis sub-program RD&D, and it does so with a thorough and rigorous modeling approach.
- The United States is falling short in meeting requirements of the Energy Policy Act of 2005 (EPAct), and this analysis is needed to quantify those impacts.
- This is a very relevant and important topic for analysis.
- This project is required by EPAct, and therefore, DOE has to complete it.
- While this should not be taken as criticism of the work being done, the relevance of jobs analyses in general is questionable. It seems intuitive that any technology taking market share in the light-duty transportation space will tie to employment. The more relevant question might be the effect on international competitiveness.

Question 5: Proposed future work

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

- Having a stakeholder workshop is key in providing feedback on the analysis. The groundwork laid already also provides a good foundation for the proposed expansions in scenarios and sensitivity analyses.
- The proposed future work includes tasks that are necessary to completing the study.
- Holding the stakeholder workshop and incorporating updates will be important.
- The future work was simply not stated with a great degree of detail. Overall, the goals seem appropriate, but it is difficult to gauge what the end products of the mentioned topics will be.
- Of the future work items listed, "workforce development needs" seems most actionable.
- There did not appear to be much detail on this topic, but presumably, the continuity to complete the scope and approach presented is the future work.

Project strengths:

- Distillation of a large number of data into a clear picture describing the positive impact fuel cells and hydrogen technologies can have and have had on job creation is a key outcome of this project, which is helping to quantify the benefits to U.S. manufacturing and employment.
- The strength of the project lies in the ability to assess such a complex scenario of employment for a developing market. Additionally, regional insights are valuable, and this may be the only work to date that provides such quantitative assessments of employment outlooks in the fuel cell and hydrogen industries.
- The project's strengths are its relevance and its synthesis of existing projections and data sets. It is, and will continue to be, critical to justify U.S. employment opportunities from continued federal investment into clean, advanced technology development and deployment.
- The Argonne National Laboratory and RCF team is well versed in this type of study, and the project appears to be on track to deliver what is required.
- Integration of both vehicles and fuels (eventually) is a project strength.
- The project is thorough in scope and approach.

Project weaknesses:

- No significant weakness exists.
- No major weaknesses were noted.
- It would be good to better understand the breakdown of contributions to net jobs. Also, if FCEVs become more competitive with conventional vehicles and hybrid electric vehicles, it is not clear whether they will create fewer jobs. It would be good to come away from this presentation with a clearer understanding of this issue.
- There was some difficulty following the presentation of how all the various associated models and data inputs correlated to one another within the project. It was especially difficult to gauge which input factor or model had a greater or lesser impact on output results.
- The team also needs to include medium- and heavy-duty markets in the analysis. Almost 11 million heavy-duty trucks were registered in the United States in 2014, according to the *Transportation Energy Data Book*. The project is missing a big opportunity to account for further job growth.
- The project is questionable in value. Job creation is certainly not the goal of advanced technologies. It is better to focus on workforce needs and the required supply base.

Recommendations for additions/deletions to project scope:

- In the context of H2@ Scale, it would be good to compare the other hydrogen applications on the list where water splitting could penetrate in the near term and the implication on jobs.
- The team should add medium- and heavy-duty vehicles to the project scope, if not already included.
- Sensitivity analyses are mentioned, although it is recommended that these focus on delineating how the various models' outputs feed into and affect the results of this project.

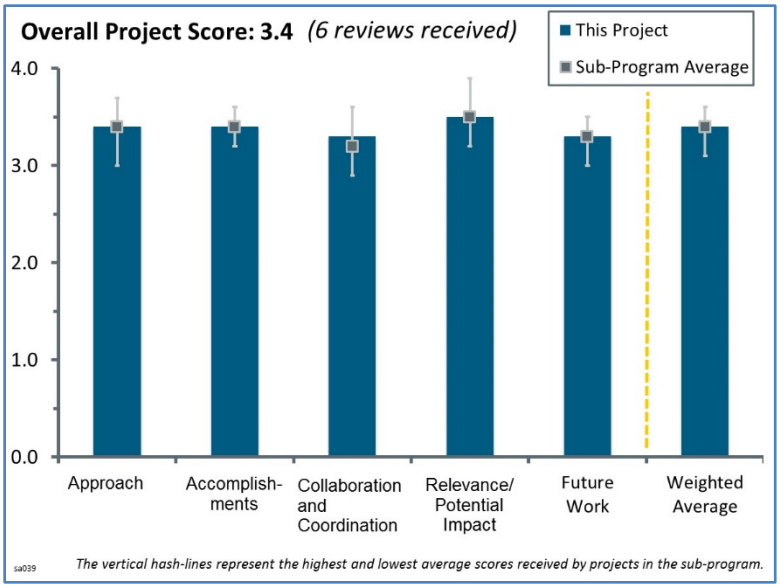
- It is recommended that the project team limit their efforts to the base case, unless the clear value of multi-market analysis can be articulated.

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

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 **3.4** for its approach.

- The project has an excellent approach. It is not only addressing the needs of the project at hand but enhancing the capabilities of GREET overall.
- This project follows previous work expanding the GREET life-cycle analysis model to include water consumption and uses the revised model to understand 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. Use of the water consumption life-cycle analysis features of GREET allows for a consistent approach to assessing the impact of various transportation fuel and vehicle pathways on water resources.
- This is a very important topic for comparing hydrogen to other fuels. The approach is sound, given the limited data and ability to understand substitution or displacement effects across different water uses. Incorporating the water use associated with gasoline miles displaced would be an improvement to the current approach.
- This is excellent analysis, but it needs to be contextualized to water impact relative to current conditions. For example, it needs to reflect the fact that increased water consumption for hydrogen production really displaces two gallons of gasoline production and its associated water consumption. In this sense, western regions where water impact is crucial will show a relief by local hydrogen production, which yields net reduction in water consumption. In this context, it would be best to start producing hydrogen in California to alleviate water stress.
- Overall, the structure of the assessment is good, but it needs to put the water issue in better perspective. The project should compare it, for example, to water usage in a given area, including the major U.S. water usage, which is for agriculture.
- It is unclear how the water value is being calculated. The assumption is that the hydrogen will be produced in the same county it is used. This not a good assumption. It was not clear whether the Available Water Remaining (AWARE) index was invented by ANL or whether someone else devised it. While this addresses potential water stresses, it does not address available water. In many western states, the water rights have mostly been sold off; buying the water rights may substantially increase the cost.

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 study makes important comparisons of the water consumption of various vehicle-fuel platforms and further breaks down water usage from different stages and processes, allowing a good understanding of what process elements drive water consumption. The preliminary county-level regional analyses of water consumption and water stress are excellent. The finalized results will be very useful in understanding how different hydrogen production technologies can be used regionally and how they will affect water resources.
- The initial studies attempt to identify the areas and counties that could be stressed by hydrogen production and others in which the hydrogen production may be a job source. Preliminary data does look very interesting. The areas where people wanted to put in solar (and wind) for water splitting tend to be the areas that are most susceptible to water stress factors.
- This is an excellent project, and ANL is doing a great job attributing and disentangling water consumption and stresses.
- Characterization of a stress index is very valuable. More details of supply chain component locations would improve on the assertion that fuel cell electric vehicle (FCEV) demand centers are driving water demand. Additional context around the economics or policies affecting water use in different regions or watersheds would also be informative.
- The analysis is well done, and results are clearly presented.
- There is good progress, but additional work is needed to better assess water usage overall. It is pretty clear that water usage in the first place is not a major issue/limitation for large-scale hydrogen production, but it needs to be confirmed/quantified.

Question 3: Collaboration and coordination with other institutions

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

- The study team appears to have collaborated with the appropriate experts in the field, including water researchers from the federal government, national laboratories, and academia.
- Work has been coordinated with DOE H2@ Scale scenarios and draws from other DOE models such as the Hydrogen Analysis (H2A) model and VISION model.
- There are good collaborations. More policy and economic context may add value to these results.
- The collaboration is adequate.
- It would be prudent to include California water management entities in the process. These entities would have the right framework on how to think about producing hydrogen and reducing transportation water consumption. Also, it would be good if such entities would view this opportunity in terms of tackling their own targets.
- The project team has some collaborators and is using them. It is unclear how the team will validate the model. The industry partners could also make their voices heard.

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.

- These results lay the groundwork to begin to understand water usage and stress. Bringing them to final impacts in terms of economics or external costs—in dollar values—would allow water use to be monetized in a full social cost accounting framework.
- Because much of the focus on new hydrogen production is on water splitting with renewable power, it is important to understand which areas of the country have reasonable water supplies that could be used.

- This project helps expand life-cycle modeling to investigate water consumption associated with various vehicle and fuel technologies, including hydrogen FCEVs, which will be critical in the future.
- This is very relevant research.
- The project confirms a perhaps expected outcome: water usage is not substantial compared to other uses. The project does identify local areas where there may be an issue.
- Water stress is a good starting point, but the more relevant question might be whether access to water presents a barrier to hydrogen at scale. A good next step would be to estimate water costs in the high-stress regions and quantify impacts on end-user hydrogen fuel cost.

Question 5: Proposed future work

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

- These future work items flow naturally from the work done to date, and all items are important.
- Proposed future activities are appropriate. The continuing emphasis on completing and expanding regional data and regional analyses is critical, as consideration and concern regarding water resources are inherently regional in nature.
- The proposed future work is well-thought-out.
- The project does address the need to expand the evaluation to identify regions of the country where water limitations may be an issue, but it should provide an overall conclusion that, as a whole, water will not be a limitation to an expanded hydrogen energy system.
- It is suggested that the project team add an economics assessment. It is not clear what it takes to procure water in high-stress regions, whether the cost is significant, and which current users of water would likely be displaced.

Project strengths:

- There is continued interest in transportation sustainability. Policies regarding zero-emission vehicles such as FCEVs have been implemented to address air pollution concerns, but it is important to expand the understanding of the life-cycle impact of vehicles to include water resources. This project uses life-cycle modeling to investigate water consumption associated with FCEVs as well as other vehicle-fuel platforms.
- This project has an excellent purpose, a motivated team, and the expertise to quantify the water consumption impact of hydrogen transportation.
- The project has a good, strong team. The team lead is especially strong. The project has done a good job, given limited funding.
- It is great to have a consistent treatment of stress at the county level.
- The project highlights regional differences in water resources that could drive different regional approaches to hydrogen (or other alternative fuels) production.

Project weaknesses:

- The findings on water consumption and water consumption factors established within GREET would benefit from continued peer review. However, this is not necessarily a weakness because the project team is already collaborating with water researchers.
- Adding stresses along a supply chain geographically would be a significant improvement. Context around economics and policy/management issues could also add value.
- The project assumes hydrogen water use is incremental. If a region is truly stressed, displacement of other users seems more likely (assuming hydrogen is higher in value added per unit of water consumed).
- The project needs to put water usage in perspective as a whole by comparing it to existing usage, and identify portions of the United States where water limitations may impede hydrogen generation/ distribution.

Recommendations for additions/deletions to project scope:

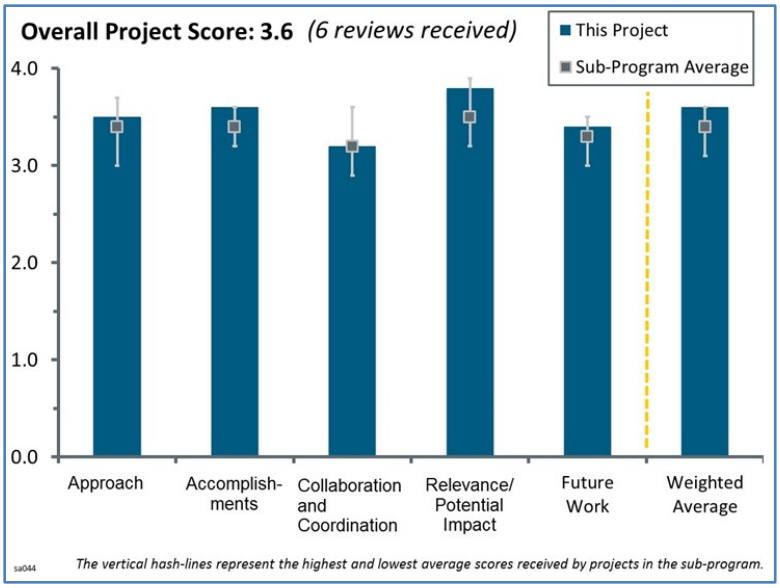
- It is important to try to address net water impacts if future FCEVs are displacing conventional vehicles or hybrid electric vehicles running on liquid fuels.
- The project should connect with southwestern state water management entities in order to ensure the right context of impact is being applied. It will make future interactions with these states smoother and may inform policies being considered by such jurisdictions.

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 its approach.

- Multiple models, including comparisons to expert feedback, provide more grounding to the numbers, and make the work more relevant. Cost-performance benefits are important to help set research and development priorities and decide what "done" is (or what breakthrough needs to happen to break the cost curve).
- The project has a very good analysis framework.
- The approach and study goal are very sound and relevant.
- The project uses the well-known Autonomie model and input from the Office of Energy Efficiency and Renewable Energy (EERE), consistent with the project team's benefits analysis and planning studies.
- The clear description of assumptions was very helpful in understanding the results.
- A particular addition to the approach that could be valuable for the near term would be to add sensitivity to the cost of hydrogen, much the same way as there is a sensitivity to annual vehicle miles traveled (VMT). The $4.00 per gallon gasoline equivalent, while good for gauging long-term development requirements, is unrealistic in today's hydrogen market (and likely for some years to come). There may be opportunity to inform FCEV development in the short-term, but only looking at the cost–benefit tipping points for a hydrogen cost target that is so far in the future may miss other important factors. Otherwise, the approach is sound and the project provides fundamental assurance that U.S. Department of Energy (DOE) targets are valuable for the end consumer.
- The analysis seems rather idealized. It appears that a rather small number of variables were modulated or reported (e.g., efficiency and cost of storage). It is not clear whether there are assumptions on what it costs to achieve such gains. Automakers often use performance gains for improving other vehicle aspects, such as acceleration, range, and towing capacity, so they can compete better with other technologies. The analysis also would be more meaningful if it were contextualized against what may be feasible from other power train competitors (e.g., gasoline, electric vehicle, hybrid electric vehicle, compressed natural gas, and others).

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 accomplishments today seem to already be directly answering the broader questions in the project's scope. More specific insights may be provided with future work but important high-level messages are already being developed through this work.
- Modeling results demonstrate DOE targets provide a significant benefit if achieved, which is important in determining whether targets should be reassessed.
- The results presented show very good progress in identifying the costs versus benefits of the target points. The inclusion of the three annual vehicle miles scenarios was very helpful.
- There is good progress in setting up cost models and including key sensitivities.
- Apples-to-apples comparisons in terms of vehicle range make results more meaningful and show the impact of each change.
- These results are good in terms of establishing "fair" comparisons across component sizing options and vehicle platforms. However, fuel savings alone may not be the main criteria. It seems that market share is also an important criteria and one that depends upon more than just fuel price.
- A greater level of insight was expected from this application of Autonomie.

Question 3: Collaboration and coordination with other institutions

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

- It looks like all of the right inputs and tools are being pulled into the analysis.
- There is a high degree of collaboration with other national laboratories and DOE-funded projects; however, an industry partner may help as particular questions representing gaps in industry knowledge may be posed and seem to be largely addressable through this work. This could increase the overall benefit of the project outcomes.
- DOE tools already developed were effectively used and input from the fuel cell systems team at Argonne National Laboratory (ANL) and industrial input from the U.S. DRIVE Partnership provide educated assumptions on the component and vehicle impacts. The frequency of interaction and method of providing input were not really described.
- There is a good network of collaborators. It is always valuable to get more industry input.
- The project relies on input and assumptions that have been used in EERE analyses for program records and Government Performance and Results Act (GPRA) reports.
- This project could greatly benefit from more input from industry and the fuel cell community. As partners, it appears that only internal resources were applied. It would, for example, be beneficial to include Strategic Analysis, Inc., (Brian James) or automotive companies' perspective behind non-disclosure agreements or even just in a reviewer capacity. It would also be helpful to evaluate various DOE technology development efforts and estimate their impact if they were successful (e.g., catalyst formulations, non-platinum catalysts, higher operating temperatures of stack, and smaller radiators and cooling systems).

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

- This project seems critically important as it not only moves toward DOE Hydrogen and Fuel Cells Program (Program) goals but also helps assess and define those goals.
- The project fully supports the Systems Analysis sub-program's mission of integrated analysis in support of various FCTO efforts for optimization purposes.
- The relevance is essential in guiding DOE activities for FCEV performance improvement.
- The project has a very important analysis and vehicle design question to address.

- This project helps to define whether the targets and objectives in the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan are even worth achieving by trading the direct benefits versus the other impacts on parts of the vehicle or system.
- A tradeoff analysis (planned for fiscal year 2017) should be used to provide guidance to technical programs and should be used in assessing overall technical progress. Allowable cost can be used to help screen projects and tradeoff analysis can be used to optimize system configuration in assessing overall program status (e.g., total cost of ownership).

Question 5: Proposed future work

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

- The future work seems to address several of the gaps the reviewer identified in the completed work so far.
- The proposed work is necessary. For example, the impact of hydrogen prices and the tradeoff between efficiency and increased cost needs to be better ascertained.
- Plans through the end of project look good. It is important that the final report and tools be useful to FCTO teams.
- The project ends in two months and only has a few validation steps left.
- The proposed future work is fine but this type of modeling could be used to address a broader range of interesting questions. If vehicles are to be subsidized, such as through a “feebate” system that rewards high fuel economy and penalizes low fuel economy, it is not clear what types of vehicles would be “optimal.” The effect of a carbon price signal is not clear. If vehicle ownership structures change and these vehicles belong to pools of vehicles that drive many more VMT per year than an average vehicle today, it is not clear what the affect would be. Each of these issues could be informed by this type of modeling.
- Sensitivity analysis parameter selection may stand to benefit from expert insight.
- It is essential to bring in external experts. It would have been better to bring them in at the beginning of the project.

Project strengths:

- The strengths are in combining the available systems-level modeling tools and existing target assumptions to analyze tradeoffs in weight, cost, and efficiency on life-cycle cost.
- Exploration of the design space available to FCEV engineers and the customer-based impacts of those decisions is an important perspective to have. The fact that this project provides an analysis from that perspective is its greatest strength.
- The systems approach and ability to assess cost tradeoffs in applying (or not applying) technical solutions are project strengths.
- Project strengths include the consistency of approach and is a good project goal.
- The project team and model are the same ones used on relevant EERE target-setting and GPRA analyses.
- The project leverages a good peer-reviewed model.

Project weaknesses:

- No major weaknesses are noted.
- The reviewer has no comments on project weaknesses at this time.
- There are no weaknesses, but the General Computational Tool may not be known to some in the audience and may deserve a brief description.
- The project could be broadened to address wider-ranging policy and market questions.
- The project needs more expert insight and industry competitive perspective.
- The presentation of materials needs to be simplified. Assumptions need to be made explicit.

Recommendations for additions/deletions to project scope:

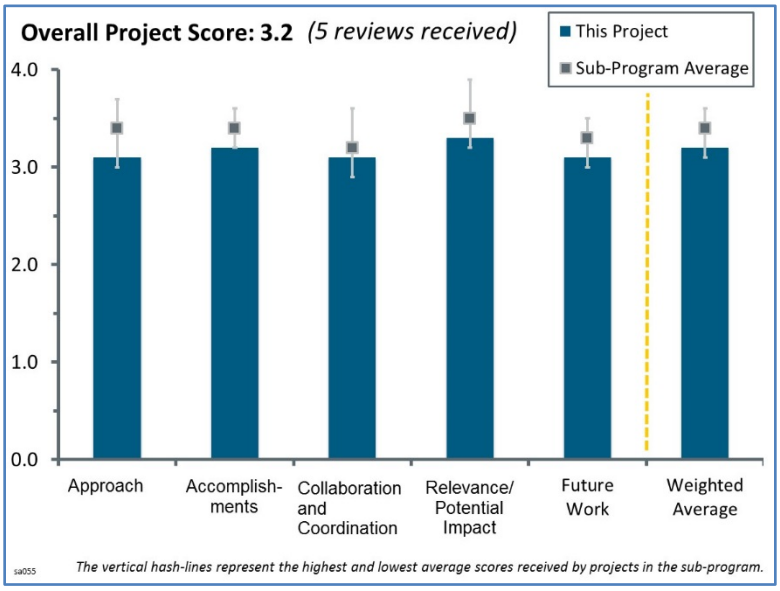
- In another project review, there was a comment that this project could help answer, or at least provide a stepping stone toward answering: a question regarding the cost-benefit effects of reducing platinum loading, at least in terms of the driver's total cost of ownership, as lower platinum loading may require higher purity hydrogen to ensure performance. A lower level of platinum represents a cost savings on a vehicle purchase price, but a higher purity requirement may add an incremental cost increase to operational fuel costs. It is unknown what would be the optimal point from the driver's perspective. This is important to understand: reducing component cost (a goal of the Program) should not result in increasing total cost of ownership. This project seems like it could be used to address a specific question such as this.
- It would be nice to see cost scenarios/tradeoffs incorporated into a single assessment tool with an intuitive user interface.
- A similar analysis would be highly worthwhile for related technologies where the targets exist at this level of detail.
- The project team should consider bringing in expert input external to ANL as soon as possible to improve framing and scope of analysis.

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 **3.1** for its approach.

- This work is taking an excellent approach to overcome the barriers associated with future market behaviors on fuel cell electric vehicles (FCEVs) and inconsistent data by performing system-level analyses leveraging well-established U.S. Department of Energy (DOE) sources, such as the MacroSystem Model (MSM); Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET); and Autonomie.
- The approach is generally good. The researchers are leveraging several other modeling efforts. There is some concern that they are comparing gasoline and other fuel prices with the levelized cost of hydrogen from the Hydrogen Analysis (H2A) model. The challenge with this approach is that gasoline and other fuel prices are set by the market, whereas the levelized cost does not include market considerations. It would be better if they provided a cost range.
- There is a very good team—including industry and public stakeholders—and good parameters are considered for modeling.
- The study team uses a rigorous approach using a set of well-developed models and analysis techniques to understand how different vehicle platforms might enter the market over time. A next step in strengthening the analysis would be to investigate how modeling and analysis assumptions affect the results. Sensitivities around such things as ownership time window (3 years versus 15 years), vehicle resale value, and consumer penalty for FCEVs would help better demonstrate the robustness of the results and show how sensitive the results are to analysis assumptions. More clarity is needed for the approach used for understanding how key parameters were arrived at by the study team. For instance, hydrogen fuel price is a key parameter used in the analysis. The presentation notes that hydrogen prices were taken from the MSM. The MSM is a modeling tool that allows users to exercise key DOE hydrogen and transportation models at the same time, including H2A, the Hydrogen Delivery Scenario Analysis Model (HDSAM), and GREET. It is not clear what input parameters and variances from the stock model reference cases were changed to develop hydrogen pricing. Stating that hydrogen pricing comes from the MSM does not provide enough transparency on how the study team developed hydrogen prices using the MSM tool.
- On slide 9, it says “Calibrated so national average price in 2015 is ~$12/kg.” It is not clear what parameters were used to perform this calibration or what type of dollars those are (nominal/real). It is not clear how this matches with prices seen in California’s commercial deployment. Slide 9 shows price drops from $12.00 to $6.25. As this chart spans 2050, it is important to state whether those are real or nominal dollars. It is not clear how the team arrived at $6.25. Slide 9 shows 50,000 kg/day units could serve neighboring states. The team may want to consider urban areas for better relevance of supply and demand estimation of number of units required.

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 was demonstrated this year, mainly on the areas around the 2050 hydrogen price projections based on natural gas and coal future prices as well as on the FCEV sales projections based on the analysis of market-driven hydrogen infrastructure.
- This project is progressing well, and the overall project framework is solid. The project is providing useful results, particularly in understanding how hydrogen FCEVs might enter the vehicle fleet over time in comparison to conventional internal combustion engine vehicles and other alternative vehicle platforms. Also, the ability of the ParaChoice model to highlight which parameters most affect vehicle adoption rates is very useful. It is unclear in some instances what was accomplished this year versus previous years. For instance, the business-as-usual sales fraction by vehicle type findings are important, but they were presented at the 2016 DOE Hydrogen and Fuel Cells Program (the Program) Annual Merit Review. Similar sales fraction analyses based on various levels of the Program's success would be an important addition.
- The sales comparisons are very interesting. For slide 15, a parametric analysis is used to predict hydrogen prices. This is very interesting. The only concern is the researchers are using projected coal and natural gas prices, which are generated based on current market prices, to compare a projected levelized cost, which is what H2A generates. It would be more accurate to say "2050 Pump Fuel Hydrogen Levelized Cost" rather than "Hydrogen Price." The projected penetration rates are very interesting. How the team vetted the numbers would be interesting to know. Given the current status of coal and the minimal development efforts in the United States for coal gasification, the projection of hydrogen from coal seems unlikely.
- Accomplishments are reasonably good. The team needs to include some realistic scenarios—particularly current higher growth of battery electric vehicles (BEVs) and emerging autonomous cars.
- Slide 11 shows a nice breakdown of total cost of ownership. The team should consider including BEVs with a 300-mile range (i.e., Tesla-type vehicles).

Question 3: Collaboration and coordination with other institutions

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

- The project has some very impressive unfunded partners. It needs to indicate how the partners provided reviews and inputs.
- Based on the interactions and collaborators listed, it seems that there is a good team and expertise available, although is not very clear what the contributions are from some of them, such as other national laboratories (Oak Ridge National Laboratory and the National Renewable Energy Laboratory) and Toyota, who is already entering the hydrogen FCEV market in California.
- The project leverages modeling capabilities and analysis efforts conducted for the Vehicle Technologies Office (VTO) and, based on that work, has collaborated with vehicle manufacturers such as Ford. The project would benefit from additional collaboration with FCEV and hydrogen fuel researchers and analysts. Such collaboration would yield improvements to the study approach and assumptions.
- The collaboration team is good. However, how the project benefits from them in the modeling and analysis should be explained.
- Collaboration could be improved by including technical reviewers from market leaders in FCEV development.

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 to DOE's Fuel Cell Technologies Office because it provides an excellent analysis by including vehicle, fuel (by several production pathways), and infrastructure in the mix, which may provide an indication of possible future market behavior for FCEVs.
- These parametric studies may be able to provide some guidance and direction to hydrogen and fuel cell stakeholders on direction of development.
- The project seeks to provide useful insight into how key parameters such as hydrogen fuel price and FCEV vehicle price affect how FCEVs enter the market and how penetration rates of FCEVs compare to other advanced technology vehicles over time.
- At-home refueling (AHR) would have substantial economic and practical disadvantages because it provides very low utilization and the highest cost on a per-capacity basis. An at-home refueler has only about one fueling per week. While it may be a practical way to test vehicles, AHR would reside at the most unfavorable economics in terms of utilization, economies of scale, and codes and standards (e.g., set back distances and insurance). It is not worth considering AHR in the analysis. It might be more realistic to look at some resource pooling, such as fueling at an office building or campus.
- Distributed hydrogen from on-site solar photovoltaics or hydrogen from tri-generation are excluded, but they may be worth considering.

Question 5: Proposed future work

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

- The future work on including AHR as well as extending the analysis to include fuel cells in the heavy-duty space are great additions to the current work being performed.
- The project should consider dropping AHR. Heavy-duty FCEVs may be a great opportunity for focus. Interstate traffic congregates in tight corridors, requiring one-dimensional infrastructure coverage (along the highways) as opposed to two-dimensional coverage (along cities). Also, the scale of heavy-duty vehicles will allow economies of scale.
- The future work plan for this project looks appropriate. The study team should (if not already planned) provide vehicle market penetration results over time for a hydrogen FCEV success scenario, in addition to the baseline scenario results that have already been completed. It would be more appropriate in fiscal year 2018 to investigate uncertainty and sensitivity cases around passenger FCEVs to better understand the robustness of the findings than to begin work on heavy-duty FCEVs.
- The project team needs to identify preferred ways to make stations more competitive.

Project strengths:

- This project provides an important analysis of how FCEVs might enter the vehicle fleet and compete with other alternative vehicle platforms. The ParaChoice model helps show which vehicle/fuel parameters most affect the ability of FCEVs to penetrate the vehicle market.
- The project encompasses a wide consideration of competing technologies.
- The DOE sources and models used for the baseline of the work are project strengths.
- The project team is excellent.

Project weaknesses:

- The project needs more analysis to test out uncertainties, analysis assumptions, and the Program research and development (R&D) success cases would strengthen the overall analysis. For instance, investigating the response of FCEVs if no (inconvenience) penalties are assessed in the analysis, or where penalties are reduced to zero over time, would be important for understanding how great an effect that analysis

assumption has on the results. Similarly, analyzing consumer costs over a full 15-year vehicle lifetime or providing for a vehicle resale value assumption for the three-year analysis case are warranted.
- The project needs to benefit from the project team feedback—its latest experience.

Recommendations for additions/deletions to project scope:

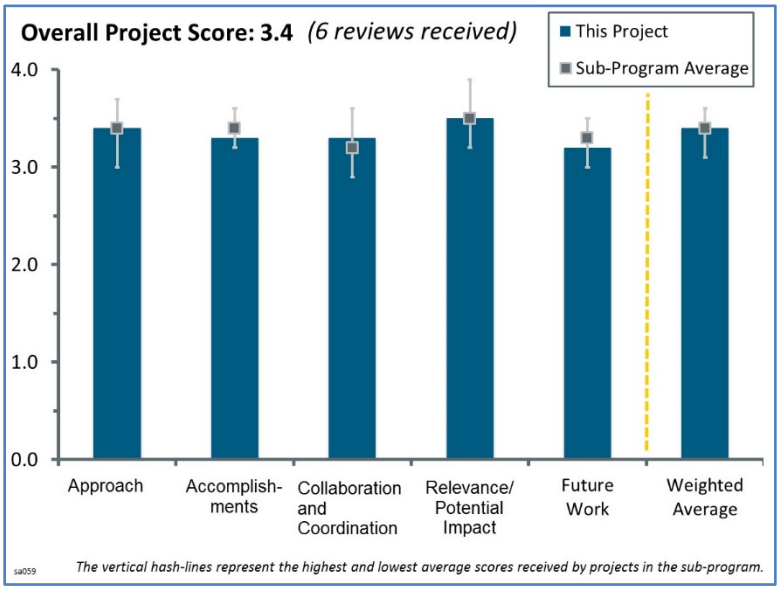
- The project team should make sure to include responses to reviewer comments. They did not seem to be in the presentation this year.
- Completing an analysis of a FCEV and hydrogen fuel R&D success case is a critical addition. Also, additional analysis of uncertainties, modeling assumptions, and sensitivities would provide insight into the robustness of the results.
- There is a good plan.

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

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 **3.4** for its approach.

- Integrating the individual models together to create a single system that can provide a sustainability assessment is a significant benefit to the Hydrogen and Fuel Cells Program (the Program). This will allow a user to answer multiple questions relative to fuel cell vehicles and hydrogen. The only concern is that it is not clear what the final model will look like when the project is done, and what possible inputs and outputs would be. In the future, this should be clarified.
- Integration of the various models better facilitates industry use of the various U.S. Department of Energy (DOE)-sponsored models. The link of GREET and SERA is an outstanding connection.
- This project has a good approach with good collaborative efforts and incorporation of project partners' expertise.
- The project demonstrates good integration of existing data sets and models. It would be good to see an organized, consistent set of output metrics for sustainability that could be used to increase the utility of the tool(s) for a broad audience.
- This work builds upon some other models.
    - The team reinvents information that is available. For example, Argonne National Laboratory (ANL) is doing water analysis, and this project is doing water analysis. Since the ANL analysis is more advanced, this project should incorporate ANL's analysis rather than do its own.
    - The team is including several technologies that are not relevant or at least are not being developed by DOE and, to the reviewer's knowledge, by industry. For example, the team is using biomass gasification for hydrogen production. The Bioenergy Technologies Office program has essentially stopped researching this area. It would be better to use something like pyrolysis or hydrothermal liquefaction oil reforming.
    - The use of the Automotive Deployment Options Projection Tool (ADOPT) and FastSim is a good approach.
- The integrated assessment framework leverages key models such as SERA, GREET, and the Environmental Protection Agency's well-known models.

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

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

- Progress is commensurate with time and spending; the case study results, the EV400 and fuel cell electric vehicle (FCEV) assessment, etc. were illustrative of good progress.
- The project's accomplishments are very beneficial. The project team needs further work in describing the accomplishments to a wider audience. There is too much detail in the accomplishments. The team should describe how the accomplishment is progressing toward a larger goal and why that accomplishment is important. The actual details of the accomplishment or how the accomplishment was achieved should be emphasized less.
- The project's analytical results are very useful and encouraging.
- The project's progress appears to be on track for the timeline.
- The water analysis work is duplicative of what ANL is doing, and ANL is further along in the analysis. The team should use ANL's analysis and use the saved funds for other areas. The regional supply of hydrogen is also being done on another project. The team really should coordinate with that work to prevent duplicative efforts. The team chose a biomass gasification pathway, which is not a good pathway. The project really should use something like pyrolysis oil or hydrothermal liquefaction oil reforming. It is presumed that ADOPT uses hydrogen price in its decision-making process. The project is using the Hydrogen Analysis (H2A) model for the hydrogen levelized cost. This hydrogen cost is not a price. Price is set by the market. The project should use hydrogen market prices and not H2A. If H2A is used, the researchers need to give a range. It is not really meant to project prices. ANL is in the process of updating GREET. The project should get the updated version of GREET, as the changes in the emissions GREET is calculating are substantial. At a minimum, the researchers should point out that they are using a levelized cost. This is especially important because the gasoline and other fuels have market-based prices.
- Although the slides claim that 63 indicators were identified in the literature and down-selected, it is not clear which ones were selected, how the selection process was done, and why the particular ones were selected. The team offered no clear path as to what they were trying to accomplish and when they are going to arrive. The goal should be to have the model be compatible with existing sustainability frameworks. It was not clear how or if that is being done.

Question 3: Collaboration and coordination with other institutions

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

- The steering team includes a major FCEV manufacturer that is also a world leader in conventional and hybrid electric vehicles, the Institute for Sustainable Infrastructure—a world leader in sustainability ratings—and others.
- The project has excellent collaboration and coordination with proper institutions.
- The project's stakeholder involvement appears to be good.
- The team is collaborating with ANL for the GREET model. Therefore, the team should use the updated version of GREET and use ANL's water analysis work. The steering committee looks impressive, but it is not clear what direction the steering committee has provided.
- Industry participants are interested in this information. Toyota makes cars, not stations. It is unclear why there are no fuel providers collaborating in this effort.
- It would be good to describe what the project steering committee is doing for the team and how the team is using the committee's input and incorporating it into the approach.

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 is developing an evaluation tool that can help the Program show the sustainability of its technologies to decision makers and major stakeholders in a timely manner—when commercialization starts to pick up.
- This project fits well within the system analysis in evaluating technologies and pathways, including resource and infrastructure issues, guiding the selection of research, development, and demonstration (RD&D) projects, and estimating the potential value of RD&D efforts.
- The project is fundamentally relevant since it addresses environmental and economic sustainability.
- The work is very relevant and has potentially very good impact.
- The project's lack of broader industry collaboration is challenging the impact of this work.

Question 5: Proposed future work

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

- The proposed work is needed for the Program to have a good sustainability assessment capability, because the identified model integration and data updates will support the results defensibility.
- The team seems more interested in accomplishing technical objectives than making it relevant and useful. There must be a balance between science and education/outreach. This team should dedicate more time to education and outreach. The objective should be "additional steering team members *will* be added."
- The team should work with ANL to integrate the latest version of GREET into the system. The researchers should include ANL's water analysis rather than spend precious time and budget on performing their own.
- It is not clear what it means to "increase relevance to stakeholders by aligning with corporate practices." As described in future work, an important step forward is to automate the integration of simulation platforms and to demonstrate a comprehensive set of pathways.
- Future work appears to be needed but must stay focused on utility and ease of use for broad use and acceptance.
- The project's proposed work builds on good results, but further analysis is warranted.

Project strengths:

- The ability to tie the total cost of such things as water, carbon, system economics, and health to specific vehicles, hydrogen production approaches, and locations is critical to understanding the benefits and challenges of hydrogen and fuel cells. This project combines models together to answer multiple questions with the analysis they each provide. This will result in greater utility for the models already developed and expand their capabilities.
- Project strengths include inherent relevance and progress being made, given the complexity of the issue.
- The integration of complementary capabilities and data sources is the project's major strength.
- This project provides a much-needed analysis for the Program. The steering committee is good.
- This is very relevant and necessary work.
- The project team is the strength.

Project weaknesses:

- While there is no identifiable weakness at this time, the team should attempt to ensure the timely updating of results from the diverse models and projects whose funding may fluctuate in the future.
- This project duplicates the work being done on other projects. Where there is duplication, this project should stop its work and use the work being done by others. The team should not be considering biomass gasification for hydrogen production.

- It would be good to know how case studies are chosen, especially since it appears they are being used as a validation tool.
- One challenge is understanding the capabilities, inputs, and outputs of the model when it is complete and the steps that will be taken to get there.
- Input from operating experience and realistic initial data will improve the value of the analysis.
- The project has a lack of broad industry involvement and a means to provide feedback.

Recommendations for additions/deletions to project scope:

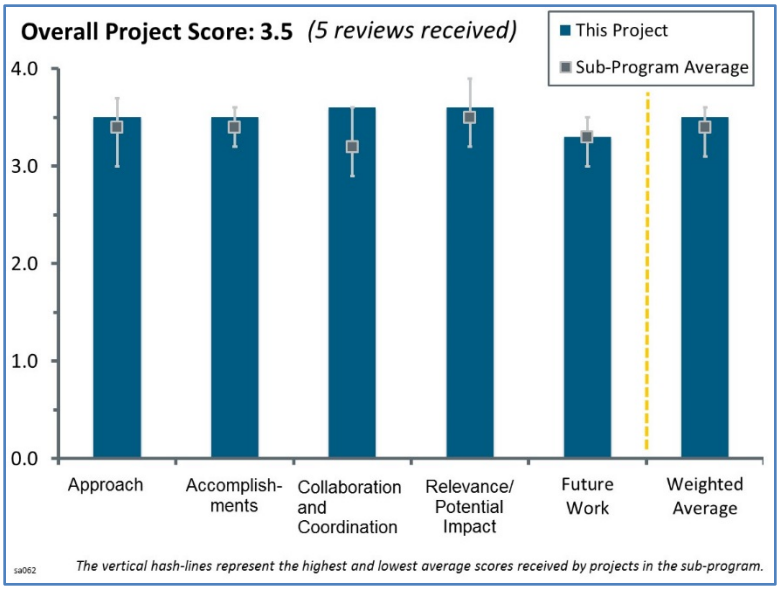
- Societal value and monetization of FCEVs is very important. This is a good start toward that. Continued efforts in this arena are needed for long-term sustainability.
- Framework output needs to be considered and optimized.

Project #SA-062: Hydrogen Financial Analysis Scenario Tool (H2FAST) Updates with Analysis of 101st Station

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 **3.5** for its approach.

- The team has taken an excellent approach by employing very comprehensive models in addition to the risk analysis studies, which will serve as an enabler for the deployment of hydrogen infrastructure.
- The clear value and benefits of H2FAST are demonstrated. Industry collaboration demonstrates clear use of the model for informing current network development and planning.
- The project has a very good integration/utilization of available resources and models.
- The project has a very consistent and comprehensive approach and a good team.
- The project's work is progressing well, and the accomplishments are in line with what is expected of the model. Last year, the project was asked to provide additional outreach to socialize the software, but efforts to get this done were not seen in the presentation. It is important that the software is used by more than just a handful of stakeholders.

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

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

- Cost analysis is critical to the success of advanced vehicles and associated infrastructure. It is necessary to know where research can best be used to improve technology and lower cost, and how cost compares in various areas in the country as a whole.
- Excellent accomplishments have been achieved on this project, mainly by incorporating H2FAST into the Scenario Evaluation, Regionalization, and Analysis model, as well as its use to evaluate real-world stations.
- The team's financial model strategy and parameters are very realistic and useful. Results can be used for commercial purposes for hydrogen stations.
- Each year the project determines new means for adding value to the analysis.
- The project's accomplishments are appropriate; however, it is important to socialize this software more to get additional exposure outside of just a handful of stakeholders.

Question 3: Collaboration and coordination with other institutions

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

- Excellent collaboration with other entities to include government agencies, such as the Fuel Cell Technologies Office, the California Energy Commission, and industry partners through H2USA.
- The project has excellent collaboration with multiple institutions having a significant role in financial analysis. In addition, the project utilizes several models to provide a fully integrated assessment.
- This project is well known and well connected to ongoing industry and policy initiatives.
- The National Renewable Energy Laboratory team and collaboration team are excellent and well qualified.
- Coordination with outside stakeholders is appropriate to build the model and get it to run appropriately. However, the team needs to communicate with users to understand who they are, how they are using the model, what features are more useful, and what can be improved. Customer feedback is essential.

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

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

- This project is very relevant, as H2FAST will help to provide investors and policymakers with a very comprehensive financial analysis, which will serve as an enabler to the initial rollout of hydrogen infrastructure.
- Financial analysis of various pathways/technology options provides a focus for effective research to best lower costs.
- The growth of stations and making them commercially viable is critical now. This effort is extremely valuable.
- As others have mentioned in previous years, industry will use in-house models to make investment decisions. At this point, it is not necessary to continue to invest resources in the model to improve it. The team should figure out whether customers find it useful and continue to socialize it.
- Beyond internal modeling, H2FAST provides key insights to much of the current station network development. Since site locations contain many variables beyond the H2FAST model, the actual network development is not clearly correlated to the model predictions.

Question 5: Proposed future work

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

- The project ends September 2017. The completion of planned work through then should provide an effective analysis tool.
- The proposed addition of fixed operating cost will be a great feature, which will further enhance H2FAST.
- The project's regionalization is okay, but it is not really necessary if the user can enter project-specific assumptions, which is already the case. It is a feature that is nice to have, but it is unnecessary. In addition, refining other assumptions is similarly good to have, but is also unnecessary since the user can specify those values.
- For California stations, 50 c/kWh cost seems to be unrealistic, but it was unclear why this estimate was so high. The team should check this estimate and identify solutions for peak hours, perhaps via energy storage. The team should examine the per kilowatt-hour costs of producing its own hydrogen polymer electrolyte membrane power. The project has a very nice work plan.
- The future work should focus on the various station sizes; specifically, the impact of substantial investments in hydrogen supply (liquefaction vs. pipeline). Connection to other models will be critical.

Project strengths:

- The project has a thorough use of existing models and extensive collaborations. A critical objective is to address re-implementation of advanced vehicles and research needs to lower costs.
- The project has a robust model framework, including a knowledgeable team and collaborations with experts.
- The project's team is very strong and suited for the modeling needed for 101st station.
- The great expertise provided by the principal investigator is a project strength.
- The project is very relevant and very useful.

Project weaknesses:

- There are no project weaknesses of significance, except that many assumptions are needed in such an effort. Thus, it is inherently challenging to provide firm financial forecasts.
- The project can operate in isolation far from the users. Better outreach and "customer experience" is needed. The senior leaders of industry are not the users of the model. The project team should use these connections to "dig deeper" into the industry organization to speak directly with the engineers and business analysts using this tool.
- One project weakness is the lack of outreach soliciting customer feedback.
- The project needs to develop scenarios that demonstrate profitable use cases.

Recommendations for additions/deletions to project scope:

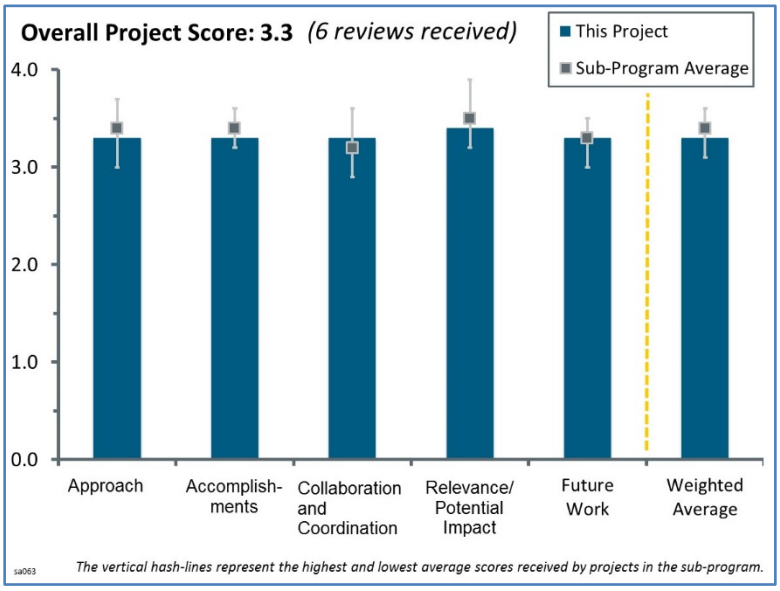
- The team should spend more time socializing the model and making it useful to potential investors. There is no need to fine-tune assumptions if the model is flexible enough to accept user input.
- The team should use the model to validate cost estimates for high-capacity stations. The project has a good plan.

Project #SA-063: Regional Supply of Hydrogen

Marc Melaina; 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 market demand, simulates regional supply chain network dynamics, and incorporates market competition considerations.



Question 1: Approach to performing the work

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

- The researchers have shown an excellent approach, as they are building the work on a very strong and well-established tool: Scenario Evaluation, Regionalization, and Analysis (SERA). In addition, they are incorporating other key elements, such as economic drivers and market competition, for very comprehensive work.
- The project has taken a good approach to addressing the relevant questions and problems identified. By considering "semi-central" production along with compression, the investigators may have identified a new low-cost option for delivery and fueling.
- The key to understanding the infrastructure challenges and the real costs that will be incurred in transportation is the modeling of the existing hydrogen capacity and surrounding radius for delivery and where hydrogen will be used.
- This project's much-needed study objective is well integrated with other related efforts to understand/optimize regional hydrogen provision for fuel cell electric vehicles (FCEVs).
- The team is using the Hydrogen Analysis (H2A) model to project the price. H2A generates a levelized cost and not a price. The price is set by the market. The team should use a levelized cost range in its analysis to compensate.
    - The team spent a lot of effort looking for hydrogen production numbers, when this information is available on the Hydrogen Analysis Resource Center (HyARC) website, which is now located on H2Tools.org. Other projects that were doing regional analysis used this data.
- The project approach is adequate. However, in the end, production networks will develop based on market conditions, including regulatory requirements, available incentives, and ease of permitting and resource availability, including land for pipelines. These considerations are not yet part of the model.

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

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

- Setting up an accurate model for distribution is a large and complex task, which was done well in this project. The project shows the stress points geographically as hydrogen needs increase based on current production. One aspect that was not that clear was how "emerging" technologies were simulated at a centralized scale, given the huge extrapolations that would be required.

- Excellent accomplishments have been made, even on a limited budget. The accomplishments center mainly around the development of the modeling framework for semi-central production, which could serve as a near-term option for regional hydrogen supply.
- The team has made excellent progress towards the objectives, especially given the limited budget.
- The results are good for the level of funding allocated to the project.
- The findings reported so far are fairly obvious. Given the large refining capacity in the South and West, it is not surprising that those regions will have some capacity. Given the agricultural need for fertilizer and given the oil shale in the Midwest, it is not surprising that this area will not have a lot of stress. Finally, given that the Northeast has little in terms of refineries, less demand for fertilizer, and less oil shale, it would make sense that it will be the least stressed.
    - The pipeline rollout scenario of short pipelines seems unlikely. It is unclear that the cost in terms of time to gain permits and litigation fees is not included. It may take years to get the permits in place to put in a pipe and permission to actually start the installation. In this case, it is unclear why the team would do it for only a short couple-mile segments. Use of a natural gas pipeline is okay, but authorities having jurisdiction and the average person are used to natural gas. However, they are not used to hydrogen, which will cause concerns that result in delays, especially for installing a high-pressure line in the middle of a city.
    - The presenter did a good job talking with utilities about natural gas pipeline installation and about costs.
    - It is not clear that it will be utilities that put in hydrogen pipelines, which is assumed, at least in the discussions with the presenter.
- The project's progress is fine. The semi-central solution seems to be an interesting proposition to get hydrogen delivered at low cost. It is not clear how much the high-pressure pipeline would cost per mile, though. It seems that cost was calculated, but it cannot be compared against a traditional pipe with a 3-inch to 6-inch outside diameter.
    - The first and second objectives have not been met, and no information was presented to cover these topics. Nothing was seen in the presentation about calculating hypothetical excess capacity, which would have been interesting to review. Further, there was no information about how capacity expansion would happen to meet a growing demand for FCEVs.

Question 3: Collaboration and coordination with other institutions

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

- The team has strong collaboration with numerous other institutions using available resources including past learnings, existing models, and relevant expertise.
- The investigators have worked with non-DOE entities and used varied data sources to carry out the work.
- The team can give good information. The team seems to be California-specific, with both the California Energy Commission (CEC) and the California Air Resources Board (CARB). Representatives from the Northeast would have been good.
- Collaboration with the CEC and CARB is crucial, but there is a need for additional collaborations to make the effort a true nationwide endeavor. Adoption of the results for state planning purposes would deem the project successful; however, these collaborations have not been fully established. There is a need to have the semi-central dispensing model assessed by a pipeline company.
- It would seem that a more collaborative dialogue with the vehicle companies and strategies for consumer preferences would be helpful to better understand how infrastructure and vehicles can be better matched. It was not totally clear why the *Oil and Gas Journal* was viewed as a more credible source than actually interacting with industry. It may be viewed as a neutral source that can provide unattributed data, which should be emphasized.
- Collaborating with the H2A and Hydrogen Delivery Scenario Analysis Model (HDSAM) experts at Argonne National Laboratory is key for this analysis work. It would be valuable to obtain more details on the external reviews mentioned on the presentation.

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 analysis work is very relevant, as it addresses one of the Fuel Cell Technology Office's barriers in understanding future hydrogen market behavior. It will provide some guidance on how regional hydrogen supply, either centralized or semi-centralized, will have an impact on the demand and on the supply strategies.
- This project demonstrates a critical need; addressing how best to eventually provide hydrogen for all or most regions of the United States.
- If the "semi-central" production concept works out, it could have a large impact on the Hydrogen and Fuel Cells Program.
- Understanding the regional pipeline supply of hydrogen is important for DOE.
- The project could potentially help accelerate the introduction of additional hydrogen refueling stations, but it remains to be seen whether this project will remain purely as an academic exercise, or if it will actually be used to plan out expansion of hydrogen production and distribution networks. Collaboration and buy-in from regional planners is crucial to success.
- Understanding the different economic pathways and regional impacts is needed in collaboration with the vehicle companies to determine the most logical rollout strategy, as well as where to prioritize station deployment with distributed or centralized production.

Question 5: Proposed future work

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

- The proposed future work involves engagement with additional stakeholders and initiatives, which would tie the whole infrastructure story together.
- The incorporation of these concepts into the SERA model and full evaluation of total production and delivery costs is a good addition.
- The integration of the Hydrogen Regional Sustainability (HyReS) project, as well as the further opportunities with H2@ Scale, are very appropriate for the continuation of this work.
- The future work sounds like they are going to finish the model.
    - The team should include some form of validation. This could be a workshop or survey with industry and other stakeholders. They need to ensure there is a balanced participant list, and that one group, such as a state, does not have so much representation that it skews the results.
    - Other uses for hydrogen in addition to filling stations should be considered, especially if there is a pipeline present.
- Continuous updates and integrating results into other models is relevant. Integration of low-carbon fuel standard price signals and integration of non-FCEV markets are the most interesting next steps. It would be good to see additional collaborations with state and local officials to get their input and buy-in.
- The project team has a well-planned study with the right amount of consultation and use of existing resources at associated organizations. Plans for completion are focused correctly, but it is concerning that the budget will preclude sufficient future analysis.

Project strengths:

- The project team has done an excellent job planning, and it has accomplishments to date and plans for project completion with effective use of outside information and available models. In addition, the project has a strong list of proposed reviewers that includes the U.S. DRIVE Partnership Fuel Pathway Integration Technical Team.
- Project strengths include clear analysis of a complex infrastructure and demand system and consideration of several different models. The overall approach is sound and points out potential constraints and transition models.

- This analysis work is critical for understanding near-term and long-term future hydrogen supply strategies for the development of a cost-effective hydrogen infrastructure.
- The project builds on strong analytical experience and expertise. Identification of a novel production delivery scenario is a great development.
- The current SERA model is robust and is comprised of very comprehensive pathways and regional datasets.

Project weaknesses:

- There are no evident weaknesses, except there is a great budget needed for thorough completion.
- The project's compression model seemed a bit simplistic in transportation of high-pressure hydrogen. It is certainly true that centralized compression would save significant cost versus distributed compressors, but the capacity of the pipeline would be severely reduced, and the cost was only listed for the low-pressure option ($800/mile).
- This project has a difficulty of accessing business confidential data. This is always a problem in addressing commercial processes.
- The project does not address the hypothetical excess capacity question. It is unclear how semi-central gaseous hydrogen delivery compares with liquid hydrogen delivery pathways.
- The team needs to include some way of validating the work.

Recommendations for additions/deletions to project scope:

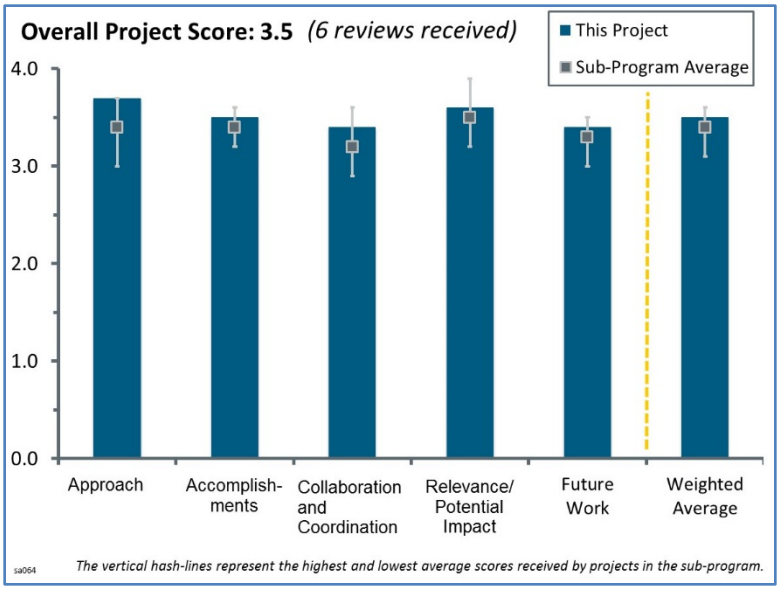
- The project's future work is well laid out. There are no recommendations for additional scope.
- The team should compare semi-central gaseous with liquid hydrogen delivery through the following:
    - Collaborate with state/local agencies to use SERA for planning purposes.
    - Have pipeline assumptions reviewed by a pipeline manufacturer/installer.
    - Assess the use of existing natural gas pipelines to move hydrogen molecules.
- The team should look into costs for pipelines in urban areas for semi-central scenarios.

Project #SA-064: Greenhouse Gas Emissions and Petroleum Use Reduction of Medium- and Heavy-Duty Trucks

Amgad Elgowainy; Argonne National Laboratory

Brief Summary of Project:

The objective of this project is to evaluate comparative petroleum use and air emissions of fuel cell electric vehicle (FCEV) technology and baseline diesel for diverse medium- and heavy-duty vehicles. A well-to-wheel accounting method is used to consider not only direct but also indirect emissions along the fuel supply chain. To conduct the analysis, the Greenhouse gases, Regulated Emissions, and Energy use in Transportation (GREET) model will be expanded to assess life-cycle petroleum use and air emissions of medium- and heavy-duty FCEVs compared to baseline diesel vehicles. The analysis is based on high-fidelity vehicle dynamic simulation, real-world idle fuel rates, and the most recent heavy-duty vehicle standards duty cycles.



Question 1: Approach to performing the work

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

- As noted in the presentation, the work is addressing a significant knowledge gap that currently exists in the FCEV industry. It is encouraging to see that significant effort was devoted to accurately assessing medium-duty vehicle (MDV) and heavy-duty vehicle (HDV) performance during idle engine operation, considering this is often the most pollutant-heavy operation mode of the vehicles, and it often occurs close to local communities. The use of the established GREET model is a good choice.
- It is good that analysis is assessed as an addition to GREET. The project effectively leverages past work. The project approach specifically answers the question of how much air pollution is reduced by fuel cell medium- and heavy-duty vehicles.
- The team uses results from the Fleet DNA Team at the National Renewable Energy Laboratory (NREL) and MDV and HDV components of Autonomie at Argonne National Laboratory (ANL) to improve on U.S. Environmental Protection Agency (EPA) modeling results. The nearly 500 vehicles in the Fleet DNA database provide a good source for selecting the appropriate data to use. The internally consistent Autonomie modeling approach enhances the results' credibility.
- This is a very thorough analysis of the emissions from a variety of vehicle types and original sources of fuels. It also ties to real-world data and fuel use to support the results.
- The project's approach is well-thought-out and addresses the key questions. Including the vehicle idling is extremely important in the applications the team is analyzing. The researchers should be clearer on how they estimated the fuel economy for baseline diesel and fuel cell medium- and heavy-duty vehicles. Simply stating that they used Autonomie to calculate it is not transparent.
- This project has a very nice combination of models and a strong team for collaborative analysis.

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

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

- The assessment of fuel economy for multiple drive cycles is a good contribution. Assessing the impact of idling fuel consumption/impact is also a good contribution. Quantification of petroleum fuel reduction and greenhouse gas emissions with use of fuel cell trucks is a key achievement. Overall, the project has good accomplishments, given the size of the budget.
- The preliminary results look very interesting and make a strong case for the emissions side on why this is of interest. It is unclear how the fuel cell and battery power selection were validated. The EPA/National Highway Traffic Safety Administration cycle is a good start, and it was good to hear the project will be looking at other drive cycles. The use of the improved GREET model in the analysis is well done.
- The analysis covered a broad range of duty cycles, vehicle types, and regions. The models demonstrate the benefit of different vehicle types across a range of hydrogen sources.
- This is a very good analysis using models and input from team members, including industry and laboratories.
- The project's progress is very good for the allocated budget.
- One concern is that expansion of GREET to include MDV and HDV was listed as an accomplishment. However, it was unclear if this referred more to the exploration of Autonomie and Fleet DNA and the eventual incorporation of those results into GREET, or if there was some other separate work that was done within GREET specifically. If it is the latter, there did not appear to be any discussion of the validation of those additions. Quantification of criteria air pollutants for medium- and heavy-duty hydrogen fuel applications is also a major accomplishment, as this previously presented a significant knowledge gap.

Question 3: Collaboration and coordination with other institutions

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

- Collaboration appears to have been a particular strength in this project's accomplishments so far. The one improvement that may be suggested is to find additional MDV and HDV manufacturers/system integrators to bring into the project. A single partner of this type may rely too heavily on a single market perspective.
- Leveraging of expertise of other groups, across vehicle types, was good. The description of each collaborator's role was clear. One element that might be missing is feedback from the vehicle companies, although the data collected from other consulting groups may already include that data.
- Pete Devlin (DOE Fuel Cell Technologies Office) has a drayage truck project. It would have been good to see collaboration with the industrial team developing those trucks. The industrial team could validate some of the performance assumptions.
- The collaboration with NREL, other ANL teams, industry, and university researchers is excellent.
- The interactions with other team members is very well organized and coordinated.
- The project has a good collaboration with the Autonomie team.

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

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

- This project will be critical for emphasizing the benefits of hydrogen-powered MDVs and HDVs, especially in communities that are disproportionately affected by heavy industrial activity. In addition, the work of this project can help policymakers and local air quality agencies make informed decisions to more appropriately gauge and target investments in hydrogen-powered vehicles and infrastructure in order to meet their air quality and climate change goals.

- MDVs and HDVs represent an important and under-investigated sector. They contribute a substantial percentage of emissions. Thus, they are worthy of study to assess the potential savings if converted to fuel cell vehicles.
- Comparison with real-world data provided visibility into accuracy of different models and important parameters to consider.
- There is growing interest in using fuel cells for medium-/heavy-duty trucking. Therefore, this analysis is very relevant and timely. It might be interesting to see how fuel cells for trains, such as metro, would fare.
- As light-duty vehicle fuel consumption begins to stabilize in future years, the rapid increase in petroleum consumption by the HDV and MDV segments justify this project's relevance and impact on the mission of the DOE Office of Energy Efficiency and Renewable Energy (EERE).
- The work is very relevant to DOE plans, as it leads to societal and economic benefits of FCEVs.

Question 5: Proposed future work

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

- The project has good plans that include consideration of battery-dominant fuel cell design strategies.
- The project's future work seems to be a logical extension of the existing program.
- The listed proposed future work is extensive and seems complete.
- The proposed work is highly relevant because it will use real-world duty cycles and provide a measure of uncertainty and variations in fuel economy as a function of operating conditions.
- The proposed work is built on good analysis so far; it is well coordinated with team members.
- The team is addressing the key problems.

Project strengths:

- The careful attention to accurate medium- and heavy-duty engine and fuel cell performance is a major strength of this project. In addition, the high degree of coordination with existing tools, and their own separate updates related to this project, is a necessary step for ensuring consistency across studies and data outputs going forward.
- The project makes comprehensive, methodical investigation of MDV/HDV emissions reductions possible with fuel cells. There is effective leverage of existing modeling platforms (GREET, Autonomie). The project has good collaboration and data collection from a variety of sources.
- The presentation as a whole was very informative and clear. The breakdown of the different results under different scenarios pointed out key points for specific conditions, such as idling or variation with season.
- This is a very well-designed and -executed project. The team has collaborators who can provide needed input.
- The use of well-known EERE-funded models and databases, and excellent collaboration and coordination among organizations, are major strengths.
- The project team is very strong and capable.

Project weaknesses:

- No significant weaknesses were noted.
- It appears that higher funding would, to a certain extent, allow more progress to be made in this highly relevant work.
- Adding health benefits from emissions reduction is critical in FCEV justification. It is not planned and, hence, not addressed.
- Validation of the power assumptions needs to be accomplished.
- There are no comments on project weaknesses at this time.

Recommendations for additions/deletions to project scope:

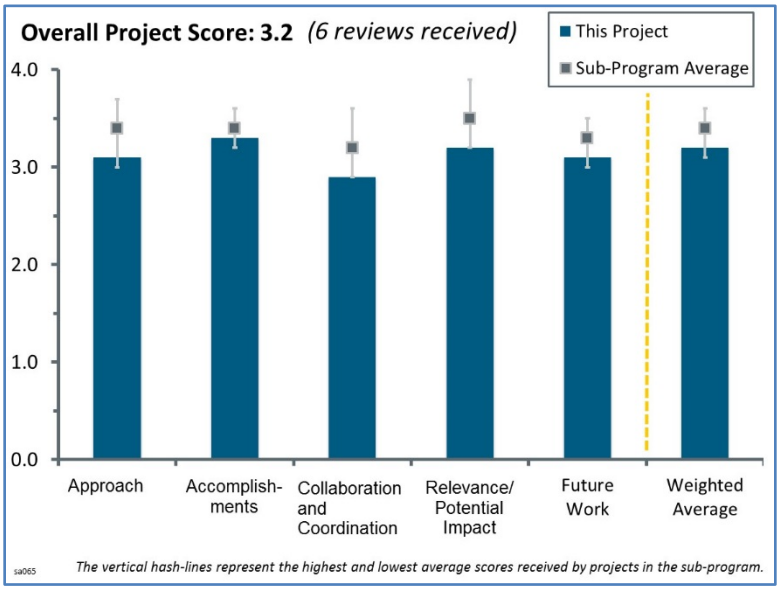
- It is recommended that battery-dominant architectures be considered to determine whether emission benefits differ substantively from those of fuel-cell-dominant architectures. The relatively high production of particulate matter $(PM)_{2.5}$ emissions due to steam methane reforming is not clear. Further clarification and explanation as to why these particulate emissions occur with a gaseous fuel would be of interest. In addition, future studies should consider whether these emissions could very easily be captured at the production plant.
- The project's work as proposed is very good.
- There is no additional scope recommendations beyond the planned future work.
- Considering the budget constraints, no recommendations are made now.

Project #SA-065: Agent-Based Modeling of Consumer Behavior

Marianne Mintz; Argonne National Laboratory

Brief Summary of Project:

This project explores the role of consumer choice in hydrogen technology adoption and infrastructure expansion and seeks to understand how the entire system might evolve through the decisions and behavior of individual actors. Existing agent-based models—which simulate the decisions and actions of individual players in the system—will be updated and extended with new data and lessons learned from vehicle and station owners in the Southern California market. Results of this work provide insight to other U.S. Department of Energy Fuel Cell Technologies Office analyses.



Question 1: Approach to performing the work

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

- The approach is based on previous work and appears to have been validated by the researcher continuing the work. The approach seeks to answer technically relevant solutions with a unique solution path. It will provide a very valuable balance to the "top-down" methods employed by other models.
- Agent-based modeling (ABM) is the right approach to gain additional insights that can help influence the deployment rate of new technologies and infrastructure.
- The project's overall concept is good and could provide needed insight into hydrogen fueling station network planning. However, as presented, there are several potential gaps in the input data knowledge base, and not really a definitive resolution determined yet for many of them. In addition to data issues already discussed in the presentation, others that may arise and were not discussed include:
    - The resolution, completeness, and degree of representation of consumer driving patterns, especially with geographical resolution
    - Seed points and resolution used for determination of station location by the infrastructure investment agents
    - Several of the key financial and business decision-making parameters, and metric values required to accurately simulate investor decisions
    - The method of quantifying inconvenience (not the translation into monetary values, but the actual factors and their quantitative metrics that are used to determine and quantitatively gauge inconvenience)
- The project's approach seems sound, but it is unclear to what degree sufficient data will be available to quantify some of the important feedback loops that have been identified. Many are real and important to the Hydrogen and Fuel Cells Program (the Program); however, if sufficient data are not available to tune the feedback loops, relative to each other, then this approach will result in only limited guidance for the Program.
- There is software available that does similar modeling of consumer behavior. It is unclear how this work differentiates from what is available. This work should be funded and done by industry. The comparison of only internal combustion engines (ICEs) and fuel cell electric vehicles (FCEVs) is too limited. There are a large number of existing and emerging technologies—hybrid electric vehicles (HEV), plug-in hybrid

electric vehicles, and battery electric vehicles, as well as compressed natural gas, diesel, and biofuel vehicles—that all could and should be included in this work to make it relevant.
- The project approach is good. However, it would be nice to work toward a tool that could be used by a wider audience to make economic, business, and policy decisions. In addition, it would be nice to see a validation step, such as using a historical case example to compare against actual empirical data (such as market growth).

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

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

- The project has not been in process for very long, but good first steps have been made. It is certainly worthwhile for the computing platform to be updated in order to take advantage of today's capabilities. Some of the collaborative work has started but does not seem to have progressed very far.
- This is just the beginning of the project. Therefore, the accomplishments to date are good but are relatively minor and theoretical. The accomplishments thus far do not yet reflect significant progress. For example, rather than a simple "refresh," the entire feedback loop structure of the model should be revisited and updated according to new conceptualizations of influences and relevant input data.
- This is early in the project, but it is almost a third complete.
- The project began in December 2016 and has not had much time. Considering this, progress is quite good.
- The accomplishments presented were reasonable, given the relative maturity of the current project.
- This project has been going for only a few months, and it has made acceptable progress in that time.

Question 3: Collaboration and coordination with other institutions

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

- The list of potential collaborators is complete and representative, although there was not yet a strong sense conveyed for how many are likely to eventually join the project. At the current moment, there is only one auto manufacturer collaborating, and this could be a significant problem for the project.
- At some point in the project, the collaboration network must be extended in such a way to collect feedback from the actual actors to be represented in the model. It will not be sufficient to collect feedback from just industry. For example, state agencies (other than California) and external investors (e.g., green banks) must also be included.
- The short time spent has not allowed for more significant collaboration, but the team intends to significantly increase its collaboration with appropriate entities in the near future.
- The project has an unnamed original equipment manufacturer. The researchers have plans for collaborating with others, but it is not clear if they have reached out to potential collaborators at this time.
- It was not clear that this project has made any attempts to develop collaborative partnerships with industry. Industry participation and collaboration, such as those identified in the presentation, are critical to relevance and accomplishment. The project team should have already started a steering committee or similar group to identify the correct industry contacts and relationships and begin the effort of collaboration with industry.

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

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

- This project is extremely relevant. The project risks relevance issues and not meeting its potential through a lack of involvement from industry leaders.
- This project could greatly inform several ongoing efforts to help forecast the needs of a developing fuel cell vehicle market and economy. The project approach is unique among the several other projects that have

been occurring to date, and it has a high chance of providing new information and insights into the station network development work currently ongoing across the United States.
- The model relies on data for fueling station costs, hydrogen prices, FCEV prices and performance, drivers' fueling preferences, etc. These are very relevant to the understanding of factors that affect deployment.
- The potential impact of this project is significant, but the presentation has not focused in on the types of outputs that will be adding significant value to the overall systems analysis suite of models. The goal of "understanding how the system works" is too vague and broad. It seems unlikely that the model will be able to do this. Rather, it may be possible to improve understanding of a few specific feedback loops that can be calibrated using actual empirical data. The "whole system" will be far too complex.
- This work should be funded and done by industry. It is not clear how this will aid DOE in technical development of hydrogen and fuel cells. This seems to primarily aid industry in decision making.

Question 5: Proposed future work

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

- Items proposed for future work are important and highly relevant but also very ambitious and somewhat duplicative with existing systems analysis projects. A more streamlined approach to accomplishing these tasks by leveraging existing capabilities, rather than starting from scratch, would be most welcome.
- Future work is good, but it would be good to see validation, work toward a usable tool, and impacts of disruptive technologies considered, such as on-demand rides (e.g., Uber and Lyft).
- Given that this is a new project, much of the entire project's work remains as future work to be done. The approach seems sound and the process logical. The one area that could perhaps be described in greater detail is exactly what form of output the project partners are expecting to provide, and what kinds of recommendations for eventual application of the work may eventually be evaluated and reported.
- The proposed future work is to update the team's old model with new algorithms that are now available. The team plans to include other vehicles beyond ICEs and FCEVs. If DOE continues funding this work, the team needs to get other industrial feedback for this work.
- The proposed work includes looking at smaller fueling stations that are more relevant for the near term. Note that future stations could increase in capacity as more FCEVs are on the road.
- The proposed future work satiates the wants and desires of the researchers toward improving the model, but it is unclear to what end or whether it is relevant. No part of the future plans includes the extremely difficult process of collaboration, particularly as industry leaders will certainly provide various and sometimes opposing recommendations. Making a model is easy, but collaborating with industry to make that model relevant is difficult. The project should not do just the easy stuff. The project has a lot of potential, but only if the team does the hard stuff as well.

Project strengths:

- The greatest strength of this project is its implementation of an approach to hydrogen fueling and fuel cell vehicle market forecasting that is not replicated in many other places. This confers a high possibility of new insights to the outcomes of the project. A second strength is the use of a prior model to essentially gain a "head start" on an effort that would typically include significant effort across computer program development, observational data-gathering, and market research.
- This is a very interesting model approach and one that provides a very robust method to simulate the various strategies of market competitors, both station providers and car manufacturers. The model also provides the time-based dynamic changes in the network, which are often missing from simple linear forecast models.
- The strengths are the (still quite novel) bottom-up approach based on user decisions. The presenter provided a good explanation of ABM and input variables.
- Understanding actors within a broader systems context is a good goal. The ABM approach should be able to inform this research question.
- The team uses a model that was built to address this kind of issue, albeit updating it is needed. The planned emphasis on working with other entities, if funded, will be very helpful in making the model more credible.
- The team has an old program that was used over a decade ago. The project does have an industrial partner.

Project weaknesses:

- A significant project weakness is the potential for a skewed market picture based only on the input of a single auto manufacturer collaborator. It is strongly suggested that the project engage a wider range of auto manufacturers to inform this project. It is readily known that each manufacturer has a different target market and audience for its product offerings, different strategies, and therefore different views of the market. While this work is not meant to be predictive, there may still be some bias introduced in review and interpretation of market effects with only one auto manufacturer collaborating.
- It would be good to see more on model validation (understandably difficult here) and to see more on output data sets and products available.
- There is other software that does similar analysis to what is being done, and what is proposed to be done, in this project. This is work that industry, not DOE, should be paying for. The project has a very limited number of technologies it is evaluating.
- It will be difficult to calibrate decision-maker preferences and systemic feedback loops with empirical data.
- The team has a lack of involvement from industry.

Recommendations for additions/deletions to project scope:

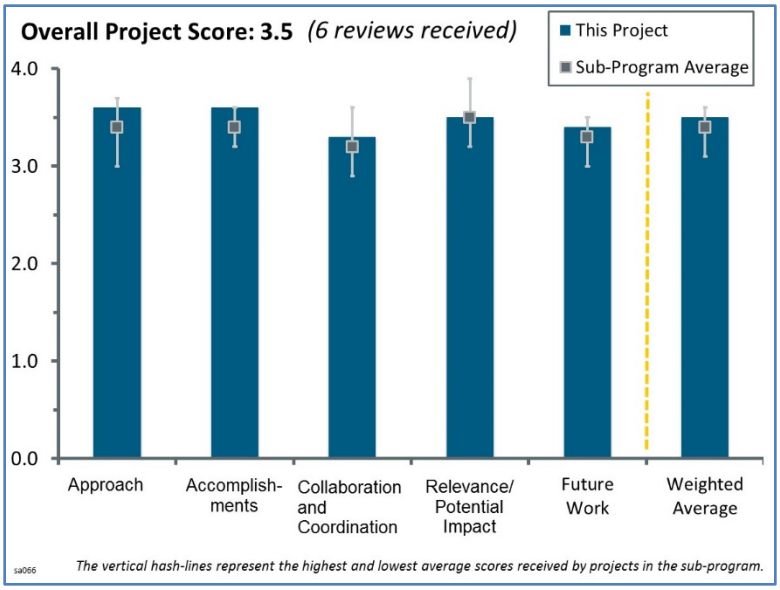
- It would be interesting to compare the insights of this model to the several other model outputs available through DOE and other entities' efforts, and to further compare these to the actual progress of hydrogen fueling network and fuel cell market development over time. A comparison of this type may provide insights to stakeholders on gaps or inconsistencies in their own understanding and forecasts of these two markets.
- The team should develop an effective tool for users to make economic, business, and policy decisions.
- Adding more FCEV types may not be a high priority in the near term.

Project #SA-066: Life-Cycle Analysis of Air Pollutant Emissions for Refinery and Hydrogen Production from Steam Methane Reforming

Amgad Elgowainy; Argonne National Laboratory

Brief Summary of Project:

The objective of this project is to provide life-cycle analysis (LCA) of air pollutant emissions for petroleum fuels and hydrogen production pathways. While fuel cell electric vehicles (FCEVs) have zero tailpipe emissions, there are upstream emissions resulting from hydrogen production, delivery, and compression. To conduct the analysis, emissions inventory and production data for petroleum refineries and steam methane reforming (SMR) hydrogen plants will be acquired, and emissions will be allocated to individual refinery products using flow schemes from linear programming (LP) modeling.



Question 1: Approach to performing the work

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

- This project takes a deeper dive into available data to improve the accuracy of the Greenhouse gases, Regulated Emissions, and Energy use in Transportation (GREET) model to provide life-cycle data on criteria air pollutants. Previous work used sparser secondary data on criteria pollutants to provide life-cycle air pollution estimates. The present study uses refinery data, LP modeling, and U.S. Environmental Protection Agency (EPA) emissions inventories to develop a robust set of data on refinery air pollution, which will improve GREET and enable better regional analysis. The project also takes a deeper dive into hydrogen production from SMR using emissions inventory data and national laboratory SMR facility data to more accurately develop combustion and non-combustion emissions factors for SMR production plants.
- The air pollutant data in GREET was outdated and is based on single point estimates. As criteria pollutants are becoming more relevant, it is necessary to have a better representation of their life cycle in transportation fuels. Argonne National Laboratory (ANL) is doing a good job of finding publically available information, cleaning up the data, and using an LP model to allocate emissions to different refinery products. There is very little room for improvement on this project.
- The use of the LP model to understand dynamics is excellent, especially with plans to expand the number of refineries beyond 11 to increase representativeness of input assumptions. The assumption to include only merchant plants is questionable; some future scenarios with high FCEV or other alternative fuel vehicle penetrations may result in reduced internal demand for hydrogen at the refineries. It is unclear what would happen to the refineries if total domestic gasoline demand declines. It is unclear whether some equipment would be repurposed. This would be scenario-dependent but is still worth examining, and probably not a major effort given the groundwork that has already been done for merchant plants. A corollary to this idea would be repurposing to refine biocrude. If that is worth pursuing analytically, repurposing for hydrogen should also be worthwhile.
- The project's approach is very good. The team used existing data available from DOE as well as industry surveys. It would seem that the EPA should have a lot of these data and have done a lot of this analysis. The team is trying to get data directly from industry rather than rely on inputs from others.
- This is a very nice study, just right in scope and level of detail.

- Use of LCA for this project's core objectives is definitely needed, and the insights the project is looking to create are important for industry and government to understand right now. However, there seemed to be some work that remains to be done with the presentation and interpretation of the data. While significant effort appears to have been put into the baseline emissions inventories and rectifying various sources, there still seems to be too few data available for statistical interpretation, especially considering the small number of data points that may exist in a single region. At least in the presentation, there also seemed to be something wrong with the presentation of the inner-quartile ranges on output emission factors. Therefore, it is difficult to really gauge their validity. Finally, the work as presently formulated seems to address only primary pollutant emissions (National Emissions Inventory, etc.) and does not include secondary pollutant formation. Thus, the total effect of SMR for hydrogen or petroleum is not yet captured for species such as particulate matter. Especially given that sulfur-containing species are also shown to be emitted, the potential secondary pollutant formations could be significant and would need to be accounted for in regional air quality planning.

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 results of this project are very significant.
    - The substantial decrease in the emissions in the new data compared to the previous version of GREET was very important. This implies that many analyses were overstating the emissions from refineries.
    - The efforts to get primary data sources were well worth the work since it improved the accuracy.
    - From the results, it is obvious that this is a much-needed update to the GREET model.
    - The team needs to increase the sample size to the smaller producers.
    - The team should weight the data from the source. For example, data from larger plants and refineries should count more than data from the smaller ones. The reason for this is to prevent a few small dirty sites from skewing the data.
    - It would be interesting if the project would include projections to improvements in the refineries and gas production units.
- The project team has successfully revised GREET modeling of criteria air pollutant emissions from refineries and from SMR-based hydrogen production facilities. Previous criteria air pollutant estimates within GREET were based on secondary data sources and less rigorous emission factor estimations. The work in this study greatly improves the accuracy of GREET results to better estimate criteria air pollutants, both from refinery operations (and hence conventional internal combustion engine vehicles [ICEVs]) and hydrogen SMR production, better reflecting current-technology hydrogen FCEV life-cycle criteria air emissions. Based on this, the project team was able to better estimate well-to-wheels (WTW) criteria air pollutant emissions of conventional ICEVs compared to FCEVs.
- The amount of work that has been accomplished so far is clearly large and important. This work will have far-reaching impacts, especially in helping state and local governments determine the needs for air quality improvement programs and realistic expectations of the impact that can be achieved through SMR-based hydrogen applications. The project adds some degree of collaboration with state and local agencies to ensure that the outcomes and data are the correct pieces of information and in a readily usable form for those jurisdictions to be able to answer the questions they are currently facing. Right now, the project does not make reference to this, which is likely to be one of the most important real-world outcomes of the work.
- It is great to have updated results based upon new data. There is some concern about what may be a "tail" of high emitters that are far from "average" emitters. Perhaps there are other data sources on ambient pollution near refineries that can be used as validation for the overall emissions from particular refineries.
- The project's progress is good. The team is ready to input 2014 datasets to calculate refinery emissions, and the additional SMR data are yielding more accurate/defensible results.
- While it is important to quantify comparative emissions regarding gasoline and SMR hydrogen FCEVs for the United States as a whole, it is clear that FCEVs are substantially better in cities/congested suburban areas. Since current SMR hydrogen production would presumably give way to eventual electrolysis, or bio-

based, or possibly SMR with carbon capture and sequestration, this component should be assigned to any future work.

Question 3: Collaboration and coordination with other institutions

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

- The project's collaboration and use of available information, models, and resources is excellent. However, the database is not always ideal with some information considered proprietary.
- The project would benefit from additional industry collaborations to vet criteria air pollutant emissions from refineries/SMR to ensure that data is still accurate within the uncertainty bands, given that public data has not been updated in a few years. Otherwise, collaborations have been appropriate.
- The team has some good collaborations with larger stakeholders. The project needs to increase the collaboration to get more information since the data is from a relatively small set of producers.
- This project was conducted by members of ANL's experienced GREET team, with input from consulting firms on refinery configurations and emissions, as well as national laboratory and industry researchers on SMR plants and process emissions.
- There is a significant gap from apparently not including state and local air quality management agencies as project partners. Industry and academia will likely have interest in the project outcomes, but government agencies are also likely to be major consumers of the data produced by this project. The perspective of the team's information needs related to this topic should be a high priority.
- There should be more data to draw comparisons, such as EPA regulatory data, case studies, and outlier 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 **3.5** for its relevance/potential impact.

- This project greatly expands data on criteria air emissions for refinery operations and hydrogen SMR production within GREET, improving the accuracy of GREET in presenting WTW emissions of criteria air pollutants for those pathways. This will enable much better evaluations of the local air pollutant emissions of conventional gasoline vehicles to hydrogen FCEVs in non-attainment areas, and in regions deploying zero-emissions vehicles (ZEVs). The updates to GREET also enable better regional analysis of local air pollutants.
- This project underscores fundamental reasons for the Hydrogen and Fuel Cells Program and has the potential to significantly inform several system-wide projects currently underway or potentially occurring in the future. In particular, the H2@ Scale work seems highly likely to benefit from this project, and any follow-on efforts that ensure emissions estimation for other hydrogen production methods are evaluated on an equivalent basis to what has been established by this project.
- As stated in the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan, one of the key benefits of hydrogen fuel cells is the reduction of air pollution. This project quantifies that benefit compared to the incumbent vehicle technology.
- This project provides a much-needed update to GREET.
- Refineries are a critical baseline comparison and source of hydrogen for early FCEV markets.
- SMR is likely the worst case in response to hydrogen generation emissions and is generally better than gasoline or certainly diesel. There is probably not much need to go further. Future lower CO_2 emissions generation processes should be better in response to air pollutants, with the possible exception of bio-based feedstocks.

Question 5: Proposed future work

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

- All proposed topics for future work are important and will add value. The project's scope of impact assessment activity should be defined more clearly. Bringing calculations all the way to damage costs on public health would be a significant effort, and perhaps only worthwhile if equivalent comparisons can also be made to competing alternative fuels.
- Proposed future activities are appropriate. Expanding the current work to incorporate data from the 2014 emissions inventory will help improve the accuracy and reliability of data incorporated into the GREET model. Assessing the variability of data and emissions by region will allow for important regional analyses using GREET, particularly the ability to analyze emissions occurring within air pollution attainment areas versus emissions within air pollution non-attainment areas.
- It is suggested that the next public release of GREET rely on more than just journals for review. An effort should be made to reach out to the ultimate end users, especially local and state agencies, and incorporate their comments as appropriate into the review process. The regionalization effort is definitely a good choice, although it may necessitate some broadening of the project scope to include air quality modeling, depending on the ultimate goals for how many factors the regionalized data seeks to account for.
- Future work presents logical steps: adding 2014 refinery data, assessing regional variability, and updating GREET. Publication of results in a peer-reviewed journal is an excellent way to document results.
- The future work seems logical and well-thought-out. The team should include some validation work.
- Minimal additional work is suggested. Comparative emissions are adequately addressed already, except for any future bio-based processes.

Project strengths:

- The potential impact and the current need for the data that this project is developing are particular strengths. In addition, the methodical approach of LCA is a good choice for developing this knowledge base. The project team seems well composed for accomplishing this task.
- Improving GREET data and GREET accuracy for local air pollutant emissions will enable critical evaluations of conventional ICEVs versus ZEVs such as FCEVs—particularly in non-attainment areas.
- Consistent treatment of the entire integrated refinery system is a strength. The LP model seems to provide significant value.
- The project demonstrates strong knowledge of the industry and the GREET model. The team is experienced staff.
- Overall, this is a nice study using available resources and collaboration effectively.

Project weaknesses:

- No weaknesses are evident except that not all emissions data are reasonably available.
- Additional data on new refineries, as proposed in Future Work, is important.
- The largest weakness for this project is the lack of air quality management agency input. More input could help guide the formulation of input and output data products from the project so that the outcomes have the maximum possible impact.
- The database is not comprehensive. It is to be hoped that the 2014 database will be better. Refinery complexity varies, which is not well represented in the results.

Recommendations for additions/deletions to project scope:

- The team should consider presenting results of the LP model either by process unit or by refinery type (refinery complexity makes a big difference in the allocation of emissions). Results of hydrogen FCEVs should be compared not only to gasoline but also to battery electric vehicles, hybrid electric vehicles, plug-in hybrid electric vehicles, and diesel vehicles.
- It would be important to examine refineries under other than business-as-usual conditions, for example, with a greater use of bio-crude or heavier fossil crudes. Alternatively, greater reliance on alternative fuels

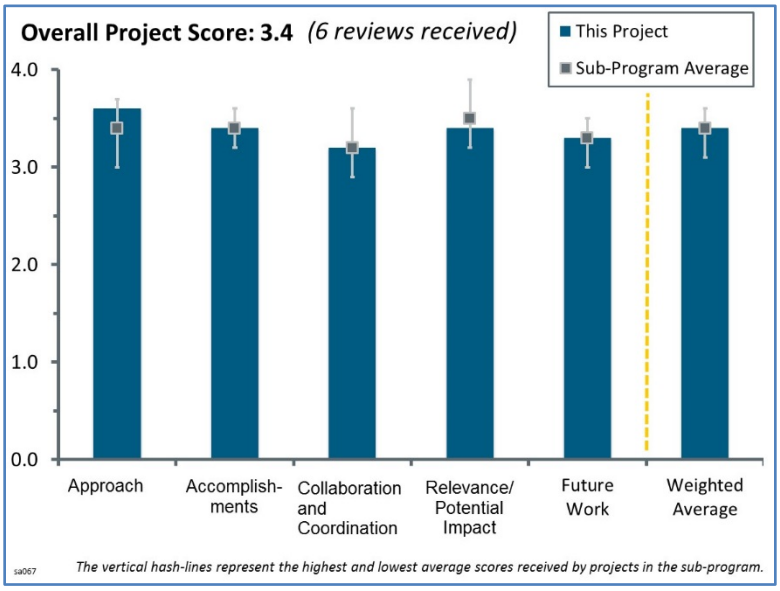
may reduce domestic demand for gasoline/diesel, but it is unclear how refineries might adapt. Perhaps they would export products, or perhaps more hydrogen production capacity could be freed up.

- The project scope seems well planned. The team might carefully consider how broad the modeling tools will need to be to truly capture all the possible information necessary for a regionalized analysis effort.
- It is suggested that the work not be pursued much further since conclusions are already adequate, unless bio-based generation becomes economically viable.

Project #SA-067: Resource Availability for Hydrogen Production

Marc Melaina; National Renewable Energy Laboratory

Brief Summary of Project:



This project seeks to provide insights into the long-term potential to develop a hydrogen infrastructure that is robust, resilient, and economically competitive by improving understanding of energy resource availability and diversity. Specific project tasks include (1) developing an estimate of hydrogen production required for potential future fuel cell electric vehicle (FCEV) demand; (2) updating estimates of hydrogen production potential from a wide range of energy resources, including natural gas, coal, uranium, biomass, wind, and solar; (3) comparing resource requirements for hydrogen to projected consumption in a future without significant FCEVs; and (4) determining resource availability spatially and on a per-kilogram-of-hydrogen basis.

Question 1: Approach to performing the work

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

- The approach is extremely valuable to industry and is the type of activity that is well suited to the national laboratories. The work is technically strong, and the approach ensures a clear start and end to the project objectives. The approach also outlines the integration of the new efforts to the existing network of models, along with clear collaboration and leveraging of ongoing co-collaborator models.
- The project is well designed to understand how supply chains may develop in different regions of the United States, depending on resource availability. The tie-in with SA-067 will make the information more usable and valuable. This update was important given the improvements in efficiency of photovoltaic, wind, and biomass technologies. The approach could be improved by including uncertainties.
- The approach was deemed excellent because it identifies a deployment scenario that is sufficient to evaluate the adequacy of resources for hydrogen, with updates to past resource estimates.
- The project is well designed. The project is reliant on, and makes effective use of, existing data from past National Renewable Energy Laboratory reports, H2@ Scale, and the United States Geological Survey (USGS).
- The investigator has used appropriate data, tools, and methods to address the problem.
- The project's basis for study is quite reasonable, but consideration should be given to relative cost and CO_2 emissions potentials of the various options.

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 has excellent progress from a technical aspect. It is not clear whether this project includes a steering committee or close partnerships, which would facilitate easy uptake of conclusions and guidance.
- This is a well-thought-out and -executed project. Consideration of availability of each individual resource is critical.

- The project's progress is excellent because the team has updated several major resources.
- The project has progressed well. It seems that most of the data have been gathered, and preliminary results are available. Once data are integrated into the Scenario Evaluation, Regionalization, and Analysis (SERA) tool, regionalization of the results will provide more useful information.
- Given the project budget, the investigator has done an excellent job of carrying out the tasks and producing a good product.
- The study itself is quite good using available resources, but it should include CO_2 emissions.

Question 3: Collaboration and coordination with other institutions

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

- Collaboration through the use of USGS data is clear. Collaboration with H2@ Scale is not clear. The collaboration slide suggests that only future results will be coordinated with the H2@ Scale project team, implying that formulation and execution of the project so far has not been coordinated. It is the same with USGS.
- Product efficiencies are key model parameters. Collaboration with industry to generate distributions for these parameters would be valuable.
- There is a strong consultation/interaction with other relevant institutions—a nice effort in this regard.
- The investigator has worked with various data sources to assemble the information needed to address the problem.
- Collaboration with USGS, Idaho National Laboratory, and H2@ Scale (planned) was deemed very good.
- The team's collaboration with industry could be much stronger.

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 supports Multi-Year Research, Development, and Demonstration Plan objectives quite well by factually collecting information and displaying it in a uniform format for a variety of resources. Cross-resource comparisons are not always easy, given the differing reporting metrics and conversion efficiencies. Creation of a transparent and referenceable study on resource availability will enable data use for a variety of needs and other studies.
- This update is definitely relevant to ensure that subsequent analyses such as H2@ Scale, SERA, and the Hydrogen Demand and Resource Analysis (HyDRA) are accurate.
- New fuels need to be evaluated with respect to supply potential. This project is very relevant because it gives a basis to address potential inquiries from stakeholders, particularly through SERA.
- The project has significant potential for significant impact. The project needs to ensure that industry and policy developers are co-collaborators to ensure strong policies are feasible for industry.
- The work clearly shows the availability of relevant resources for regional hydrogen production.
- The study is important in terms of assessing availability of hydrogen generation resources around the United States, but should differentiate resources better in terms of cost potential and CO_2 emissions.

Question 5: Proposed future work

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

- The proposed work was deemed to be excellent, with a planned report and other output through the SERA model.
- The extension of the work to include transportation is a good direction. It would be interesting to begin to site hydrogen production (biomass gasifiers, solar electrolysis, wind production, etc.) and to begin to look at a technoeconomic analysis (TEA) of producing and delivering hydrogen to market.

- The proposed future work is basically finishing the report and using the results in other models. Additional work could be done to improve the usability of the information, including the following:
    - Provide variability ranges for production efficiencies
    - Assess potential land use from different renewable resources
    - Consider likely availability of resources, given the regional resource mix and available transmission lines
- The proposed future work (assuming funding is available) is very reasonable, but it should address cost projections as well as CO_2 emissions.
- Feeding resource information into SERA is a good move.
- Future work should identify the industry uptake and education steps beyond the creation of a report or list of conclusions.

Project strengths:

- The project has a number of different strengths, including the following:
    - Availability of data: resource potential in 2040, given anticipated technology improvements
    - People resources: researchers involved in original studies are updating information
- This is a well-conceived and well-executed study. Identification of percent-resources needed for hydrogen production is a good metric.
- This project has strong analysis, expertise, and tools. In addition, the project has effective consolidation of data from multiple sources.
- This project is very relevant to the long-term planning and considerations by all hydrogen energy stakeholders.
- The project involves a good overall assessment using available data and working with other institutions with relevant expertise.
- The use of appropriate data sources and the format of the results outputs are the project's strengths.

Project weaknesses:

- There is a lack of economics. However, this was out of scope, and there certainly was not enough budget for it.
- The project has a lack of uncertainty assessments for resource potential and production efficiencies.
- The project should focus more on the relative cost of hydrogen generation options, as well as CO_2 emissions.
- The project lacks involvement from all stakeholders and industry in particular.

Recommendations for additions/deletions to project scope:

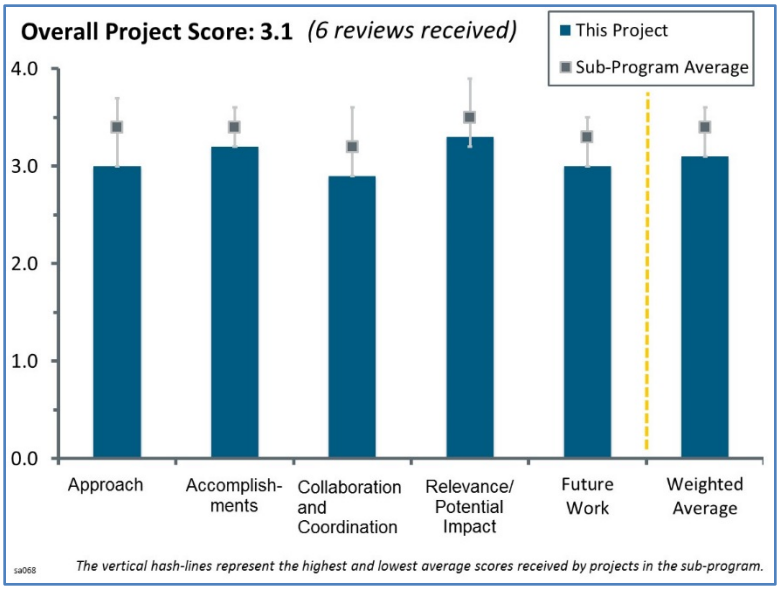
- Additional work could be done to improve the usability of the information, including the following:
    - Provide variability ranges for production efficiencies
    - Assess potential land use from different renewable resources
    - Consider likely availability of resources, given the regional resource mix and available transmission lines
- The hydrogen requirements for 50 million fuel cell vehicles is currently measured against each of the resources to assess the resources' ability to supply the demand. However, in reality, the demand will be met by multiple resources simultaneously. Thus, the project should consider how this split might be implemented.
- The project should add hydrogen production at appropriate locations and scales and begin TEA for production and transportation.
- There should be a greater focus on the relative cost of hydrogen generation options, as well as CO_2 emissions.

Project #SA-068: Benefits Analysis of Multi-Fuel/Vehicle Platforms with a Focus on Hydrogen Fuel Cell Electric Vehicles

Tom Stephens; Argonne National Laboratory

Brief Summary of Project:

This project seeks to estimate potential future benefits attributable to the Fuel Cell Technologies Office (FCTO) Hydrogen and Fuel Cells Program (the Program), including petroleum use reduction, greenhouse gas emissions reduction, market acceptance of fuel cell electric vehicles (FCEVs), and economic impacts. The analysis utilizes data, models, and tools from various national laboratories and other entities, and synergies and interactions with the Vehicle Technologies Office (VTO) activities are taken into account. Two scenarios—with or without successful deployment of Program and VTO technologies—will be compared.



Question 1: Approach to performing the work

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

- The approach to investigate the benefits of FCEVs and other advanced vehicle platforms (including greenhouse gas [GHG] emissions and petroleum use) considering a business-as-usual case and a Program research and development (R&D) success case is very good. The project uses the well-regarded and industry-vetted models, such as Autonomie and Sandia National Laboratories' ParaChoice, to assess vehicle stocks over time, as well as vehicle prices. Additional analysis sensitivity cases would be informative, particularly sensitivities around vehicle ownership (e.g., 3-year, 5-year, 15-year), vehicle resale value, and applied discount rate.
- The approach is sound. This project provides an understanding of the potential societal benefits of the VTO and FCTO activities' meeting their targets, both separately and together, using existing models to predict costs of driving, reduction in fuel expenditures, and FCEV market share. It was good to see these predictions provided for the FCTO only as well as FCTO and VTO combined.
- It is great to have combined results from multiple consumer choice models. Attribution of benefits to Program vs. industry is something that could perhaps be made more nuanced in future work. Significant work has been done to understand the technology innovation process—some of that theory, those data, and/or those case studies should be able to inform these types of analyses.
- The project's approach is reasonably good. Different types of FCEVs—truck vs. bus vs. car—make a big difference.
- FCEV technology was pulled into the market as a result of California's Zero Emissions Vehicle mandate to address air quality. The project should consider including quantification of air quality benefits as part of the analysis. According to the California Air Resources Board, approximately 6,000 premature deaths annually are attributed to air quality; nationwide, this number should be larger. The project should consider monetizing carbon dioxide emission reductions. On slide 9, if the dispensed costs are per gallon gasoline equivalent, the hydrogen costs look a bit low, unless we are considering a pipeline distribution system.
- The following comments apply to the project approach:
    - The use of the Hydrogen Analysis (H2A) model costs as a price input needs to be reviewed. H2A estimates a production cost based upon its many assumptions; it does not include taxes or profit margins. The price is set by the market. The project should use hydrogen market prices and not

H2A whenever possible. Also, H2A was meant to give an apples-to-apples comparison. It has many assumptions specific to H2A that may or may not be correct for each application and region of the country, and it estimates a cost subject to those assumptions.
  - It is not clear whether the delivery cost is included in the hydrogen price.
  - The 5-year ownership period is very short; the project team should consider a 10- or (better yet) 15-year ownership. At 5 years, there is a resale value, especially for the fuel cell and the batteries.
  - For the ownership cost, a range should be used. The error bars seem much too small, given the number of assumptions and the uncertainty in some of the technologies being examined.
  - It is not clear whether policies are being used to encourage or accelerate the adoption of the vehicles. If policies are being used, they need to be spelled out, and a justification for why the policy will stay in place for 30 or more years needs to be given.

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 made good progress on evaluating vehicle ownership costs, projected on-road vehicle stock by powertrain, and GHG emissions for both the business-as-usual and Program success scenarios. Once finalized, these results will help show the benefits of R&D into FCEVs.
- One of the most useful metrics demonstrated is that, if the DOE goals can be met, the levelized cost of driving for an FCEV will be on par with the other vehicle classes.
- The progress is reasonably good, though it is not clear how the collaborative efforts are ensuring the quality of analysis and conclusions.
- On slide 11, it seems that most of the development for this technology is being attributed to the Program. This may be understating the effort and development done by auto manufacturers, states, and other stakeholders. Generally, in the absence of DOE, international efforts would continue. In the long term, technological leadership and profits made from FCEVs will be realized outside the United States, which may be the more significant cost impact of the Program. Regarding slide 13, it may be good to frame the slide as "National Energy Security Benefits."
- If the projected on-road vehicle stock uses a 5-year ownership, then these numbers are questionable since most vehicles are on the road for 10–15 years. The petroleum savings are interesting; the researchers should consider including the work being done by Argonne National Laboratory (ANL) on medium- and heavy-duty trucks. It is not clear if they are using the most recent version of the Greenhouse gases, Regulated Emissions, and Energy use in Transportation (GREET) model with the improvements being developed by the other ANL team.
- The hydrogen price trend cited by the team seems very optimistic. It is nice to see attributions to FCTO specifically (slide 14), but it would be interesting to see how some VTO goals may also be helping improve the market competitiveness of FCEVs. Surely there are spillover effects that can be quantified and allocated to VTO targets using this same approach.

Question 3: Collaboration and coordination with other institutions

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

- The study team appears to have had appropriate collaboration with researchers from relevant national laboratories and consulting firms, particularly on the VTO side. It is not clear what level of collaboration the study team had with hydrogen and fuel cell vehicle researchers.
- The results have a stronger basis as a result of the project's using multiple laboratories to develop market share projections. The results would be further improved if other collaborators were used and credited for providing estimates of the fuel economy in the no-FCTO/VTO program case.
- Teaming with other national laboratories is very good. However, industry review for this work is extremely important. An industry advisory or steering committee is recommended.
- Greater scrutiny and vetting by industry could add value.

- The team may want to include an economics institute to help frame the economic benefits. It may be good to have a California entity for this, as they are at the leading edge and have the most forethought on the subject.
- The team should provide more information about how the collaborative efforts produced effective analysis and useful conclusions.

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

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

- This project provides information to decision makers as to the benefits of the FCTO and VTO to the development and acceptance of fuel cell vehicles.
- This project, once finalized, helps show the benefits that might accrue with continued R&D into hydrogen fuel cell vehicles.
- The purpose of the project is essential. However, the framing of the benefits could be improved. For example, the project needs to include air quality benefits, energy security impact from locally produced hydrogen, U.S. leadership in technology and manufacturing profits, and GHG emission reductions.
- This project will show the cumulative savings between the VTO and FCTO programs.
- It is important for the team to show market impacts and social benefits of FCTO R&D activities.
- Multifuel and impact-related goals and accomplishments are satisfactory but could be presented more clearly.

Question 5: Proposed future work

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

- The project's proposed future activities are appropriate. The study will benefit from investigating uncertainties and developing sensitivity cases, though the presentation provided little detail on what uncertainties and sensitivities might be investigated. Analysis of study assumptions such as vehicle life, resale value, and discount rate would be particularly useful.
- Evaluating the fuel prices and hydrogen availability will provide a better understanding of the impacts of FCTO and VTO on FCEVs. A large increase in fuel prices or expansion of the hydrogen infrastructure will further strengthen the results. In contrast, low fuel prices and a retarded growth in infrastructure may significantly reduce the FCTO/VTO benefit.
- Examining selective side cases is important, but the team really should consider enlisting some industry and stakeholder input on their approach, assumptions, and results. The team also needs to include the updated GREET models to better understand the emissions, and include fuel-cell-powered medium- and heavy-duty trucks.
- It is important for the project to expand the scope to include medium- and heavy-duty vehicles. However, a proposal to make the overall approach address the innovation process itself more directly would also be welcome.
- It would be helpful to benchmark projections against other studies to understand any differences and considerations.
- The work is almost complete, and no new work is expected.

Project strengths:

- The project's investigation of the benefits of FCEVs and other advanced vehicle platforms (including GHG emissions and petroleum use), considering both the business-as-usual case and a Program R&D success case, is very good.
- This is a very useful project in supporting the benefits of the FCTO to the government and the public.
- This is interesting work that is looking at an important problem. The team has the right tools to accomplish the project goals.

- The project enjoys good consistency across components and vehicle platforms.
- The project's analytical models include reasonable parameters for FCEV and electric vehicle benefits and GHGs.

Project weaknesses:

- The team should consider involving industry to validate the assumptions and results. The team should also update the GREET model.
- The project team should conduct more sensitivity analyses to evaluate the impact of study assumptions to understand the robustness of the study's findings.
- The project may have underestimated the possible impact of non-federal funding (including state and industry) on progress toward the goals.
- The project has a somewhat simplistic approach to innovation and allocation of benefits.
- The project's quantitative parametric analysis may be inadequate.

Recommendations for additions/deletions to project scope:

- The project should consider putting a price on the benefits relative to the cost of meeting these targets. Estimates of cost benefits to health, carbon production, and oil savings, for example, would be useful. Other projects in the Systems Analysis sub-program have done that.
- The project could add more material around different policy drivers and how those may or may not influence FCTO R&D outcomes.