2013 — Systems Analysis
Summary of Annual Merit Review of the Systems Analysis Program

Summary of Reviewer Comments on the Systems Analysis Program:

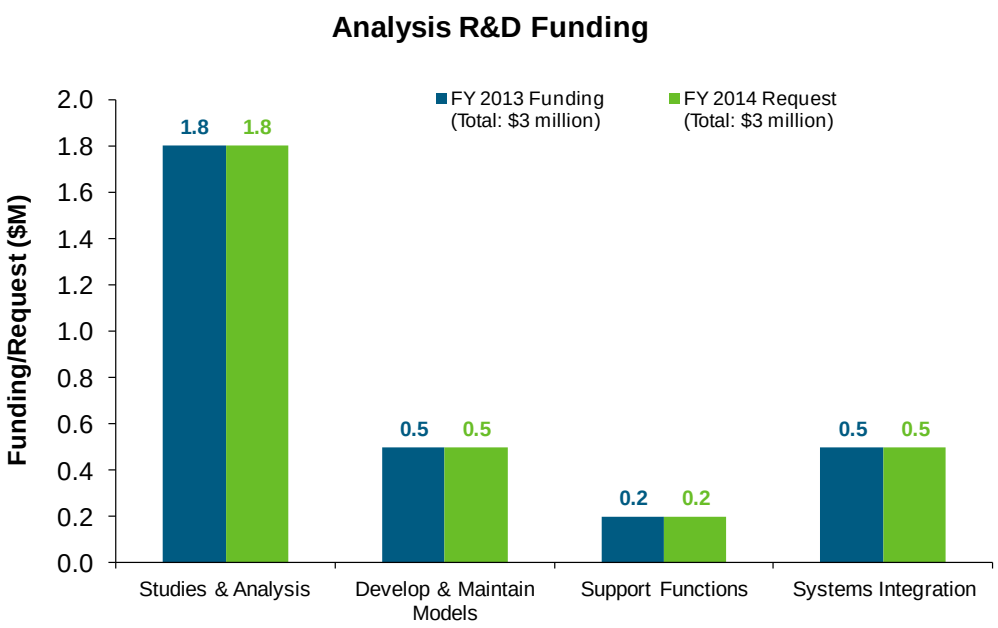
The reviewers considered the Systems Analysis program to be an essential component of the U.S. Department of Energy (DOE) Hydrogen and Fuel Cells Program's (the Program's) mission. The projects were considered to be appropriately diverse and focused on addressing technical barriers and meeting targets. In general, the reviewers noted that the Systems Analysis program is well managed and demonstrated the ability to address immediate analytical needs and overall objectives and plans, especially to implement the new initiative, H_2USA.

Some reviewers commented that the program is effective in providing analytical support and key insights for the Program's research and development (R&D) efforts and that it is helpful in appropriately directing R&D efforts to address key barriers. Reviewers also commented that the analysis and model portfolio was making good progress toward understanding the issues, challenges, and opportunities related to achieving the Program's technical targets. Some reviewers commented that the use of flowcharts to articulate the interactions between the types of analysis and applications was effective in describing the program's analysis process.

Key recommendations for this program included the following: (1) more emphasis on near-term market barriers is warranted, given the status of fuel cell vehicles and the challenges with infrastructure deployment; (2) analysis is needed to assess the policy options to incentivize stakeholders and finance mechanisms for infrastructure and fuel cells; (3) analysis is critical to the Program; and (4) the level of funding for this program continues to be a concern.

Systems Analysis Funding:

The fiscal year (FY) 2013 appropriation for the Systems Analysis program was $3 million. Funding for the program continues to focus on conducting analysis using the models developed by the program. In particular, analysis projects are concentrated on infrastructure development for early market fuel cell introduction, the use of hydrogen and fuel cells for energy storage, biogas resources, life-cycle analysis of water use for hydrogen production, employment impacts of developing infrastructure to supply hydrogen for fuel cells, and the petroleum and greenhouse gas emission reduction benefits of various pathways. The FY 2014 request level of $3 million, subject to congressional appropriation, provides greater emphasis on analysis of hydrogen for energy storage and transmission, early market adoption of fuel cells, continued life-cycle analysis of water use, levelized cost of hydrogen from future hydrogen production pathways, cost of onboard hydrogen storage options and associated greenhouse gas emissions and petroleum use, and other impacts such as job creation.



Majority of Reviewer Comments and Recommendations:

The maximum, minimum, and average scores for the Systems Analysis projects were 3.5, 2.9, and 3.2, respectively.

Infrastructure: The analysis projects reviewed in this topic area received a favorable average score of 3.2 for assessing the costs of hydrogen infrastructure development and understanding the hydrogen infrastructure costs compared to other alternative vehicle infrastructure. Reviewers acknowledged the insights gained from a wide array of stakeholders and analysis of the economics of hydrogen refueling stations in a dynamic context. The suggested next steps included the following: linking station siting and overall station needs to vehicle choice modeling and expected fuel cell electric vehicle (FCEV) purchases, continuing to calibrate the findings with key stakeholders and other studies, and expanding the analysis projects to a more comprehensive and integrated study of vehicle/infrastructure rollout.

Model Development and Systems Integration: Two projects involving model development were reviewed (one for assessing the employment and economic impacts of deploying fuel cells and hydrogen infrastructure and one for life-cycle analysis of water use for hydrogen production) and each received a score of 3.2. These projects received favorable reviews and were regarded as well aligned with the current program goals and objectives.

Reviewers commented that the JOBS model provides valuable economic and job creation information for project funding justification. Reviewers recommended that the project continue to expand the model to include assessment of the employment impacts of infrastructure construction.

Reviewers acknowledged that expanding the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model platform to include water use life-cycle assessment addresses critical and relevant Program issues associated with hydrogen production. Reviewers pointed out that the model would have to be expanded to include all fuels so a proper comparison can be completed. The project will benefit from collaboration with industry stakeholders.

Programmatic Benefits Analysis: The reviewers commented that the analysis projects to assess the program's benefits (in terms of reducing greenhouse gas emissions and petroleum use) for multiple hydrogen pathways and the inclusion of various onboard storage options for hydrogen pathways are relevant to the Program's objectives and provide valuable projections of the impact of FCEVs and hydrogen in the U.S. transportation mix. Systematic

evaluation of the pathways and with future onboard storage options for cost and greenhouse gas emissions is critical to the overall systems analysis effort and guiding research goal settings and prioritization.

Resource Analysis: This project received a favorable review for assessing biogas resources available for *renewable* hydrogen production. Reviewers specifically appreciated the insights the analysis provided about using waste in a way that not only provides clean fuel for FCEVs, but also eliminates costs and environmental problems associated with solid waste and associated biogas. Future work will include additional waste feedstocks, economic analysis, and costs.

Studies and Analysis: Six analysis projects were reviewed, with an average score of 3.2. The projects covered a range of topics including energy storage, fuel cell integration with biofuels facilities, and the global status of FCEV technology. In general, the reviewers felt that the projects supported Program goals, but they also agreed that the results of the analysis projects need to be (1) disseminated to a wider audience outside the fuel cell community, (2) used to modify goals and assumptions used for various analysis and modeling exercises, and (3) used to examine other applications.

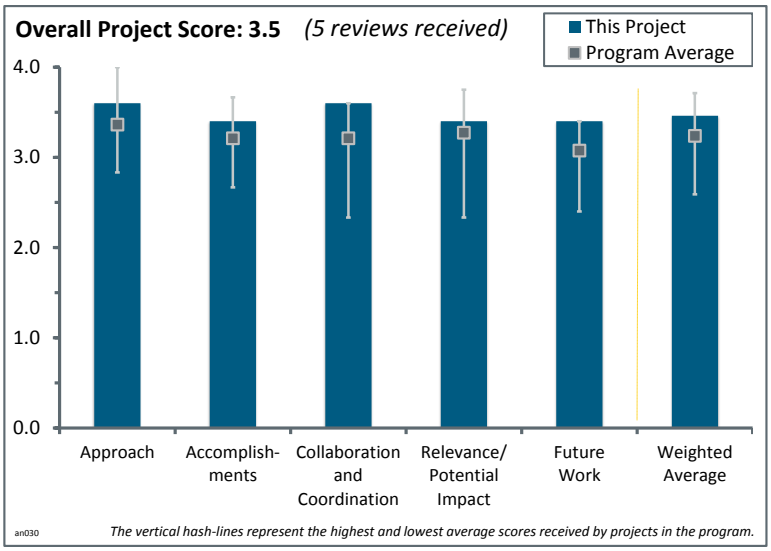
The analysis project to assess the worldwide status of hydrogen FCEV technology and prospects for commercialization was commended for its thorough approach and collaboration with automobile original equipment manufacturers (OEMs) to acquire critical data for modeling input. The project provides critical insight on fuel cell technology progress; trends; and the plans of major OEMs that should be incorporated in research, development, and demonstration planning and future direction.

Project # AN-030: Worldwide Status of Hydrogen Fuel Cell Vehicle Technology and Prospects for Commercialization

David Greene; Oak Ridge National Laboratory

Brief Summary of Project:

The goal of this project was to establish the status of fuel cell electric vehicle (FCEV) technology and commercialization plans in Japan, Korea, the European Union, and the United States. Benchmark progress has been seen by original equipment manufacturers (OEMs) in the performance of FCEV technology, manufacturing costs, and the timing of commercialization. Government and industry plans for deployment of FCEVs were documented, and the data collected were used to recalibrate the market transition models. FCEV performance will be ready for commercial introduction by OEMs in 2013, 2015, 2017, and 2020, depending on the availability of refueling stations.



Question 1: Approach to performing the work

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

- This is a very thorough approach to obtaining data and insight for study and analysis with targeted partners.
- This project includes a comprehensive approach, utilizing available data and analyses supplemented with direct input from OEMs.
- This project is contacting relevant stakeholders in different countries and seeking detailed insights from them. This is a valuable approach, and such interactions should be continued on a regular basis so as to keep abreast of relevant developments and to receive insights that could shape future research decisions.
- The approach was comprehensive. The data was presented in a useful and informative way and directly addressed the barriers of FCEV component cost and performance. This project also highlighted areas where improvement is needed, such as in the interplay between platinum loading and durability.
- This project has access to multiple sources of information and data that are required for this analysis, although there seems to be a disconnect between the status of the technology, the focus of the research program, and the information coming from the U.S. DRIVE Tech Teams. Additional discussions are needed to ensure that information collected from stakeholders is indeed representative.

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.

- This project provides a comprehensive assessment of FCEV status and commercialization prospects.
- This is a great collection of data. It is hard to predict if cost and rollout of stations and vehicles will match the estimates.
- Based on the information obtained from OEMs, the analysis points to particular issues that can be used to focus research efforts in other programs. This is an important outcome of any analysis project. The information should be vetted with the appropriate subprogram leads and checked against the technical teams.

- The project made significant progress in understanding projected future costs for components of FCEVs and vehicle costs, which is a major factor in future market adoption. The project also helped address the barrier of inconsistent data by gathering and analyzing cost data from diverse OEM sources. The work made significant progress toward its goal of better understanding future costs, a key driver for market adoption of FCEVs. This project also helped clear up inconsistent data on FCEV costs and performance.

Question 3: Collaboration and coordination with other institutions

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

- There is great collaboration with countries and OEMs, especially with South Korea.
- The project includes excellent collaborations with government agencies, vehicle OEMs, and non-government organizations.
- The project drew on industry data and coordinated with diverse international programs on hydrogen and fuel cells in Japan, Germany, South Korea, and the United States. This project succeeded in getting projections on costs, which are difficult to obtain. It is not clear if the report was fully up to date on regional infrastructure plans, but this is not surprising given how fast they change. The overall conclusions were still very useful.
- This project has access to knowledgeable collaborators who provide needed data that can be used to improve the believability of the results. Additional discussions with the Fuel Cell Technologies (FCT) Office's Fuel Cell program are warranted, as the presentation implies that the OEMs have solved many of the problems on which researchers continue to work.
- South Korea is mentioned as one of the countries from which data and insights are gained, but the results do not show much information relating to South Korea; they seem more geared towards the other countries.

Question 4: Relevance/potential impact on advancing progress toward DOE research, development, and demonstration (RD&D) goals

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

- Having independent studies to point to is useful and helps corroborate other studies and boost arguments for FCEV and infrastructure. The data are very important.
- Understanding the costs and the international status of hydrogen and fuel cells is of high relevance to the DOE Hydrogen and Fuel Cells Program. This is an excellent summary of the current state of the technology.
- Gaining insight into technology progress, trends, and developing plans based on input from the major industry players and countries is key to calibrating modeling assumptions and to conducting effective analyses. Connections with these stakeholders should be kept on a continuous basis so that any developments that might have an effect on research direction and other decisions may be identified in a timely manner.
- The project provides a necessary evaluation of the status of fuel cell technologies and the prospects for FCEV commercialization. The project is aimed at understanding the current status of fuel cell technologies, which is important to DOE's understanding of where these technologies stand and what further research is needed. This project does not directly help achieve DOE's targets for fuel cell technologies, and further R&D will be needed to achieve these targets.

Question 5: Proposed future work

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

- The proposed future work and reporting on this project are necessary and appropriate.
- This project could also try to identify/quantify the risks of not meeting deployment plans and targets.
- This project focuses on important issues for a hydrogen transition and the adoption of FCEV vehicles, including early market dynamics and the effect of international developments on FCEV adoption in the United States.

- This project mentioned two upcoming reports based on data, but it is not clear what other work will be done and how reports might be distributed to key stakeholders and publicized in conjunction with the introduction of FCEVs and hydrogen infrastructure stations.

Project strengths:

- This project has good access to some stakeholders.
- This project provides a comprehensive assessment of the current state of fuel cell technologies for the transportation sector.
- This project is necessary to support vehicle/station rollout and increase the visibility and awareness of both with the public, lawmakers, and key stakeholders.
- This project addresses key barriers by providing knowledge on the current cost and performance status of hydrogen FCEV technology and projections. The international focus gives a full picture of the industry.
- This project highlights the status of technology, developing trends, and also where plans and projections do not match reality, all of which are useful insights affecting research.

Project weaknesses:

- This project has no weaknesses.
- There was not much mention of the data on South Korea, even though that is stated as one of the countries investigated. It seems like the focus was more on the other countries.
- This project could do better promotion of the study and results, such as working with the groups involved to distribute information and make the public aware. This project should emphasize the corroboration with other studies and groups to build a case for vehicles/stations.
- Some of the information collected from OEMs seems to be in direct conflict with the U.S. DRIVE Fuel Cell Tech Team (FCTT), as well as with the research agenda of the FCT Office's Fuel Cell program (especially the information provided on slide 6). The state of the technology needs to be clarified with the FCTT and/or the FCT Office leadership.

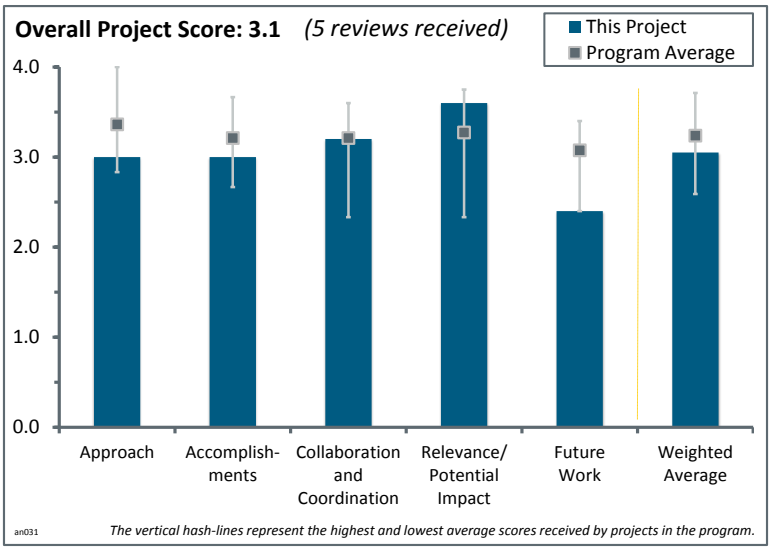
Recommendations for additions/deletions to project scope:

- There are no recommendations for this project.
- A discussion with U.S. DRIVE Tech Teams is necessary for this work to be relevant.
- This project should present the findings to other groups outside of fuel cells, such as The Society of Automotive Engineering, the Electric Drive Transportation Association, or other automotive groups.
- It would be good to modify and enhance the assumptions of various models used by the Hydrogen and Fuel Cells Program based on input from the major industry players and countries (to the extent that it is possible and feasible).

Project # AN-031: Siting Strategies for Early Hydrogen Refueling Infrastructure in California: Learning from the Gasoline Experience

Michael Nicholas; University of California, Davis

Brief Summary of Project:



Research in this project focused on determining the minimum number of hydrogen fueling stations necessary to serve the maximum number of fuel cell electric vehicle (FCEV) customers in order to reduce the capital investment needed for hydrogen refueling infrastructure. Strategies for placement, quantities, and network development of early hydrogen fueling stations were analyzed to provide fuel accessibility for an initial rollout of hydrogen fuel cell passenger cars based on studies of existing gasoline refueling behavior. Case studies were conducted for California using geographic information system-based analysis for station siting and convenience from the perspective of consumers. The research showed that an "anchor" station with a wide network of surrounding stations is a prerequisite for the consumer to purchase an FCEV.

Question 1: Approach to performing the work

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

- It would be good to include a concise statement of the objectives, function, and data inputs in order to understand how this model is distinct from others. Overall, the approach is intuitively appealing and appears to be rigorous.
- The approach of clustering stations is good. This would provide redundant stations. If one station is down for maintenance or out of hydrogen, for example, drivers will have a nearby option. Placing stations at the exits of neighborhoods as they connect to highways is a good approach.
- The analysis methods are well designed and executed. The key shortcomings are identified, but potential solutions have not been explored. A key question is how to translate a particular configuration of station availability (type, size, and location) into a measure of consumer utility. The question of pricing hydrogen needs to be addressed from a policy perspective. The price of hydrogen will affect station economics, hydrogen demand, and consumer satisfaction with hydrogen vehicles. There needs to be a move towards an integrated analysis of these issues.
- The approach to this work seems reasonable, but it would have helped if the assumptions were explained in more detail and if additional information was presented on the other cited models.
- Development of the station siting network seems fairly generic. The project needs to better tie station siting and overall station needs to modeling of vehicle choice and expected FCEV purchases. It is not clear how station siting within clusters was accomplished. This project should tie station siting and travel distances to the households most likely to purchase FCEVs based on household market analysis (household income, education level, etc.). Given the breadth of hydrogen infrastructure, siting, and infrastructure rollout studies, the investigation should explicitly attempt to build on the findings of other available studies.

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

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

- The accomplishments and progress towards the goals seem to be on target. It would be clearer to provide an explanation of where the capital cost numbers presented came from, as well where the hydrogen cost figure of $13/kilogram for 2015–2017 came from.
- This project has made excellent progress in developing the cluster concept and measuring its coverage. More attention needs to be paid to costs and benefits to identify and measure the trade-offs, and to the evolution of networks over time and the profitability of refueling outlets. This project has made good progress, but more needs to be done. At present, the project focuses on the first few stations, then assumes the market will take over. It is not clear if this is really true or how the economics work.
- Good progress has been made on the development of a conceptual siting approach. This project needs to progress beyond the conceptual, however, and refine station siting needs based on vehicle choice modeling and expected FCEV sales over time. At the same time, actual station siting should be developed based on census data relating to expected buyers of FCEVs (using metrics such as household income, education, etc). As there are a number of infrastructure rollout and siting studies, these investigations should compare and contrast them to other relevant studies and build on the growing base of knowledge.
- It seems like there should be better data than a survey from 1987; the 50% assumption needs justification or qualification. It is not clear how that results in new or relevant information. The principal investigator should restate the survey question on slide 16. It would be good to focus on new results.
- It was unclear what the new accomplishments were at this phase of the project. Good concepts of what is needed for station placements were presented, but maybe it is too early to see digested outputs from the analysis process.

Question 3: Collaboration and coordination with other institutions

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

- This project has an impressive list of collaborators. The NextSTEPS program appears to provide significant leverage of DOE funds.
- A significant list of collaborators and interactions were presented, and the fact that this work was conducted under the NextSTEPS consortium demonstrates that the interaction with industry is quite strong.
- This project has good collaboration. If possible, the retail fuel sector should be consulted more to see if they can help identify the appropriate business models. Benefit can be drawn from the research being done in Germany, Japan, Korea and other countries (e.g., Norway and Denmark), and vice versa.
- The reviewer has interfaced with California hydrogen developments. The work could be more visible in the California Fuel Cell Partnership forums. It would be beneficial to this project for California and the US Hydrogen Infrastructure project (H2USA) to communicate more frequently, such as by attending meetings and presenting to each other.
- This project lists good collaborations with California organizations, national laboratories, industry, and other academic researchers. While the list of collaborators is extensive, it is not clear how this work fits in with the other related research and modeling on both hydrogen infrastructure siting and deployments of FCEVs. The project should more explicitly build on research on likely FCEV purchases and vehicle choice modeling, and should more clearly coordinate with other researchers in this area to better ensure that station siting research is conducted in unison, not as individual, unrelated pieces.

Question 4: Relevance/potential impact on advancing progress toward DOE research, development, and demonstration (RD&D) goals

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

- This study is very relevant to the issue of infrastructure investment needs and market barriers.

- Given the status of FCEV in the world and the announcement of the H2USA organization, this analysis is of central importance.
- This project helps DOE better understand near-term deployment needs for hydrogen infrastructure. This project helps DOE understand the investment needs to develop the necessary hydrogen infrastructure to enable commercialization of FCEVs.
- This project provides a good regional analysis for early market hydrogen station placement, and this same analysis, expanded beyond California, will provide DOE with a good tool for analyzing early hydrogen market adoption in the United States.
- At this phase of transportation hydrogen technology proliferation, this is the most needed type of analysis. The analysis must, however, be digested quickly and disseminated to policy makers, investors, and the public in general. Hydrogen is a real winner in the technological realm, but it is severely suffering in public education and perception realms. Analysis of this type helps ground the public.

Question 5: Proposed future work

This project was rated **2.4** for its proposed future work.

- The proposed work may need to be better defined.
- This analysis would benefit from detailed interaction with vehicle purchasing models. However, an approach to provide station availability to a majority of the market as fast as possible is appreciated.
- This project needs to focus more on the market impacts of station deployment to attempt to coordinate station deployment and vehicle market evolution. We need to develop more confidence that a given number of stations of particular types, deployed in a specific spatial consideration, will be sufficient to sell an appropriate number of FCEVs
- It would be good to refine the results of future work with respect to particular policy goals or industry partnership initiatives. Significant exploratory work has been done, and more focus seems appropriate at this point in time. It appears that the market hunting algorithm may be able to predict relative demand between stations, which could be useful in providing insight into investment risk.
- The investigator did not fully develop (or communicate) a plan for future work. The future work should include an assessment of the minimum number of stations needed in the early market (in specific build-out areas, such as southern California) based on evaluations of expected FCEV purchases. This evaluation should be conducted on a geographic basis to help DOE understand initial station usage levels and patterns over time and the potential need for government subsidization of station development and operation.

Project strengths:

- Working under the NextSTEPS consortium is a strength of this project.
- The approach is robust and elaborate, and there is strong collaboration.
- This project is well focused on the most important barrier. It uses sound methodology and realistic data and assumptions. The geographic detail for station locations and markets and the inclusion of different types and sizes of stations are project strengths.
- This project helps DOE and California state government understand how hydrogen stations might be deployed during the early commercialization of FCEVs, which, in turn, will help government understand minimum station needs and the potential need for government support of hydrogen infrastructure.

Project weaknesses:

- The approach could be more focused and relevant to particular policies or stakeholder decisions.
- This project needs to provide more detailed information on the assumptions and on the models cited.
- The project should more clearly tie hydrogen station needs to expected purchases of FCEVs. The project should more explicitly show how this investigation ties into and builds upon other research on hydrogen infrastructure siting and deployment, and the expected deployment of fuel cell vehicles.
- This project does not address the pricing of hydrogen during transition, the utility of stations to potential car buyers, and the effect on sales or customer satisfaction, except through coverage measures. This project

falls short of an integrated analysis of the evolution of an adequate hydrogen refueling infrastructure. This project needs to expand the scope, think bigger, and come up with new ideas and new methods..

Recommendations for additions/deletions to project scope:

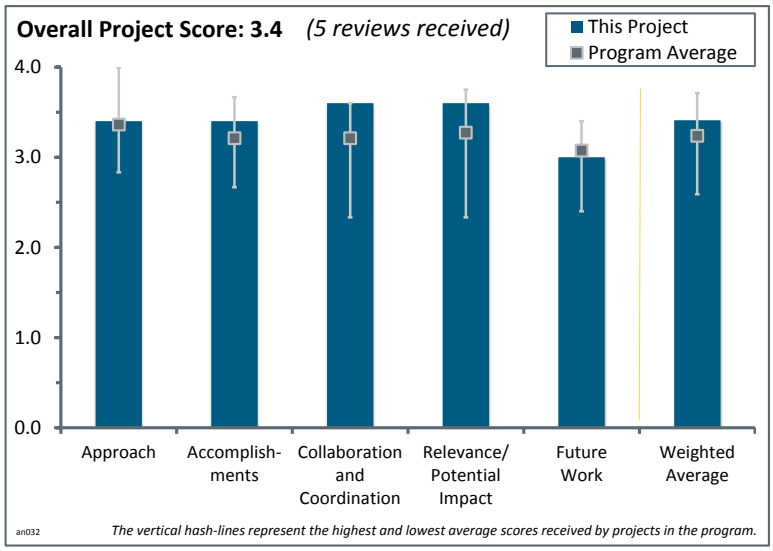
- This project should continue to pursue station size and relevance to investment risk. It should continue to pursue the value of networks to overall market growth rather than revenue for individual stations.
- This project should integrate with Professor Ogden's analysis of station economics and consider subsidy costs. It should also include measurement of consumer utility of stations and address dynamics of market evolution.

Project # AN-032: Design and Economics of an Early Hydrogen Refueling Network for California

Joan Ogden; University of California, Davis

Brief Summary of Project:

The objective of this project is to assess alternative strategies for introducing fuel cell electric vehicles (FCEVs) and hydrogen infrastructure in Southern California over the next decade to satisfy the zero emission vehicle regulation while taking into consideration station placement, quantity, size, and type. The analysis studies infrastructure economics from multiple perspectives: network, station owner, consumer. The project analyzed rollout strategies for FCEVs and hydrogen infrastructure in Southern California over the next decade through input and discussion with stakeholders in the auto industry, energy industry, industrial gas industry, state agencies, and national labs.



Question 1: Approach to performing the work

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

- Evolution of station profitability over time is a very useful addition. This is an excellent first step in analyzing the economics of hydrogen refueling stations in a dynamic context.
- Analyzing the economics from several perspectives and including the station network and single-station owner is a good approach for this analysis work. It is also good that the work provided a comparison of several station types.
- It is reassuring that the approach has been vetted by project collaborators. Some additional analytics (sensitivities, perhaps) would be useful to better understand the relevance of different types of assumptions. It is difficult to judge how optimistic the cash flows are, for example, relative to the probable market outcomes.
- This study helps provide vital information on hydrogen station cost and infrastructure needs during the initial rollout of hydrogen infrastructure in California. Evaluations of infrastructure cash flows and break-even timing are crucial to understanding the necessary government role in developing a network of hydrogen fueling stations. This investigation should more explicitly attempt to build on the findings of other U.S. Department of Energy (DOE)-funded studies of hydrogen infrastructure rollout and hydrogen cost.
- This is great work in terms of considering multiple pathways of onsite refueling (liquid hydrogen [LH_2], steam methane reforming [SMR], and electrolysis); however, there is a concern that SMR systems require a significant footprint, especially at the 1000 kg/day scale. The stations in the highest population density (first market) areas are very space-limited and overwhelmingly do not have room for SMR. In addition, SMR systems require significant onsite monitoring and maintenance; for example, gas-quality verification and maintenance. It is not clear if it is really feasible to consider this system type for early market forecourt applications. The upgradeability of SMR systems is also challenging. A station upgrading from 100 to 250 kg/day would need to replace the SMR because they do not stack gracefully; for example, the full footprint would be needed around the SMR to service components with a forklift.

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 overall incentives per station look comparable to expectations.
- This is a significant amount of work for the level of funding. NextSTEPS provides good leverage of DOE funds and enhanced the quality of this project through collaboration.
- This work showed good initial progress and accomplishments by providing some estimates for cash flow and a break-even year for different infrastructure build-out scenarios.
- The analysis is sound; however, the assumptions about the rate of increase in hydrogen vehicle sales are overly optimistic. More realistic scenarios need to be evaluated. It is also assumed that once the initial stations become profitable, future stations will be added by market demand. This may be the case, but it is not clear. The pricing of hydrogen needs to be considered in order to enable a practical policy analysis. Hydrogen price and station availability will strongly affect the willingness of consumers to purchase hydrogen vehicles. Thus, it is ultimately necessary to include consideration of consumer utility and vehicle choice.
- This project's initial findings will help DOE to understand near-term hydrogen infrastructure costs and the appropriate level of government support of infrastructure during early FCEV commercialization. The project provides estimates of the cost of both hydrogen fuel and the cost of a fueling network expected during the initial rollout of FCEV. The study should attempt to better link expected purchases of FCEV over time with station capacity utilization over time, considering the minimum number of stations expected to be needed during the early commercialization phase. Changes in station capacity utilization over time can then be tied to the expected hydrogen cost over time from these stations. This work seems to have been done in the context of station cash flow analyses, but it does not seem to be reflected in the reported levelized cost of hydrogen by year.

Question 3: Collaboration and coordination with other institutions

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

- NextSTEPS provides good leverage of DOE funds and enhanced quality through collaboration.
- This project involves excellent collaborations with California organizations, national laboratories, industry, and other non-profit and academic researchers.
- This project has extensive collaboration and interaction with industry by conducting this work under the NextSTEPS research consortium.
- Collaboration with a local business school will be invaluable.
- The principal investigator needs to collaborate with colleagues doing similar analyses in Germany and other places and should establish contacts with the fuel retailing industry.

Question 4: Relevance/potential impact on advancing progress toward DOE research, development, and demonstration (RD&D) goals

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

- This line of analysis is absolutely essential at this phase of hydrogen infrastructure rollout planning.
- A robust regional economic analysis for the initial rollout of hydrogen and FCEVs is a key contribution to DOE's goals and objectives.
- This project helps understand the cost of both hydrogen fuel and hydrogen infrastructure, as well as the investment needs to develop the necessary hydrogen infrastructure to enable commercialization of FCEVs.
- The approach would be improved with additional focus on probable outcomes or additional vetting of how optimistic the different model input assumptions might be compared to values that can be substantiated empirically.

- The subject addressed is of critical importance to the early evolution of the hydrogen vehicle market. It is the critical factor in original equipment manufacturers' decision making today when it comes to where and when to introduce FCEVs to the market.

Question 5: Proposed future work

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

- The incorporation of other types of costs would be an improvement to the methodology.
- The proposed future work shows good direction towards the main goals for this project and towards addressing DOE barriers.
- The project suggests moving towards analyzing other regions and production pathways. More work should continue on the present analysis of southern California. The investigation should more clearly link to and compare to other DOE-funded analyses of hydrogen infrastructure in California. More work investigating the effects of low station utilization during the initial FCEV rollout is warranted, and the sensitivity analyses should be expanded. Additional work should be conducted on the underlying cost analysis assumptions to provide modeling validation. In particular, station cost assumptions relative to Hydrogen Analysis (H2A) mature market costs should be assessed and validated based on the current cost of stations sited in California, and based on literature and analyses related to the expected economies of scale cost curves and learning-by-doing improvements.

Project strengths:

- The approach and collaboration are strengths of this project.
- This project has very strong collaboration and interactions with industry.
- This project uses solid knowledge of station economics, which are well represented in the model. The project considers the temporal dimension of station profitability, which is extremely important.
- This project helps with understanding the investment needed to overcome the "valley of death" until hydrogen infrastructure reaches a break-even level. This project helps DOE and the California state government better understand the potential need for government support of hydrogen infrastructure during early FCEV commercialization.

Project weaknesses:

- This project needs to develop a more objective framework for comparing levels of optimism or pessimism for input assumptions.
- This project does not analyze hydrogen price strategies and policies. It does not include an integrated analysis of station economics and consumer response. The principal investigator needs to collaborate with colleagues in other countries that are considering similar problems.
- It is difficult to tell from the presentation, but the project might be repetitive with other DOE-funded techno-economic analyses of hydrogen infrastructure. The project should emphasize how it relates to and builds upon other DOE-funded research areas. The project needs more in-depth analyses of very early station deployments and of the effects on hydrogen cost of very under-utilized stations when relatively few FCEVs are deployed and consumer convenience requires a minimum number of station deployments.

Recommendations for additions/deletions to project scope:

- It is strongly recommended that the project collaborate with a local business school. A finance graduate student could quickly add a lot more depth to the financial analysis.
- Some of the proposed future work topics have already been addressed. A more specific focus for each topic or a reduced list of topics is needed.
- This project should expand and consider multiple station types, sizes, and delivery pressures. Station economics should be integrated with vehicle choice and consumer satisfaction. At the very least, this project should consider alternative vehicle sales scenarios and economics beyond the initial station rollout.

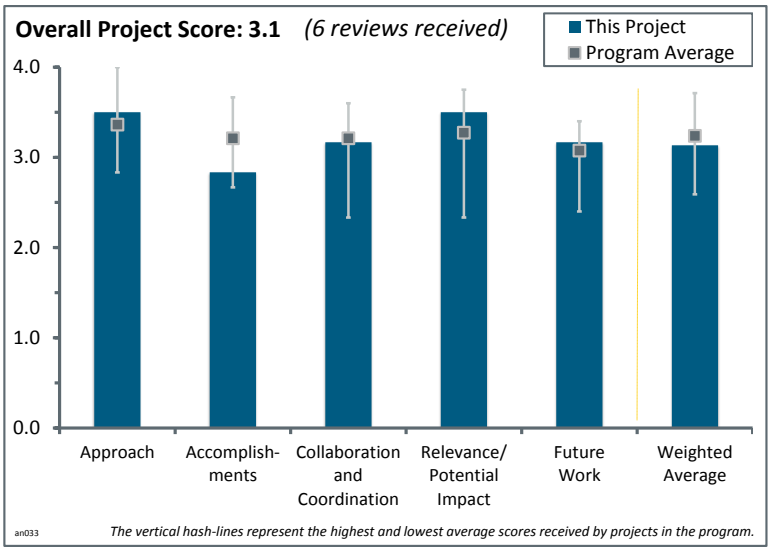
Formal collaboration should be established with Germany's National Organization for Hydrogen and Fuel Cell Technology (NOW) and similar organizations in other countries.

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

Zhenhong Lin; Oak Ridge National Laboratory

Brief Summary of Project:

The goal of the project is to gain a better understanding of optimal delivered hydrogen pressure for refueling fuel cell electric vehicles (FCEVs). The project looks for a balance between storage and delivery pressure and quantity of stations to determine the best deployment of infrastructure to support consumer refueling needs. It offers an analytical framework for assessing the complicated relationships between onboard hydrogen storage pressure and range, costs, consumer acceptance, and industry risks.



Question 1: Approach to performing the work

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

- This is a very good approach in investigating the optimal delivered pressure and understanding the tradeoff between the consumer refueling convenience and infrastructure costs. Assumptions and methodology of work are clearly stated.
- The approach provides good focus for the analysis. The initial approach has been set up very well, and the initial results are convincing, but completing the future work seems very important in order to fully address this research question.
- The approach to evaluate hydrogen fueling pressure (and hence range) to total consumer cost and consumer value is excellent and well needed. The project approach enables a better understanding of the interrelationship of storage pressure/range, infrastructure cost, hydrogen cost, and consumer value.
- The project addressed important barriers with respect to storage (cost and lifetime assessment) and market transformation (high capital cost of infrastructure for hydrogen FCEVs). The choice of hydrogen pressure (350 versus 500 versus 700 bar) is a concern, as hydrogen infrastructure rollout strategies are already being developed. The principal investigator considered direct costs of higher pressure on refueling stations and also consumer costs for the inconvenience of refueling as measured by the extra time for traveling to stations and refilling with low-pressure versus high-pressure hydrogen. The project looked at trade-offs between station costs and inconvenience costs at different pressures. The methodology for estimating consumer inconvenience could have been explained more fully. Also, it would have been good to understand the total spectrum of costs and benefits of high versus low pressure (including impacts on the vehicle cost and performance) in addition to station cost and driver inconvenience. Just optimizing with respect to station cost and the cost of consumer travel time may not be a true optimization unless other factors are accounted for. Automakers have already largely decided on 700 bar based on wanting a longer range. This should be considered in the framework of the study.
- In general, questions posed and parameters studied are good, but collaborating more with colleagues working on other station deployment-type analyses could provide better insights and different parameters to investigate.
- This project is generally effective for what it set out to do, but the goals are quite limited. The cost approach for system pressure comparisons is rational and straightforwardly executed. However, this approach does not, nor can it, account for the “annoyance factor” of having to refuel more often when at a low pressure. This factor may be significant, yet it is completely overlooked.

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

This project was rated **2.8** for its accomplishments and progress.

- This work has some good initial results, mainly on the method development and the case studies presented. It is good to see the sensitivity analysis and the parameters selected.
- The project has achieved significant progress towards understanding the consumer value of FCEV range versus refueling trips/time and also towards understanding optimal hydrogen fueling pressure. It would be good to see more modeling of hydrogen infrastructure clustering during the early FCEV commercialization phase. The project's modeling should be tied to consumer choice models of advanced vehicles to understand how changes in vehicle range can affect vehicle market penetration.
- The various trade-offs, sensitivities, and specific conditions were determined through this analysis, but results seem too conditional and uncertain. Perhaps a more in-depth look at some situations may help shed some more light.
- There is only modest progress in understanding the preferred pressure. The answer seems to be that it depends on a host of factors and pressure will increase with time/prevalence of FCEVs; hence, there is little actionable information in the results.
- Error bars on slides 9 or 11 might change the interpretation of the results. It was unclear if the influence on the rate of market growth was different for each type of marginal cost. This influence seems to be considered equivalent, or similarly relevant, given this comparison framework. It was unclear if the debt supporting higher delivered costs from more stations could be more easily serviced at a lower risk, with faster future market growth and the increased likelihood of future revenues. The typical patterns of interaction have been identified, but future work may change how these patterns are interpreted.
- The project has illustrated some interesting trade-offs between pressure, consumer convenience, and cost, but more remains to be done. It was difficult to tell what was being held constant and what was being varied in some graphs. It would have been helpful to tie these results to some actual plans, for example, a closer tie with California rollout plans. Using a cluster strategy like California's for the station rollout may eliminate some of the inconvenience issues raised. Also, some of the examples (e.g., 10% utilized stations) seem unlikely. Tying the work to actual plans might make it more realistic.

Question 3: Collaboration and coordination with other institutions

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

- This project has good collaboration with industry and other researchers.
- The project has a very good collaboration, including industry within the U.S. DRIVE Fuel Pathways Integration Tech Team, Argonne National Laboratory (ANL), and the University of California-Davis (UC-Davis).
- While not reflected in the analysis, the approach and results seem consistent with ANL and UC-Davis work, thereby suggesting adequate collaboration with those groups.
- Collaborating with colleagues working on other station deployment-type analyses would also be beneficial.
- Some additional input from industry on costs associated with modular expansion of station capacities would be useful. The sizes do not have to be fixed. The project could be improved by more input on financing options, or influence of station clustering strategies.
- This project has good collaboration with national laboratory researchers to understand varying station costs relative to dispensing pressure. The project has adequate collaboration with the fueling industry, but more collaboration with vehicle original equipment manufacturers (OEMs) is needed. The project would also benefit from more collaboration with researchers investigating initial hydrogen infrastructure rollout strategies.

Question 4: Relevance/potential impact on advancing progress toward DOE research, development, and demonstration (RD&D) goals

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

- The topic is highly relevant to understanding market barriers and research and development focus.
- Understanding the pros and cons of high pressure is a very important topic. With more realistic scenarios, this project could have even more value.
- As plans are made for early market infrastructure development, looking into factors such as required fueling pressures is important.
- This project provides vital information on station development and deployment, the consumer value of FCEVs relative to range, and the trade-offs between FCEV performance and cost necessary to lower the overall cost of FCEV ownership to consumers.
- This work is very relevant to DOE's objectives and will contribute to the understanding of what could be the optimal hydrogen fueling pressure in terms of infrastructure costs, energy usage, and consumer acceptance for the market penetration of FCEVs.
- Because of limitations in the approach and accomplishments, there is limited actionable information from this project.

Question 5: Proposed future work

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

- The proposed steps will moderately strengthen the project results.
- The proposed future work shows a good path towards the main goals and barriers of this project.
- The proposed work related to demand, risks, and financial parameters is important, as it will make the analysis more realistic and can provide significant insights.
- The proposed extension is good, especially for looking at the cluster strategy. Also, exploring other tradeoffs through a consumer choice model would be interesting.
- The proposed future work is appropriate. The project as explained should be expanded to model hydrogen infrastructure clustering in the initial rollout phase, and should be integrated with vehicle choice models.
- It is good to set up a logical framework to compare marginal costs. However, some additional consideration is needed on the large uncertainties and multivariate nature of consumer perception compared to financing options for station costs. Both types of costs can be managed in different ways, and the options for doing so seem relevant to this framework. Station costs can be financed and risks managed in various ways, perhaps through partnerships or contracts, while consumer behavior is highly variable and can also be "managed" or influenced in multiple ways. Given the different nature of these options, it seems fair to ask if this is really an apples-to-apples comparison of marginal costs. If some of these management options are easier to implement than others, or are inherently lower-risk, that should be reflected in this framework. Modeling cluster rollout strategies will require some estimate of the local density of early adopters. Variations in this density (or market depth) will be relevant to the station availability metrics, so it needs to be included explicitly in this future modeling effort.

Project strengths:

- The conceptual approach is on target.
- This project highlights the important trade-offs.
- This project addresses an important question with respect to choosing the best pressure.
- This work uses very good analysis tools and has very good interaction with its collaborators.
- The project provides a vital understanding of the consumer value of hydrogen storage pressure, and thus range. This work helps DOE better understand how hydrogen dispensing pressure can be optimized to increase consumer value and lower infrastructure needs and subsidies during the commercialization phase of FCEVs.

Project weaknesses:

- This project still has several uncertainties and key parameters to consider.
- It would be beneficial to this work if there is some input/feedback from the OEMs.
- More emphasis is needed on the initial FCEV commercialization phase and what the implications of this research are for DOE's funding of hydrogen fueling infrastructure. The project needs more feedback from vehicle OEMs.
- The research question probably requires a more extensive analytic context to be addressed fully and to generate results that can be used to inform concrete policies. Additional work is needed beyond this phase (year) of the project to fully understand the analysis problem.
- The project approach does not account for the "annoyance factor" of having to refuel more often when at a low pressure (beyond the actual extra minutes spent in the station, if any). The conclusions are highly dependent on the number of FCEVs and the value of time. The first is a constantly changing number, and the second both is hard to quantify and differs from person to person.
- The framework for assessing the choice of pressure could be broader. The OEMs have already largely decided on 700 bar because they want a longer range, but this is not included in the analysis. This project should consider more realistic rollout cases, including clustering and station utilization that is reasonable over time.

Recommendations for additions/deletions to project scope:

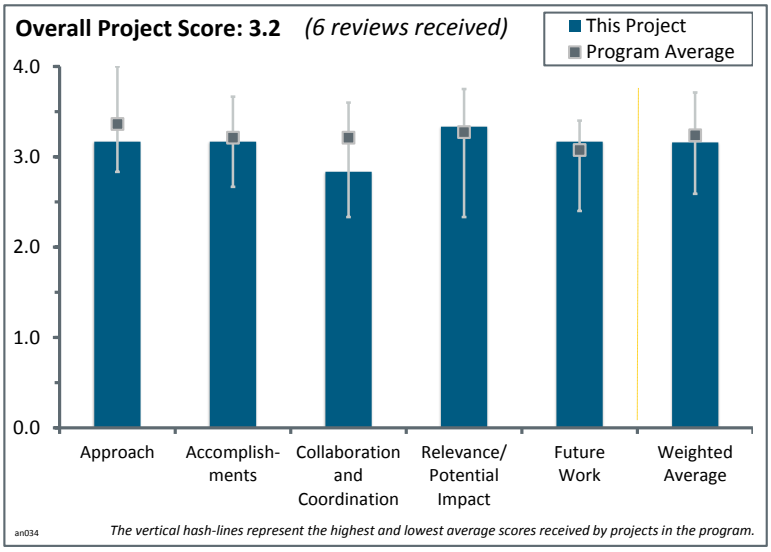
- This project should broaden the framework.
- Although the initial project funding was relatively low, the proposed future plans will probably not strengthen the project sufficiently to be worth the additional expense.
- Results and insights from this study could be integrated into other infrastructure studies. This project should collaborate closely with the financial scenario analysis of deployment strategies investigated under project AN-042, Systems Analysis.
- The modeling cluster rollout strategies will require some estimate of the local density of early adopters. Variations in this density (or market depth) will be relevant to the project's metrics for station availability, so they need to be included explicitly in this future modeling effort. There should be explicit inclusion of policies or financing options, and consumer convenience options, such as station clustering, onboard informatics, etc.

Project # AN-034: Life Cycle Analysis of Hydrogen Onboard Storage Options

Amgad Elgowainy; Argonne National Laboratory

Brief Summary of Project:

This project evaluated the impact of hydrogen storage technologies on energy and emissions for fuel cell electric vehicles (FCEVs). Onboard hydrogen storage contributes 15% to 23% of the vehicle manufacturing cycle and 3% to 5% of the total life cycle analysis (LCA) greenhouse gas (GHG) emissions. The data can be used to update the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model to evaluate emerging hydrogen production, delivery, and FCEV technologies.



Question 1: Approach to performing the work

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

- This is a good approach using available data and appropriate sources, for the most part. The project needs to incorporate information obtained from additional technical teams.
- The utilization of the GREET modeling tool for this work provides an excellent approach for addressing project deliverables. The data sources used for the analysis are very appropriate for this work.
- The use of the GREET model is a good choice. The analysis has been carefully done. While the decision to use current practices for estimating life cycle impacts is understandable, it is probably misleading. By the time any of the pathways (with the possible exception of onsite steam methane reformers [SMR]) are actually implemented at a large enough scale to matter, the technology will be substantially different, and the energy sources and processes for manufacturing inputs will be less carbon-intensive (unless the project is not attempting to mitigate GHG emissions at all, in which case the project should not bother measuring them).
- The overall approach of the GREET model for LCA is excellent, and the GREET model is the de facto model for assessing transportation-related energy use and emissions. The approach for evaluating hydrogen storage systems, including literature assessments, simulation results, and interaction with storage researchers (particularly through the storage technical teams), is excellent. Likewise, the project team's approach to FCEV manufacturing using literature, simulations, and interactions with original equipment manufacturers (OEMs) is sound. Although the GREET model is an excellent tool for conducting fuel cycle (well-to-wheels [WTW]) evaluations of energy use and emissions in transportation, more interaction with U.S. Department of Energy (DOE)-funded analysts and modelers is needed to ensure consistent analyses of hydrogen-fueled fuel cell vehicles. In particular, the project team needs to ensure that assumptions used in their GREET modeling reflect DOE's standard assumptions, particularly as reflected in the Hydrogen Analysis (H2A) production model, H2A Delivery Scenario Analysis Model (HDSAM), and the Hydrogen Demand and Resource Analysis Tool (HyARC).
- The approach appears to be a standard LCA GREET approach.
- The approach is adequate and uses existing tools. There is a question as to the validity of the tools; it is unclear if they are validated. It would have been more convincing if a quick validation test was included.

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 incorporation of additional modules and functionality into GREET is progressing.
- This work improves existing comparisons of GHG pathways and should allow for good comparisons to battery electric vehicles and plug-in hybrid electric vehicles in terms of range.
- The preliminary results presented for several FCEV onboard options show very good accomplishments towards the main objectives of this work. The analysis of the comparison between these storage options will provide very valuable information to DOE's Hydrogen and Fuel Cells Program (the Program), mainly to its hydrogen storage R&D efforts.
- The task has been done well, but the premise of using the current practices will likely lead to misleading conclusions.
- Progress is good but could be better for the funds expended. Using the system for more cases would be cheaper each time.
- This project has made excellent progress towards evaluating the life-cycle energy and emissions intensity of various hydrogen storage systems. However, many of the findings are still cited as preliminary, and the evaluations need to be finalized. The WTW analysis conducted under this study appears to be more regional in scope, particularly regarding liquefaction emissions. The study should be expanded to include a national-level analysis, either by using a national-level electricity mix or by ensuring that appropriate delivery distances are used for potentially remote liquefaction plants. WTW analyses should be compared and contrasted to other DOE-funded WTW analyses. At the same time, the project should ensure that assumptions are consistent with DOE-funded analyses and modeling.

Question 3: Collaboration and coordination with other institutions

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

- There is good collaboration with the Hydrogen Storage Engineering Center of Excellence (HSECoE). In the future, it might be a good idea to show how each of the collaborators and partners contributed to the analysis work.
- The University of Michigan has significant LCA and automotive expertise.
- The industrial stakeholders are not described; otherwise, the only collaboration is with the National Renewable Energy Laboratory.
- This project needs to vet results with additional U.S. DRIVE Tech Teams. The lack of any impact on other parts of the vehicle (slide 14) cannot be correct. There must be an impact on, for example, vehicle structure for a storage system that weighs substantially more than another storage system.
- It is not clear which industry stakeholders were involved in this project or which industries were represented. The project relies on industry stakeholders for the development of storage and FCEV manufacturing emission factors. The project team needs to include more interactions with other DOE-funded researchers and modelers, particularly in regard to hydrogen fuel-cycle analysis, to better ensure that consistent assumptions are used in DOE's WTW analyses.

Question 4: Relevance/potential impact on advancing progress toward DOE research, development, and demonstration (RD&D) goals

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

- The GHG emission load of all the various components is valuable to know.
- The impact will be more significant in the context of comparing a total portfolio of options.
- The additional functionality and improved data will serve the GREET user community well.
- This project addresses a vital understanding of life-cycle energy use and GHG emissions associated with hydrogen and FCEVs.
- Providing an LCA for various FCEV onboard storage options is of great relevance to the Program's goals.

- This project would be more useful if it were based on the premise that FCEVs are likely to claim a significant market share after 2020, perhaps after 2025; that is the time frame and technological status to focus on. This likely requires scenarios, but so be it.

Question 5: Proposed future work

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

- Continued improvements and added functionality are important for the GREET community.
- The proposed future work will provide a good expansion for the already robust GREET tool and will clearly be of great benefit in providing excellent LCA support to the Program.
- This project should include comparisons to cost estimates and "service" or "refueling experience" provided to consumers, where they exist.
- It would be good to see more examples of components and the methods applied to lots of other components that DOE is interested in. Plans for this are not specified.
- This work will get to future technologies next, which is where it should have started. This will require formulating scenarios or alternative technological and policy contexts. That needs some attention.
- The future work involving updates and improvements to the GREET model is necessary and appropriate. Technical support for DOE-funded researchers investigating transportation-related energy and emissions is crucial. The project team needs to work with other DOE-funded hydrogen researchers to ensure consistent analyses across the DOE Fuel Cell Technology Office.

Project strengths:

- This project was carefully conducted and peer reviewed.
- The use of GREET as the modeling tool provides very credible results for this work.
- Comprehensive treatment has been given to this project, but it could do with a validation test.
- This project is consistent with the GREET framework, and its input assumptions are consistent.
- This project has a strong team with unique experience and good access to expert information.
- The GREET model is the de facto model for characterizing transportation-related energy use and emissions.

Project weaknesses:

- It would be a good idea to show how each of the collaborators and partners contributed to the analysis work.
- This project has limited collaboration and vague plans to apply methodology to other situations.
- The pathway impacts today are not important compared to the pathway impacts for 20-plus years from now.
- This project needs a broader context of storage options for vehicles, but the funding level does not allow this.
- The assumptions of hydrogen pathways within the GREET model are not always consistent with other DOE-funded models.
- The lack of system-wide impact with changing storage systems is difficult to understand. In-depth analysis of the results is needed to confirm the results presented.

Recommendations for additions/deletions to project scope:

- This project should extend to other applications and try to develop a methodology.
- This project should carefully develop a set of premises for future assessments based on when the market shares of FCEVs are likely to be large and when the stock of FCEVs is likely to be valuable. This project should consider policy contexts that are consistent with an effort to transition to low-carbon, low-petroleum vehicles.

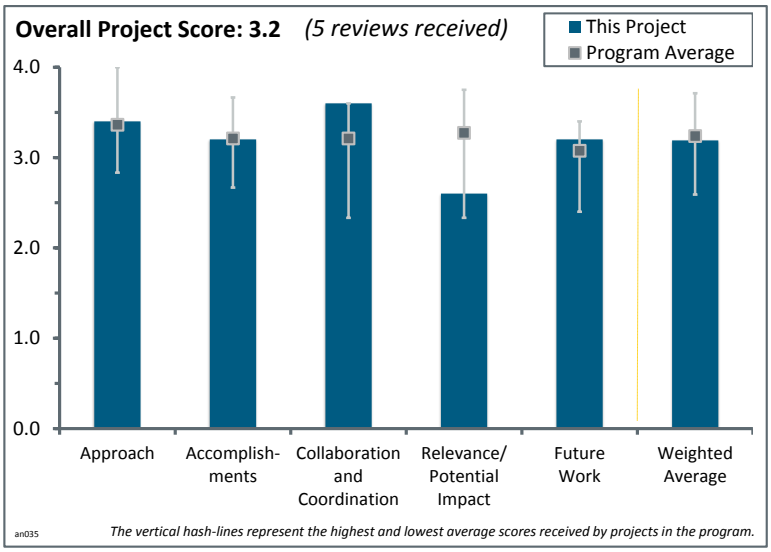
- Greater focus should be placed on operational dynamics and impacts on overall vehicle design, such as lightweighting, etc. This would be an important improvement. It seems like collaboration with other HSECoE vehicle modeling activities would be appropriate.

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

Marianne Mintz; Argonne National Laboratory

Brief Summary of Project:

This project provides a consistent platform to analyze employment and other economic impacts of alternative hydrogen and fuel cell investments and assist the U.S. Department of Energy (DOE) and stakeholders with data acquisition/validation and analysis to estimate the economic impact of deploying fuel cells and hydrogen infrastructure in early markets. The platform uses input–output economic modeling within the context of user-friendly tools—JOBS FC and JOBS H2—to calculate supply chain and induced employment, earnings, and economic output.



Question 1: Approach to performing the work

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

- This provides a methodical look at jobs creation related to technology introduction and use.
- This project makes good use of a number of different models and tools from a variety of sources.
- This project uses an excellent and in-depth modeling approach to estimate hydrogen- and fuel cell-related job growth, and includes appropriate user feedback and linkages to design parameters and costs developed through other DOE research programs.
- Other than needing more real-world data, the approach is very sound.
- One reviewer did not enter a response.

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.

- A significant amount of work has been accomplished for the amount of funding provided by DOE.
- This project has made good progress, especially given the low funding level.
- The investigators have made excellent progress in developing the JOBS FC tool and evaluating the employment impacts of fuel cell deployments funded by the American Reinvestment and Recovery Act (Recovery Act). It would be great to see this model and approach applied to transportation-related fuel cell and hydrogen infrastructure deployments.
- The various components and structure of fuel cell and hydrogen infrastructure-related jobs have been modeled well and provide a good understanding of related jobs, but more granularity, such as the types of jobs, education levels needed, temporary/long-term nature, if we have the required workforce now, etc., would provide much more realistic and useful insights.
- This tool helps advance DOE goals to show the job/economic potential of fuel cells, although results are not that impressive (assuming an outsider's point of view). This project also supports Recovery Act spending. The project is still in the process of completing other major tasks, so there is more to be done before this project is complete. The hydrogen model will be very useful, particularly since infrastructure is so far behind fuel cell manufacturing right now.

Question 3: Collaboration and coordination with other institutions

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

- This project has an excellent set of relevant partners.
- This project has reached out to appropriate stakeholders for feedback.
- Efforts to interact with many relevant stakeholders should be continued.
- This project has good collaboration with groups, customers, companies, etc.
- The project included a wide range of national laboratory researchers in the development of the JOBS FC tool and received good input from industry and industry trade groups for data collection and model validation.

Question 4: Relevance/potential impact on advancing progress toward DOE research, development, and demonstration (RD&D) goals

This project was rated **2.6** for its relevance/potential impact.

- This could be a useful tool for local and state governments to use when evaluating the impacts of new industries.
- Hydrogen models will be tremendously useful to convince key stakeholders to install stations, which are much needed for vehicle rollout.
- While this project does not directly help DOE achieve progress towards its technical targets for fuel cell and hydrogen infrastructure, it is crucial that DOE evaluate the impact of these technologies on job creation to help the broader community understand the role fuel cell technologies can play in the U.S. economy. Showing the potential for job creation will help DOE be able to provide continued funding for fuel cell and hydrogen research and development (R&D). It would be useful if the investigators could apply the JOBS FC tool and methodology to transportation-related fuel cells.
- It is not clear how these results will be used to support end-user needs. There is some concern over using results inappropriately or out of context, but it is not clear how the researchers can compensate or manage this.
- The issues of job creation and related economic impacts are valid considerations, but the findings will likely not have a significant impact on R&D goals and objectives unless more granularity is provided and these analyses are tied closely to other modeling/analysis efforts and put into context (i.e., comparison with jobs in other sectors, including other clean energy sectors).

Question 5: Proposed future work

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

- The project has a good plan to complete work in a timely manner, dependent on receiving funds.
- So many avenues could be pursued to expand this model; this project needs to focus on the most valuable to move the industry forward.
- It sounds ambitious to include novel station options, training, and combined heat, hydrogen, and power, all within a comparable budget.
- As the model is expanded, the project could consider integrating the various modules (like fuel cell, hydrogen infrastructure, and other applications) so that these components are analyzed in a more integrated and holistic way and so that interactions can also be considered.
- This project definitely needs to be expanded to hydrogen station rollouts and transportation-related fuel cells, as the investigators suggested. It would be useful to use the JOBS FC tool and methodology to understand the potential for job creation that could occur under various scenarios for fuel cell vehicle commercialization (that is, use the JOBS tool to predict job growth for potential penetrations of fuel cell electric vehicles [FCEVs]; do not limit analyses to estimations of jobs created from actual fuel cell deployments).

Project strengths:

- This project has good collaboration with key groups.
- The connection to the analysis capabilities of RCF Economic and Financial Consulting, Inc. improves on the project's methodology.
- This is a methodical approach. The principal investigator has a good understanding of the intricacies of job creation impacts.
- The JOBS model and the project's estimations of job creation provide valuable information to the administration and to legislators to support and justify continued public funding of fuel cell and hydrogen technologies.
- This project can provide some insights and answers relating to employment and economic benefits when these types of issues are of focus and answers are needed. This project can enhance the explanation of benefits for developing a hydrogen fuel cell infrastructure.

Project weaknesses:

- This project needs more granularity to be able to provide more realistic and useful insights.
- This project needs better promotion of the tool to the right people, such as investors, fuel cell companies, and especially policy makers who could create favorable policies or initiatives to entice companies to build or expand facilities once they learn about job potential.
- It is not clear how the results can be used in the appropriate policy context, especially when comparing hydrogen to other technology options. Some concerns that results may be misused include the possibility that they are not conveyed in the appropriate context. The end-user tool needs to account/control for this somehow.
- The project should be expanded to estimate job impacts beyond Recovery Act-funded fuel cell deployments. The project should expand to include transportation-related fuel cell deployments and also evaluations of transportation-related fuel cell commercialization scenarios.

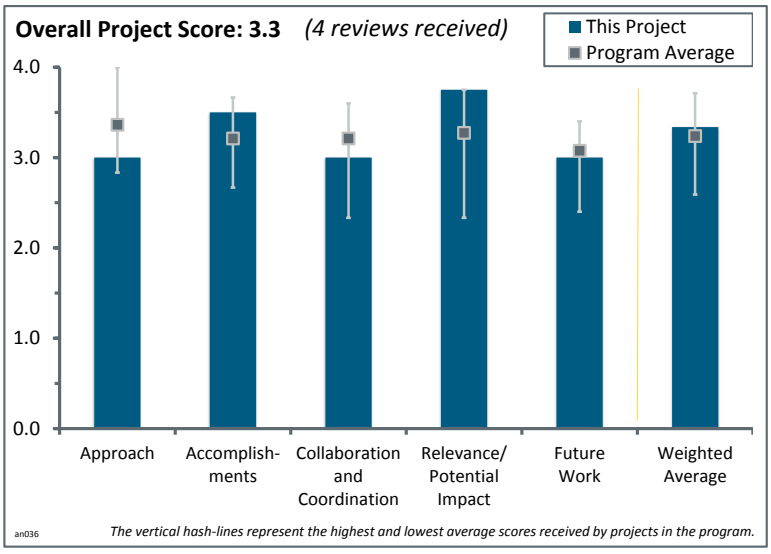
Recommendations for additions/deletions to project scope:

- The project should be expanded to include hydrogen infrastructure deployments and deployments of FCEVs.
- Factors such as the types of jobs, education levels needed, if jobs created are temporary or long-term in nature, if the required workforce is available now, etc. should be considered to provide granularity and depth to the results achieved. It would be beneficial to place the results found into context, such as showing how these numbers compare with other clean energy jobs or jobs created in other sectors.
- With Bloom Energy selling many megawatts of solid oxide fuel cells (SOFCs) to customers and expanding to the East Coast with a Delaware manufacturing facility, the tool should include SOFCs. It seems like it would add tremendous value to the JOBS tool since they are growing so much. SOFCs could also include smaller systems developed via the Solid State Energy Conversion Alliance (SECA) program and companies such as Delphi, Acumentrics, etc. for auxiliary power units and remote power. The project needs to do this first before other proposed work.

Project # AN-036: Pathway Analysis: Projected Cost, Well-to-Wheels Energy Use and Emissions of Current Hydrogen Technologies

Todd Ramsden; National Renewable Energy Laboratory

Brief Summary of Project:



The objective of this project is to conduct cost and life-cycle energy and emissions analyses of the complete supply chain of ten current-technology hydrogen pathways using the National Renewable Energy Laboratory's Macro-System Model (MSM) to evaluate hydrogen cost, energy requirements, and greenhouse gas (GHG) emissions. Detailed documentation of all input and output parameters and modeling results was developed by the project team and reviewed by industry partners. Detailed hydrogen costs and capital costs were developed for all hydrogen pathways; and upstream energy, feedstock usage, and GHG emissions were reported. The total fuel cell electric vehicle (FCEV) cost of ownership was analyzed, including fuel cycle and vehicle cycle.

Question 1: Approach to performing the work

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

- The use of the MSM for hydrogen pathway analysis provides a very good approach towards this work, as that model is based on already well-established tools such as Hydrogen Analysis (H2A), the H2A Delivery Scenario Analysis Model (HDSAM), and the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model, which provide very credible data.
- This is a highly appropriate choice of models and analysis tools. The decision to analyze current production methods and costs makes the analysis hypothetical, since by the time there are significant quantities of hydrogen produced for vehicles to justify using most of the pathways, the current production methods and costs will likely not apply. Therefore, use of current technology may seem like the most concrete and realistic case, but it is actually a hypothetical case for these pathways. This detracts not from the accuracy of the analysis but from its usefulness. It does have usefulness as a reference point: no technological change, no additional regulation of emissions, etc. For technologies that are likely to be deployed in the early transition, the cost analysis is much more useful. The peer review by the U.S. DRIVE Fuel Pathways Integration Technical Team (FPITT) is an important validation and increases the value of the research.
- The study addressed important barriers to understanding hydrogen supply costs. The study focused on near-term hydrogen infrastructure technologies but also assumed that they were deployed at large scale (for example, large-scale biomass gasifier systems with pipeline delivery to a network of stations). This was somewhat of a contradiction since FCEV market penetration is unlikely to reach these levels until 2020 or beyond (i.e., beyond the near-term technology timeframe). Overall, the time frame of the analysis needs to be clarified. It is unclear how the near term is defined. Some important near-term supply routes, such as central steam methane reforming (SMR) with truck delivery, were not considered. This seemed like an important omission, as nearly all hydrogen transportation fuel for the next five years will probably come from this pathway. Also, it would be helpful to see how the various hydrogen pathways' GHG emissions compare to other fuels and electricity.
- The approach appears to be valid but perhaps not sharply focused enough. A concern is the results from the various modeling tools. It is not clear if the results are validated. The data sets are so diffuse it is somewhat

hard to see if the results might not be undermined by a simple spreadsheet error. It is not clear what the safeguards are.

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 accomplishments of this work are very good, and the results for all the current hydrogen pathways have been reported in a very clear and detailed form.
- Although the final report is not yet published, progress towards the stated goals of the project is impressive and the report will undoubtedly will be published soon.
- Lots of work has been done, which is gratifying, but some validation tests would be more convincing.
- This study did examine costs and emissions for a variety of pathways at large scale. It would have been good to see comparisons of the results with other modeling efforts that have estimated the entire supply chain cost (for example, studies of the National Research Council of the National Academies on hydrogen, academic studies, etc.). It is unclear how the results compare to industry estimates.

Question 3: Collaboration and coordination with other institutions

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

- It seems like there was a good review of assumptions through FPITT.
- It was very good collaboration to include national laboratory and industry feedback through FPITT.
- The collaborative activities are not clearly described. Collaboration is only with national laboratory sources. It would be better to use industry sources as well as government sources.
- There is good collaboration and good use of the FPITT for peer review. Different stakeholders have different views of what the status of the technology for each pathway will be by the time the pathway might be used in the future. These views need to be somehow systematically considered in deciding on the premises for the analysis.

Question 4: Relevance/potential impact on advancing progress toward DOE research, development, and demonstration (RD&D) goals

This project was rated **3.8** for its relevance/potential impact.

- This is clearly very relevant, as it guides other research goal setting. Thus it needs a better validation test.
- The systematic evaluation of these pathways for cost and lifecycle emissions is critical to the overall systems analysis effort.
- Estimating the costs and emissions for different pathways is highly relevant to DOE's Hydrogen and Fuel Cells Program (the Program). This project combined models to accomplish this. The impact of the results could have been improved by a more careful definition of timeframe and focus.
- This work is very relevant to Program goals, as it provides a detailed cost and lifecycle energy and emissions analyses of several hydrogen pathways. This work will provide good guidance towards the initial rollout of FCEVs and hydrogen infrastructure.

Question 5: Proposed future work

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

- The evaluation of pathways using future technologies is essential. There is also a critical need to understand how pathways will evolve and change during a multi-decade transition.
- It would be interesting to see results for future technologies. The principal investigator should also consider how the grid might be de-carbonized by then.

- The proposed work of including pathway analyses for advanced hydrogen technologies is a good complement for the actual work, but since the project is complete, it is not very clear how this will move forward.
- This question is not applicable as the project is completed.

Project strengths:

- This is a relevant and comprehensive study providing important information.
- The use of well-established modeling tools is a strength of this project.
- The choice of modeling tools, rigor of the analysis, and peer review are all strengths.
- This project combined well-developed existing DOE models via MSM to look at important problems.

Project weaknesses:

- As the project is complete, it is not very clear how the proposed work will move forward.
- The validation of methods and data is a weakness. It is not clear if the tools use spreadsheet methods and whether that could cause errors.
- The timeframe needs to be better defined. Some key pathways were missed (such as central SMR with truck delivery).
- The key focus should be on future technologies and the evolution of the system jointly with other energy supply and conversion systems and with manufacturing methods. The case in which an economy transitions to hydrogen-powered vehicles and greater use of fuel cells while failing to reduce GHG emissions from electricity generation and other key systems should be considered an unusual (probably illogical) scenario.

Recommendations for additions/deletions to project scope:

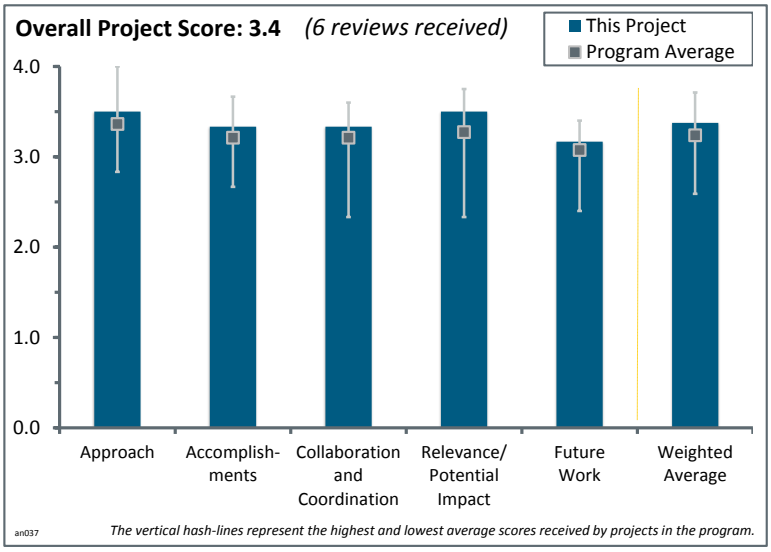
- This project concept should keep going and should give greater attention to advanced liquefaction pathways.
- There should be a comparison between well-to-wheels GHG results and other fuels/vehicles. Researchers should compare cost results with other studies.

Project # AN-037: Hydrogen from Biogas: Resource Assessment

Genevieve Saur; National Renewable Energy Laboratory

Brief Summary of Project:

This project addresses resource availability for renewable hydrogen, which provides alternatives to traditional sources of hydrogen, hedges against fluctuation in costs and demand for fossil fuels, and aids compliance with state policies for renewable fuels. The project updates prior studies on hydrogen from methane from wastewater treatment, landfills, and manure management, and expands analysis to include methane from industrial processes and organic food waste. Biogas has a diversity of geographic availability and can help support early market fuel cell electric vehicle rollout.



Question 1: Approach to performing the work

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

- This project addresses the quantity and locations of biogas sources with estimates of vehicles that could be supported by the sources, and also includes economics and potential application models for future work.
- The inclusion of waste water treatment plants (WWTP), landfill gas, animal manure, industrial sources, and organic food waste for the resource assessment is a good approach. Also a good contribution to this work is the expansion of the analysis to include net availability by assessing resources currently in use.
- This is an important area to investigate; using waste for fuel solves many environmental problems on top of emissions, such as reducing solid waste, etc. Working with different government agencies to obtain data and final products has real-world value. It is key that animal waste as a source is part of the approach. This is a very targeted methodology and should yield accurate and useful projections.
- The project has a very clear approach to the problem of assessing biogas resources, with methods and data sources clearly stated. Geographic information system (GIS) tools are excellent for visualizing results. This is an excellent approach to helping understand this resource and addressing DOE Hydrogen and Fuel Cell Program (Program) barriers with respect to information on renewable resources for hydrogen production.
- Two reviewers did not enter a response.

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.

- This project appears to be on track to meet the proposed scope of work.
- The initial estimates presented show some good progress toward meeting the main work objectives.
- This project is moving along very well in terms of addressing its goal of assessing biogas as a resource. The methodology has been implemented for some cases. The presentation of the results was clear and concise. The project needs to establish that this is reasonable progress (30% complete) considering that the project ends in approximately two months. It is unclear if there was an issue with timely funding because of continuing resolutions or if there were other issues.
- Determining the net amounts of resource availability will result in a more accurate and complete estimate.
- The project is not complete, but it has made substantial progress so far with projections and mapping.

Question 3: Collaboration and coordination with other institutions

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

- This project has had good collaboration with key government agencies, such as the Environmental Protection Agency (EPA), U.S. Department of Agriculture (USDA), etc.
- There seems to be some good collaboration with EPA and USDA for the data sources.
- There is appropriate collaboration with DOE, national laboratories, USDA, and the industry.
- This project uses a variety of source data and partners, such as the USDA.
- This project has good awareness and utilization of data sets from other organizations. The audience pointed out opportunities for further collaborations.

Question 4: Relevance/potential impact on advancing progress toward DOE research, development, and demonstration (RD&D) goals

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

- This project has a very large impact. This is one of the areas that need to be focused on.
- Hydrogen from biogas is relevant to DOE, as it is one source of renewable hydrogen.
- Utilizing biogas resources provides a renewable hydrogen pathway while also serving as a value-add to waste management processes and environmental considerations.
- The project supports the concept of using waste as a hydrogen resource. The concept is highly appropriate; key information, analysis, and models to support decisions and specific applications are intended for future work.
- This project definitely supports DOE goals and could help alleviate the need to build hydrogen stations by utilizing WWTPs, landfills, and farms to generate hydrogen. This project also helps by acting as a showcase for using waste in a way that not only provides clean fuel for fuel cell electric vehicles but also eliminates costs and environmental problems associated with solid waste, burning or flaring gas, etc.
- This is an important and relevant topic to Program goals. Strictly on a resource basis, biogas appears to be a near-term renewable source for hydrogen that could fuel a percentage of the U.S. fleet if fuel cell vehicles were fueled with biogas-derived hydrogen. To judge the competitiveness of biogas and hydrogen, the quality of the hydrogen obtained and the costs still need to be assessed, but that assessment is not part of this project.

Question 5: Proposed future work

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

- The proposed techno-economic analysis and the cost and biogas quality implications will be very good additions to this current work.
- There is a good plan for follow-on work. Biogas availability might also be correlated with analysis of combined heat and power (CHP) and combined heat, hydrogen, and power (CHHP) options.
- The future work, including additional feedstocks, economic analysis, and costs, is appropriate and should be undertaken. The existing work is currently not sufficient to support decisions and applications.
- Looking into biogas quality requirements and related costs will aid in determining the feasibility of these pathways, while assessment of biogas from industrial processes and food waste will highlight other potential renewable hydrogen pathways. Both aspects are important to gaining insights which will be valuable to related research and development.
- This project has lots of potential for future work. Including lipids could open a new market with fast food restaurants. This project needs to publicize its findings and report them to key stakeholders and markets, such as industrial farming, etc.
- The project needs a better tie-in with competing sources. Clean-up costs need to be incorporated, but it seems like this is already in the plan, which is good. An analysis of pipeline-ready gas is also needed.

Project strengths:

- This is a very important project. The assessment seems sound.
- Biogas-to-hydrogen is relevant to DOE as a source of renewable hydrogen.
- This project is low cost and serves as a good first step to identifying the source, quantity, and locations of hydrogen feedstocks.
- This project highlights the potential of a resource that is normally a waste but can provide a renewable hydrogen production pathway.
- This project is innovative, showing how to create an opportunity from waste. This project is useful and necessary, especially with the gap in hydrogen infrastructure development.
- The methodology was well thought-out and executed. This project addresses important issues assessing near-term renewable resources for hydrogen production from biogas.

Project weaknesses:

- The limited funding restricts the scope of this project.
- The project should be sure that all relevant data sources are included.
- To be really useful, there should be a better assessment of how hard this source of methane would be to use as "dirty" gas. This gas could be burned, but it is unclear whether there are extra costs related to the conversion to hydrogen.
- There are still a lot of issues that need to be resolved in order to gain a full understanding, such as the cost of biogas clean-up, competing uses, net resource amounts, etc. Without these factors investigated, the full and real potential of this pathway cannot be defined.
- The existing work is limited and is not directly tied to future work unless additional funding is provided. Additional work should be considered for funding with the objective of providing analysis/creating economic models to support decision making. Additional work should also consider models that include the value of waste management, greenhouse gas (GHG) reduction, and applications for electricity and thermal energy for comparative purposes.

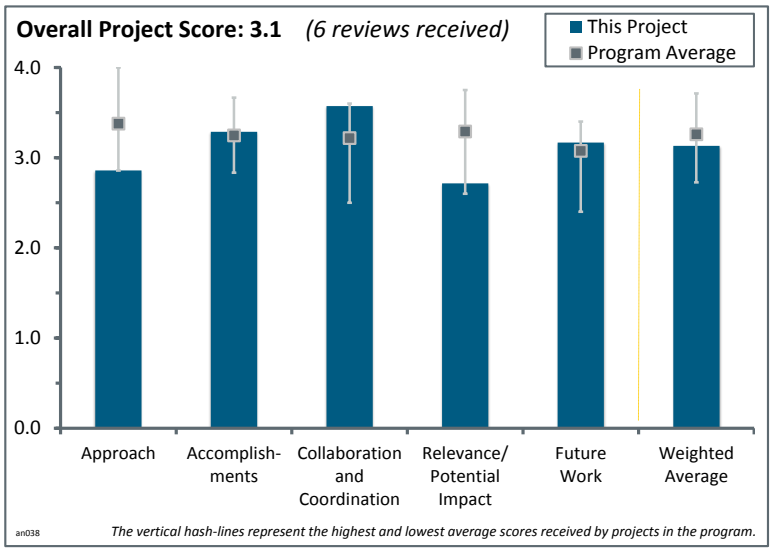
Recommendations for additions/deletions to project scope:

- The plans to incorporate cost are good.
- This project could also correlate biogas availability with regional analysis of CHP and CHHP options from biogas.
- This project should compare the costs of biogas clean-up, processing waste-to-hydrogen-to-removal (solid waste), and environmental clean-up (solid waste lagoons spilling into soil, water, etc.).
- This project could consider future trends in biogas availability. City population, waste resource availability and distribution, etc., should be considered. For example, as landfills fill up and waste treatment/handling methods change, population increases, etc., the nature of the availability and the quality of related feedstock for biogas will also change. It is important to also consider other competing uses of biogas.
- Additional work with the objective of creating analysis/economic models to support decision making should be considered. Additional work should also consider models that include the value of waste management, GHG reduction, and applications for electricity and thermal energy for comparative purposes. Also, the project may be of more value if additional clean-up systems (in addition to steam methane reforming) are considered and assessed within the project analysis.

Project # AN-038: Global Hydrogen Resource Analysis (Hydrogen Implementing Agreement, Task 30A)

Tom Drennen; Sandia National Laboratories

Brief Summary of Project:



This project aims to analyze potential hydrogen production and distribution pathways for countries participating in the International Energy Agency (IEA) Hydrogen Implementing Agreement (HIA) Task 30 (Global Hydrogen Systems Analysis), the overall goal of which is to perform comprehensive technical and market analysis of hydrogen technologies and resources, supply and demand related to the projected use of hydrogen in a low-carbon world. Another objective of Subtask A is to develop a user-friendly pathways analysis tool that allows users to understand the resource options and constraints to meeting future hydrogen demand for various fuel cell electric vehicle market shares, as well as to estimate potential petroleum savings and greenhouse gas emission reductions associated with various scenarios.

Question 1: Approach to performing the work

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

- The study has a very comprehensive scope looking at hydrogen supply options in a diverse set of countries. The study sought information about future hydrogen supply within the context of each country, rather than imposing a standard view. This open-minded approach was good in that it was more likely to elicit country-specific information and give a more nuanced global view. The study did set up a single model, which optimized the system for low cost in each country separately. It appeared from the presentation that the constraints and policies were varied by country. This gives a more realistic view of which resources were most likely to be developed, which seems like a possible approach. But it did make the results more difficult to interpret, unless these constraints and policies were cataloged during the project. The study did address a key need for the DOE Hydrogen and Fuel Cells Program (Program) to know more about international markets and supplies of hydrogen, and the study filled in information gaps.
- Development of a hydrogen pathway analysis tool for consistent analyses coupled with country-specific data is a good approach to conducting multi-country hydrogen production and delivery evaluations. Development of a hydrogen analysis tool by leveraging the U.S. Department of Energy's (DOE's) work on Hydrogen Analysis (H2A), H2A Delivery Scenario Analysis Model (HDSAM), and the Macro-System Model (MSM) is an excellent way to reduce development time and costs and ensure consistency with hydrogen analyses conducted within the United States. There are a number of U.S.-specific analyses of resources available for hydrogen production, full hydrogen pathway costs, hydrogen pathway greenhouse gas emissions, etc. It would have been better if this investigation could tie into and build on those efforts rather than replicating them.
- This high-level modeling approach allows for international communication of goals and intentions for hydrogen production pathways. The approach is, however, missing a key near-term low-carbon pathway: steam methane reforming plus carbon capture and sequestration. Additionally, long-term carbon negative pathways, such as biomass/algae gasification plus carbon capture and sequestration, are not shown. The global impact of these two pathways may be critical for economic management of transportation carbon dioxide emissions.

- The approach needs to ensure greater rigor in methodology and consistency across inputs from different countries. The project should have integrated this work with an existing global energy model and existing global energy resource estimates, especially with such limited funds.
- The background on this project is not clear. It is unclear if this project's purpose is to simply keep track of what others are doing so that the United States does not miss anything, if the team is trying to do a global market assessment, or if this a case of "all boats rise with the tide."
- It seems this is chiefly a tool for facilitating dialogue and for satisfying the requirements of an IEA implementing agreement. However, this method is susceptible to inconsistencies in assumptions across various countries. The means of resolving such problems appears to be ad hoc dialogue. There appears to be no method for ensuring consistency in assumptions about competition for feedstocks. This results in a rating of only "fair," but there are probably institutional constraints that led to the adoption of this approach; however, these should have been explicitly stated. Nonetheless, this rating might be too harsh. The use of a "least-cost" approach, given the means of obtaining input data and the decision not to rigorously validate the data provided by countries, seems inconsistent. This is a "what-if" model in which countries can input whatever data and assumptions they wish without a mechanism for checking consistency across countries; thus, the meaning of a least-cost solution for each country is unclear.

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 seems to be accomplishing the goals it set out to do.
- The project has made good progress on a very challenging scope. A large amount of information on hydrogen supply has been organized into an optimization framework.
- The model has been developed and used in interactions with countries. Discussions have been held with the countries involved; however, many country-specific inputs have yet to be entered in the model.
- There appears to be significant progress but little reassurance about the quality of the tool, the fidelity relative to other models, or consistency in relative resource availability across countries.
- It is acknowledged that each country has a different mindset. The development of this model is a practical stride forward for anticipating global impacts from different hydrogen pathway choices.
- There appears to have been good progress on analyzing hydrogen production and delivery pathways for a number of countries (especially European Union countries). It is not always clear whether the pathway analyses were conducted by the project team or through parallel efforts by other IEA member countries. Though this is an effort to analyze hydrogen pathways across multiple countries, it would be good to see more U.S.-specific results so that these results can be compared to other similar DOE-funded analysis efforts occurring in the United States.

Question 3: Collaboration and coordination with other institutions

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

- The project is all about collaboration, and it appears that this objective has been satisfied.
- The collaboration with other countries through the IEA seems very good. The process of working through the HIA seems robust and productive.
- This is obviously the project's strength. There may be almost too many partners, but that is to be expected with global scope.
- It is not clear how effective collaboration is accomplished across such a long list of international collaborators. It may be the right list of collaborators, but there is some concern about effective and clear communication.
- This project includes an impressive array of collaborations with other IEA member countries, indicating a high degree of coordination and leveraging of country-specific research and analysis efforts. More collaboration with researchers within the United States would have been preferable to ensure consistency with the modeling, assumptions, and findings of U.S.-led hydrogen research. Additional collaboration with

DOE-funded investigators in the United States would be useful to better leverage DOE's funding of hydrogen research.

Question 4: Relevance/potential impact on advancing progress toward DOE research, development, and demonstration (RD&D) goals

This project was rated **2.7** for its relevance/potential impact.

- The topic is highly relevant to the Program. A major "big picture" conclusion from the study was that resource availability is not a limiting factor for hydrogen production. This has been known for a long time through other DOE studies and other IEA studies. So what seems different about this study is the attempt to understand the different contexts within each country when doing an optimization.
- If resource availability is not a limiting factor and the least-cost analysis is not robust (i.e., high fidelity with other cost models), then it is not clear what the relevance or potential impact will be (positive or negative) of making this model available to the general public.
- It is difficult to understand what the final outcome will be. If it is to foster interaction and cooperation, then this is relevant, but from a technical point of view, the project does not result in a single tool, which makes results hard to harmonize and use.
- While this effort seems to have helped countries learn from each other and start to perform analyses on a more consistent basis, there are too many considerations/assumptions, differing values, policies, etc., and each country will follow its own path. While the effort aids in some learning, this project cannot make everything completely consistent across the countries, and this effort does not seem like it will have a critical impact/benefit on DOE's RD&D objectives.
- The presentation leaves one with the impression that this is largely an exercise required by an IEA implementing agreement and that not much of substance is expected to result. Of course, that impression could be incorrect. This makes the project difficult to rate on this criterion. If this impression is correct, there is still a need for such exercises in the context of international collaboration.
- Collaboration with international groups and researchers outside the United States is a vital component of furthering fuel cell commercialization and development of hydrogen infrastructure. Though international collaboration is needed, the project team did not provide a good understanding of how this effort would help overcome specific barriers and technical challenges listed in the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan (MYRDDP). The project team should help develop feedback mechanisms to better ensure that the findings of this project tie back into the MYRDDP to overcome challenges and barriers to widespread fuel-cell commercialization.

Question 5: Proposed future work

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

- The future work proposed seems appropriate.
- The project is wrapping up; the report and journal article will be peer-reviewed.
- Perhaps the best use of insights gained from this effort is in creating a place for hydrogen and fuel cells in the overarching analysis of the IEA, thus improving visibility.
- The proposed work is appropriate to bring the project to a close and disseminate the results within IEA. It would also be good to see some comparisons with other IEA work (for example, Energy Technology Perspective series or the Mobility Model). In addition, it would be great to catalog the different policy contexts in each country and discuss how this influences the choice of hydrogen pathways in different countries.
- Completing a final report on this investigation to share results and insights with IEA analysts and the hydrogen and fuel cell community overall is crucial. Final results should emphasize lessons learned and sensitivity analyses to better understand the requirements necessary for commercialization of fuel cell vehicles.

Project strengths:

- This project is highly collaborative and interactive.
- The project's international partners and good, broad look at the world are strengths.
- This project has strong international collaboration and cross-country analyses of hydrogen production and delivery pathways.
- The goal of "performing a comprehensive technical and market analysis" is admirable, especially in a global context and for a low-carbon future.
- This project is very comprehensive. This is an excellent attempt to gather information, project future hydrogen pathways, and organize findings into a useful tool. This project provided a good tool to stimulate discussion in the worldwide hydrogen community.
- Discussions amongst various countries/stakeholders and an attempt to follow similar/consistent methods can provide some learning and guidance, helping countries identify issues or factors they had not considered before.

Project weaknesses:

- There are not any real weaknesses, but making sense of the results in diverse countries may be challenging.
- The results may be hard to use.
- This project lacks validation and checks for consistency across countries.
- There are too many stakeholders and too many diverse assumptions and considerations.
- It is not clear why a stand-alone modeling approach was used to pursue the goal of the project. Multiple international energy market models exist. The scope of the project is very ambitious, and it would require significant resources to complete a high-quality product.
- This project needs to better integrate analysis efforts with similar efforts conducted within the United States and funded by DOE. This project seems to replicate a number of analysis efforts that have been conducted within the United States. The project should do more to leverage and build upon these efforts to better ensure consistent assumptions and findings. The project should provide better feedback to DOE to help understand where additional resources and research and development is needed within the United States to aid commercialization of fuel cell vehicles, and also to share lessons learned by other countries.

Recommendations for additions/deletions to project scope:

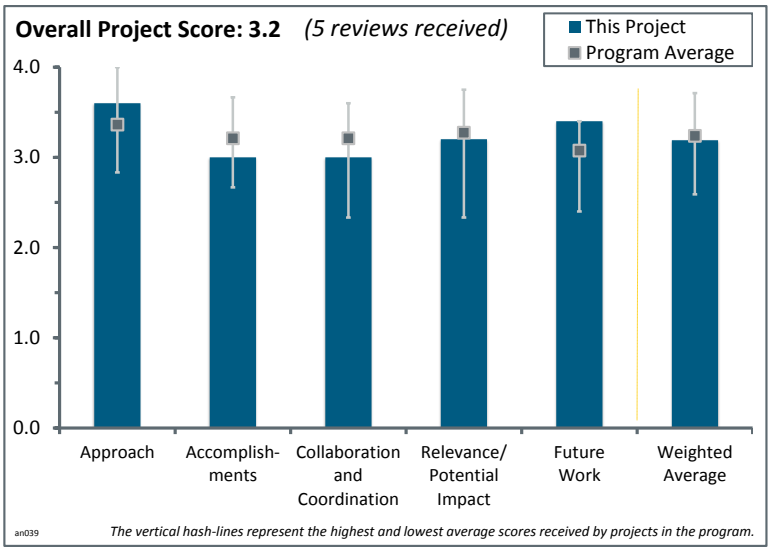
- The team should follow through with this project and wrap it up.
- This project should try to harmonize methods so countries are more comparable.
- The project should make sure all the value is extracted from the learnings in different countries. These should be written up as part of the final report. This should also be compared with the results of other, less granular global assessment models, such as IEA-MARKAL modeling.
- It would be very useful to include strategic implications of national hydrogen policies, for example, evaluating first-mover advantage/disadvantage. In light of global plans for hydrogen production, such implications should start to be visible.

Project # AN-039: Life Cycle Analysis of Water Use for Hydrogen Production Pathways

Amgad Elgowainy; Argonne National Laboratory

Brief Summary of Project:

The objectives of this project are to 1) establish a baseline of life cycle water consumption for baseline fuels and feedstock sources; 2) evaluate water consumption for hydrogen production processes; 3) assess the impact of feedstock sources on life cycle water consumption for hydrogen production; 4) identify major contributors in the upstream supply chain to water consumption of hydrogen pathways and identify improvements for more efficient water use; and 5) identify vulnerabilities with respect to resource availability by region for large-scale hydrogen production.



Question 1: Approach to performing the work

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

- This project has a well-defined scope and clear approach.
- The project approach is quite simple: integrating a power water model into the existing analysis framework to track water consumption. This approach is very logical and economical (as it builds on existing models).
- The project addresses a critical issue for future energy, including hydrogen. It builds in a logical way on existing Argonne National Laboratory (ANL) water models and on the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model to address questions.
- The approach seems competent and adequate, but the project has not yet been implemented, so what is wrong is not yet evident. The approach should be refined as the project proceeds.
- It is a good approach to add water consumption to the GREET model for all fuels, but this project may only address water use for hydrogen production. Information and models for water consumption for all fuels are needed to support comparative analysis and decision making.
- It is unclear how well the model will handle regional issues. Using this model may require coupling with other information about regional water flows. This part of the approach could have been more fully explored (e.g., how to use this model).

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

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

- Progress seems to be proceeding according to schedule.
- Progress is consistent but limited owing to a constraint and/or delay on funding.
- The project just started and thus has few accomplishments at this point.
- This is not really applicable because of the lack of funds. Accomplishments should be expected to roll in when funds arrive.
- The project has just been funded, so it is hard to assess progress so far. It seems like this project is off to a good start and will add value to the GREET model, and can help provide water use information to enable

regional life-cycle cost analyses as well. The initial evaluation includes plans to examine several hydrogen pathways that are major water users.

Question 3: Collaboration and coordination with other institutions

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

- There is appropriate collaboration with DOE and ANL, and informal collaboration with the U.S. Environmental Protection Agency and the U.S. Department of Agriculture.
- It looks like there will be good collaboration within the ANL group. The project should look at the work of other groups in this area as well.
- The principal investigator and his team have lots of experience and a history of collaboration with many outside groups. The reviewer is confident there will be substantial collaboration and vetting of assumptions. However, the slides presented do not really make this case.
- Collaborations are not strongly evident in the presentation.
- There is not really enough information to judge, but it seems as though there is good collaboration with other institutions.

Question 4: Relevance/potential impact on advancing progress toward DOE research, development, and demonstration (RD&D) goals

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

- Water availability is an often overlooked resource, and this is a timely and important study.
- Water use for energy is a highly relevant topic, and the proposed study should improve the utility of DOE's modeling toolkit.
- Inclusion of water consumption as one of the decision criteria in the GREET model is highly valuable for comparative analysis and decision making.
- The potential impact is unclear; water is an important issue.
- There is a need to comprehensively tabulate and compare water usage among production options. This program will do that in a thorough and complete way. However, a high degree of accuracy is not particularly needed, and thus a faster, less-accurate tabulation might achieve the same impact.

Question 5: Proposed future work

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

- The plans look fine.
- Because the project has just started, virtually all work is in the future.
- The project has been planned but not yet implemented. There do appear to be several alternative scenarios accounted for as the project is implemented
- The proposed work is good, but all fuels, including hydrogen, must be assessed for water consumption and included in the GREET model for effective comparative analysis.

Project strengths:

- The approach and plan appear to be sound, and the project is relevant and important.
- Water and energy are key topics. This builds on well-established ANL models, such as GREET and water models.
- The completion of a GREET model for water use for comparative analysis for all highly valuable fuels is a strength.
- A highly experienced team is conducting this project. It builds on existing analysis models and general GREET computational framework.

Project weaknesses:

- Progress is minimal owing to a lack of funding.
- There is a potential that the disruption of funding could result in gaps that challenge the effectiveness of the project for comparative analysis of all fuels.
- The project needs to show how the updated GREET with water modeling could be used in a regional context. The project does not need to actually do a regional analysis, but just indicate how it might be done.

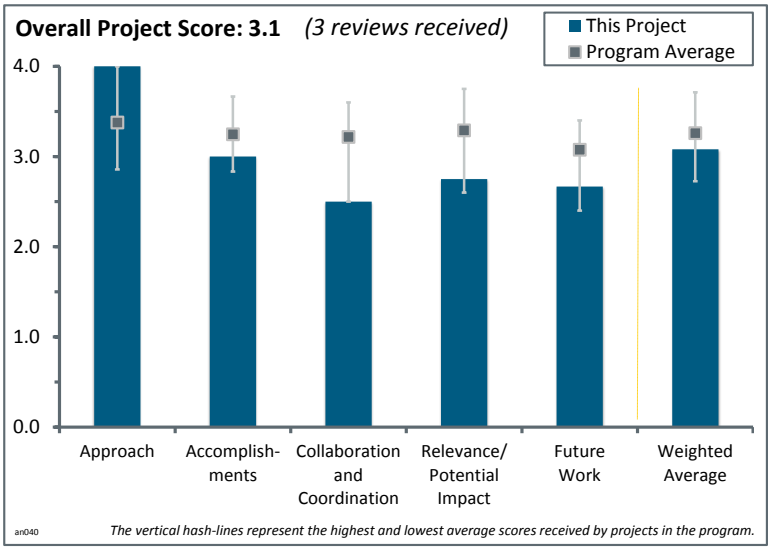
Recommendations for additions/deletions to project scope:

- The project should add regionalization.
- The project team should see what happens once the funding has been used to implement the project.
- The project should increase or confirm the scope of work to include a water analysis in GREET for all fuels.

Project # AN-040: Analysis of Fuel Cell Integration with Biofuels Production

Mark Ruth; National Renewable Energy Laboratory

Brief Summary of Project:



Objectives of this project include reviewing biomass processing options being developed; identifying opportunities for fuel cell integration with a focus on combined heat, hydrogen, and power (CHHP) options; and estimating how integration of fuel cells into biorefineries may affect levelized biofuel cost in both CHHP and combined heat and power (CHP) configurations. Future benefits may include reductions in greenhouse gas emissions, hedging against market volatility, increased reliability, and improved resilience. Analysis focuses on the cost competitiveness of CHP and CHHP systems in fast pyrolysis biorefineries. Other potential options for industrial use of fuel cells are also evaluated.

Question 1: Approach to performing the work

This project was rated **4.0** for its approach.

- This project has a clear approach.
- This is a very thorough analysis, examining several possibilities. This project demonstrates the value of such studies very well.
- The project builds on existing analysis tools to explore a specific scenario (fuel cell CHP or CHHP in a fast pyrolysis plant). The approach and presentation are well organized and clearly presented.
- The project studied the potential application of natural-gas-fueled CHP and CHHP fuel cell systems in biorefinery applications. It has a clear problem statement. The project looked for a biorefinery process that required hydrogen as an input. The problem is interesting in terms of looking for possible markets for stationary fuel cells in an industrial setting.

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

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

- The progress is good, as the project is almost complete.
- This project is now complete and provided good value for the funds expended.
- The project was well executed and logically organized and presented. Unfortunately, the results of the case study did not show a benefit of CHP or CHHP integration. Nonetheless, the analysis needed to be conducted to determine this result.
- The project made a detailed comparison of system performance and cost for a variety of input parameters. The results were not very promising for using fuel cells in this application. Only a few situations within a large parameter space showed an advantage for adding a fuel cell to the plant design. The explanation of the results could have been a bit clearer. In particular, it is unclear what the prospects are for processing hydrogen as part of the CHHP system as opposed to producing it in a steam methane reformer. It is not clear if there are situations where it is advantageous, likely, or unlikely.

Question 3: Collaboration and coordination with other institutions

This project was rated **2.5** for its collaboration and coordination.

- This project has good coordination with other institutions within DOE.
- Good collaboration was demonstrated by using the existing national lab models and coordinating with the DOE Bioenergy Technologies Office.
- This project drew on earlier DOE work on biorefinery design. It is unclear if other collaborations were included. It might have been interesting to look at other groups doing biorefinery design.
- The collaborators are limited. The presentation mentioned other collaborators that are not listed in the slides. It is difficult to determine how well the coordination works.

Question 4: Relevance/potential impact on advancing progress toward DOE research, development, and demonstration (RD&D) goals

This project was rated **2.8** for its relevance/potential impact.

- The good use of biomass is very relevant for renewable hydrogen. This topic is very important to the future of hydrogen credibility.
- This project is relevant but not critical to the DOE Hydrogen and Fuel Cells Program.
- This project merits a “good” rating with respect to relevance but only a “fair” rating with respect to the impact, as the pathway examined is not any better than the baseline approach.
- The study was a worthy analytic effort to explore the potential for fuel cell CHHP in a particular biorefinery process. The potential impact of a basically negative result is unclear. It is not clear if there are more general conclusions to be drawn or other situations where CHHP would be more promising.

Question 5: Proposed future work

This project was rated **2.7** for its proposed future work.

- The proposed plans are general/non-specific.
- This question is not applicable, as the project is completed.
- This project could be focused more on other promising options. The examination of greenhouse gases is a good idea. The system analyzed used natural gas, but biogas as a feedstock could also be examined.

Project strengths:

- This is an interesting case for hydrogen and power production.
- This project has a good approach and thorough analysis and was well presented.
- This is a logical, well-executed analysis. This was an investigation of CHP/CHHP integration where the result really was not known ahead of time.
- This project did a comprehensive technical economic analysis of a particular biorefinery process to assess the idea of adding fuel cell CHP and CHHP systems.

Project weaknesses:

- This project did not have sufficient collaboration, and it was not clear how the biofuels producers will react to the results.
- It is not clear if general conclusions can be drawn about using fuel cells for CHHP in process plants. More promising designs and the larger meaning of this study need to be identified.

Recommendations for additions/deletions to project scope:

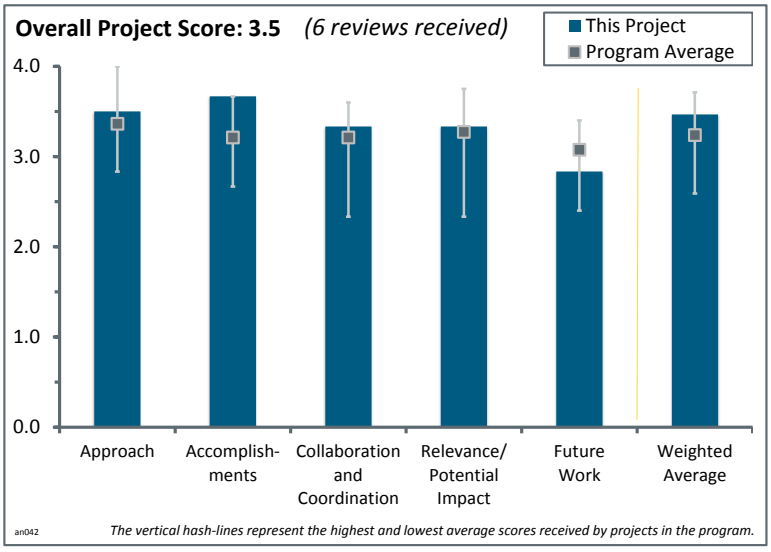
- No responses.

Project # AN-042: Hawai'i Hydrogen Initiative (H2I) Financial Scenario Analysis

Michael Penev; National Renewable Energy Laboratory

Brief Summary of Project:

This analysis helps identify opportunities and constraints for equity, debt, and public financing in the fuel cell electric vehicle (FCEV) market. The study considers vehicle adoption rates, determines infrastructure support requirements, evaluates a full range of operating expenses, applies a competitive revenue ceiling, performs accounting cycle analysis, and performs multi-year financing projections. The deployment and financial model indicates stations would need subsidies to support capital and operational expenses because of low capital utilization of early stations, and debt and equity investments will be critical to early market introduction and subsequent adoption.



Question 1: Approach to performing the work

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

- This is a well-constructed program that explores a specific hydrogen infrastructure build-out (Hawaii) and uses existing tools to conduct scenario analysis.
- The approach to the Hawaii problem is excellent. One thing to consider is whether Hawaii is an appropriate case compared with the rest of the United States, as Hawaii has relatively short drive distances. The driving range per fill assumed for the model is not realistic at present for most FCEVs.
- This is an excellent approach that includes adoption rates, costs, revenues, incentives, financing, sensitivity analysis, cash flow, pricing, and revenue shortfalls. The model would provide flexibility to modify local input data. This approach would support planning for development and deployment in other areas.
- This project was well-designed and successfully addresses the business case for hydrogen fueling stations. The work is carried out using a solid techno-economic basis. It is not clear, however, how it addresses the stated barrier of "stove-piped/siloed analytical capability."
- The approach seems appropriate given the scale of the project. It is integrated with other efforts. More information on the ADOPT sales model is needed to see how station siting and vehicle adoption are linked. It is unclear if this project addresses FCEV market competition with electric vehicles (EVs) or plug-in hybrid electric vehicles (PHEVs).

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

This project was rated **3.7** for its accomplishments and progress.

- This project has made excellent progress on the problem. A thorough treatise is presented on the issues that need to be considered, and the models appear to work well.
- This project has made good progress. This is a nice case study, but it would be good to see how an island situation translates to a mainland situation.
- Analysis, model, and conclusions are appropriate and highly valuable for Hawaii and potentially for other regions.

- Significant progress was made toward understanding the hydrogen infrastructure as it might build out in Hawaii's non-standard situation. The project has many elements, which must be examined together. This makes the project challenging.
- The results make it clear that the business case for hydrogen fueling stations is very challenging. The results should help to make it clear that additional cost reduction for hydrogen production, delivery, and dispensing, together with subsidies and incentives, will be needed to make a case for private investment in hydrogen fueling stations.

Question 3: Collaboration and coordination with other institutions

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

- This is excellent; the number and variety of the participating partners are impressive.
- The results from this analysis (and other regional analyses in the future) should be used in communicating with key decision makers and investors.
- The team seems to draw upon a diverse set of contributors.
- Some work from other institutions was incorporated.
- The collaboration is good, but additional input from other original equipment manufacturers (OEMs), gas suppliers, and regions would increase value.

Question 4: Relevance/potential impact on advancing progress toward DOE research, development, and demonstration (RD&D) goals

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

- The approach is highly valuable and timely as auto and refueling OEMs consider rollout and the government considers program incentives.
- This project significantly advances understanding of the potential factors affecting FCEV use in Hawaii. This understanding clearly shows the need for incentives in the near term (and potentially in the long term, also).
- The relevance issue is obscured by whether the Hawaii case translates to the rest of the country.
- This is a nice end-to-end analysis, but how this relates to other non-island situations needs to be demonstrated more, even if this is just the modelers' estimations.
- As the eventual discussion needs to consider both technical and financial factors, this project is a step in the right direction. Until now, analyses had been too focused on only technological factors.

Question 5: Proposed future work

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

- The future work looks appropriate, but it would be good to see a little more work (or explanation) on the market uptake of vehicles and competition with alternatives.
- The additional refinements are appropriate, with input from OEMs, gas suppliers, regional coordinators/government, and financing/developers to test assumptions.
- The model developed and analysis conducted for Hawaii serves as a good structure and baseline to perform similar analyses in different regions of the country. The model will serve as a valuable tool in understanding what is needed for deployment elsewhere, and eventually nationwide.
- This project does not have any future work planned.
- The project is completed, but there are plans to develop other cases in more representative locations.
- The present study lays out the overall challenge. Any future work to further refine the model would provide little benefit.

Project strengths:

- This project presents a complex scenario in a logical fashion and uses existing models in an appropriate and logical manner to consider a Hawaiian scenario.
- This is a detailed and realistic analysis of a deployment scenario that could be replicated in other locations.
- This project incorporates financial factors, which is a critical element in planning deployments, making results more realistic, and making better guiding decisions.
- This project has thorough treatment of the issues and considers two good cases. The project could have been stronger with an intermediate scenario.

Project weaknesses:

- These project results are relevant only to Hawaii.
- The approach has yet to be tested with industry, including finance industry for deployment and development with expectations for return on investment.
- Care needs to be taken to ensure that the model is applicable on a wide platform, that it is not constrained by Hawaii-specific factors and assumptions, and that it is flexible and dynamic enough to benefit analyses of other regions.
- This project only considers delivered gaseous hydrogen and liquid hydrogen at a price that appears divorced from its actual value. The optimistic scenario models vehicle price incentives that continue indefinitely. A case should be considered in which these subsidies end. Too many service station sizes are modeled. While one wishes to explore the "optimal size" of service stations, the market would never develop 15 different sizes for sale. The number of service stations should be reduced to maybe 3 or 4 sizes and the model re-run. The "key findings" listed are weak. There are more conclusions to draw from the modeling results, but they are not made in the presentation.

Recommendations for additions/deletions to project scope:

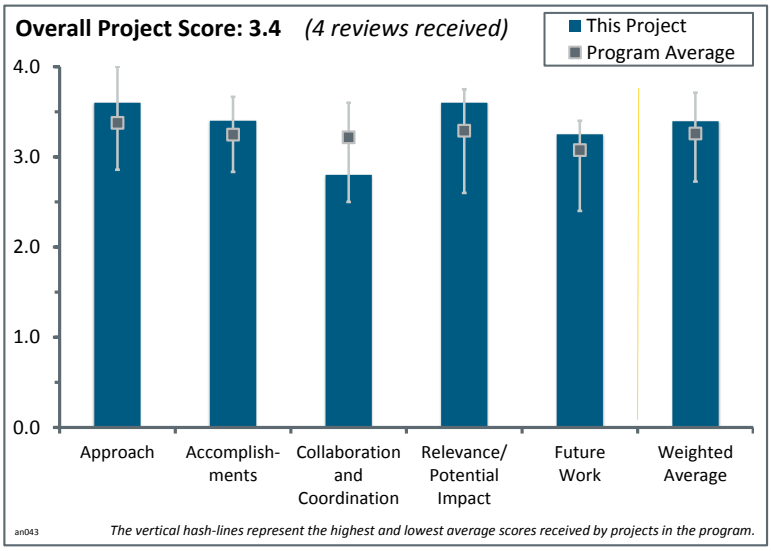
- This project should do more representative locations.
- This project could consider using a model to compare/contrast deployment plans in the United States versus other countries in order to gain an insight into what is working and why, what is not working, and what can be learned.
- This project should conduct testing/vetting with industry, expand and refine incentives and program options for incentives, consider increased OEM vehicle support within the sensitivity model, consider increased FCEV fuel efficiency and increased gasoline costs within the sensitivity model, and develop a *pro forma* model for individual refueling stations.
- The cost of hydrogen could be further explored. The source of the current "cost at the station" is unclear. A modified optimistic case in which vehicle subsidies are ended should be explored. This could indicate whether FCEV purchases plummet when subsidies end or if a tipping point has already passed. This project should reduce the number of station sizes and redo the analysis. The conclusions should be expanded to better reflect the analysis conducted.

Project # AN-043: Analysis of Community Energy

Darlene Steward; National Renewable Energy Laboratory

Brief Summary of Project:

This study evaluates the potential benefits of integrating renewable (photovoltaic [PV]) electricity generation with transportation fueling, building on a previous analysis of hydrogen for community-scale electricity storage. The project involves creating simulated hydrogen- and battery/electric-based PV refueling systems in the FCPower Model, establishing hourly building load profiles from empirical load data, applying empirical solar resource data, establishing vehicle refueling profiles, modeling system hourly energy flows, and calculating system electricity and fuel costs.



Question 1: Approach to performing the work

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

- The premise and the research direction met with a reviewer's approval. This was a discrete, nicely contained project.
- This was a very good approach to determine component sizes, assess costs, and compare options.
- This project was well-designed and successfully addresses the economics of excess PV output for vehicle refueling. The work is carried out using a solid techno-economic basis. It is not clear, however, how it addresses the stated barrier of "stove-piped/siloed analytical capability."
- The approach is satisfactory, although it could be more comprehensive as noted in the future plans.
- One reviewer did not enter a response.

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.

- This project has made very good progress in assessing the concept and comparing the options for electric vehicles (EVs) and fuel cell electric vehicles (FCEVs). The project is valuable for assessing the utilization of community loads, available roof space, distributed generation (DG) to the community, load management, grid/utility interaction, and onsite vehicle refueling/recharging.
- The progress is satisfactory and adequate for the funds provided.
- This project showed the case, or lack of a case, for hydrogen refueling at the neighborhood level.
- The results indicate a hydrogen cost of $11 to $34/kg, depending on the size of the PV system. It is unclear how this shows progress towards the DOE hydrogen production cost goal of $2 to $4/kg. The study assumed a 20-year lifetime for the electrolyzer unit, but there is no evidence of that level of durability for electrolyzers. It is not clear to what extent the study assumptions reflect today's technology or some idealized future projection of the technology. For example, today's cost of electrolyzers is probably not $600/kW.

Question 3: Collaboration and coordination with other institutions

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

- Collaboration seems to be very good, but cost estimates would be stronger if the team employed industry review and citation.
- This project utilized models from other institutions with some collaboration.
- This project should also consider collaboration with different utilities and component suppliers.
- A project like this needs to have a wider variety of participants and potential stakeholders, plus more regional data sets to account for seasonal and geographic differences.
- The project could have benefited from greater collaboration with battery and EV experts. The selection of the zinc/air battery for excess generation storage may not be the best choice; current deployments of battery systems for grid energy storage suggest otherwise.

Question 4: Relevance/potential impact on advancing progress toward DOE research, development, and demonstration (RD&D) goals

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

- This project and others that are working on distributed refueling/other energy storage have a potentially large role to play in effectively managing renewable power production at the local level.
- This investigation can help determine community-based deployment scenarios that may help with the build-out of infrastructure in a way that differs from conventional approaches, potentially uncovering more beneficial approaches while also benefiting communities and increasing technology visibility.
- This concept is futuristic but highly valuable to assess energy resource options for new or existing development with emerging technologies that could provide distributed resources directly to consumers and to utilities.
- This project provides a relevant demonstration but needs to be widened to more seasons and more locations.
- While the work is largely unbiased and technically sound, the results suggest that the work will have little positive impact on the use of electrolyzers/hydrogen storage for excess PV system output.

Question 5: Proposed future work

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

- Inclusion of existing future incentives, methodology, and seasonal variation associated with PV production is appropriate.
- The proposal to look at seasons other than July is good, but the project needs to look at other locations with different weather patterns.
- Further project refinements were proposed, but they are not likely to change the results of the study or provide much additional value.
- More fine tuning of the cases by considering optimization, deployment of different technologies, and financial factors will provide further insights.

Project strengths:

- This is a good demonstration of the approach.
- This is a creative approach that goes beyond the typical boundaries/way of thinking, potentially opening up new pathways and opportunities.
- This is a comprehensive approach with comparative analysis for a community energy system.

Project weaknesses:

- This project needs to be applied to many more seasons and locations.

- The costs appear to be low, and the capacity factor needs to be confirmed for location. The level of operations and maintenance (O&M) and equipment durability is unclear. A comparative analysis with conventional fuels and vehicle costs would be valuable for financing and necessary for development.

Recommendations for additions/deletions to project scope:

- After scenarios are fine-tuned with more detailed considerations, it would be good to look at what a community-based deployment in various parts of the country might mean for the overall development of infrastructure for the nation. It would be good to compare/contrast with typical deployment scenarios.
- This project needs an industry review and quotes on costs, capacity factors, vendor guarantee, O&M costs for long-term operation, and equipment durability. A comprehensive comparative analysis of baseline and individual scenarios (conventional fuels and grid power, PV with net metering and conventional fuels, PV with recharging, and hydrogen with refueling) would be valuable for decision making and the development of a *pro forma* for financing.