Systems Analysis – 2021

Subprogram Overview

Introduction

The Systems Analysis subprogram funds crosscutting analyses to identify technology pathways that can facilitate large-scale hydrogen use to enable decarbonization, advance environmental justice, and enhance energy system flexibility and resilience. To perform these foundational analyses, the subprogram uses a diverse portfolio of both focused and integrated models and tools that characterize technology costs, performance, impacts, and cross-sector market potential. These tools and capabilities are continuously updated and enhanced, while new tools are also developed as needed.

Cross-cutting analyses are conducted in collaboration with a range of entities:

- Other Hydrogen and Fuel Cell Technologies Office (HFTO) subprograms
- Various U.S. Department of Energy (DOE) offices: Strategic Analysis Team, Vehicle Technologies Office, Bioenergy Technologies Office, Office of Fossil Energy and Carbon Management, Office of Nuclear Energy, Wind Energy Technologies Office, Solar Energy Technologies Office, Office of Electricity, and Advanced Manufacturing Office
- State/local organizations
- Other federal agencies (e.g., U.S. Environmental Protection Agency)
- Private sector companies
- International organizations

The subprogram leverages external activities, coordinates efforts, and works with these partners to build opportunities for new technology applications and deployment.

Goals

The subprogram supports HFTO's decision-making and prioritization process by evaluating technologies and energy pathways, identifying gaps and synergies, and providing insights into future benefits, impacts, and risks.

Key Milestones

Near-Term (2020–2025):

- Develop models and analyses to prioritize program activities, including assessment of policies, creation of environmental justice goals, and areas of RD&D focus to meet Administration priorities.
- Conduct state-of-the-art technology assessments to help guide the RDD&D portfolio.

Mid-Term (2025–2035):

- Validate and refine models and tools to enable large-scale market growth, inform multisector coupling, and realize emissions reductions and jobs potential.
- Characterize market barriers and opportunities for supply chain expansion and high-volume manufacturing.

Long-Term (2035–2050):

- Assess RDD&D and market transformation processes, policies, and progress across applications and sectors to enable system resilience, emissions reduction, and sustainability, and assess jobs potential, including impacts on disadvantaged communities.

Fiscal Year 2021 Technology Status and Accomplishments

Analyses in fiscal year (FY) 2020–2021 focused on identifying the role of hydrogen in hard-to-decarbonize sectors, characterizing factors such as:

- The role of hydrogen in long-duration energy storage
- The impact of hydrogen use on lifecycle emissions of industrial applications
- Market segmentation in medium- and heavy-duty transportation
- The impact of growth in hydrogen and fuel cells on global sustainability metrics, to inform future RD&D.

Subprogram-Level Accomplishments

Global Change Analysis Model (GCAM)

GCAM represents linkages between five systems (energy, water, land, economics, and climate) at local, regional, and global scales, while identifying which sectors are economically difficult to decarbonize to reach net-zero greenhouse gases. In collaboration with other DOE offices, the subprogram launched updates to GCAM that enhance the tool's abilities to model hydrogen and fuel cells, bioenergy, and other pathways. The updated GCAM will then be able to evaluate the potential market sizes of hydrogen and fuel cells in future scenarios with drivers for decarbonization.

Role of Hydrogen in Energy Storage

Analyses showed that hydrogen technologies are among the lowest-cost pathways for multiday energy storage. The subprogram funded the development of the StoreFAST tool at National Renewable Energy Laboratory (NREL)[1] to evaluate the cost of hydrogen energy storage relative to alternatives, such as flow batteries, thermal storage, compressed air, and more, in user-defined scenarios. Systems Analysis also co-funded the completion of an analysis led by DOE's Strategic Analysis Team, along with the Solar Energy Technologies Office and Wind Energy Technologies Office, evaluating current and future costs of long-duration energy storage in high-renewable grids.[2] Additionally, the subprogram joined with the Office of Electricity in co-funding the development of Pacific Northwest National Laboratory's (PNNL's) Hydrogen Energy Storage Evaluation Tool (HESET)[3]; this tool characterizes the costs and revenue streams of user-defined power-to-gas systems and can enable developers to optimize the size and operation of power-to-gas components.

Market Segmentation in Medium- and Heavy-Duty Transportation

HFTO and the Vehicle Technologies Office collaboratively managed completion of an analysis project led by NREL to evaluate the total cost of ownership of batteries, fuel cells, and combustion engines in medium-duty vehicles (MDVs) and heavy-duty vehicles (HDVs), with varying ranges and operating conditions.4 Market segments wherein batteries were advantageous included those with shorter range (e.g., 300 miles) or flexibility with respect to available time to charge. Market segments wherein fuel cells were advantageous included those with longer range (e.g., >500 miles) or time constraints with respect to fueling.

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[1] NREL, "StoreFAST: Storage Financial Analysis Scenario Tool," accessed September 2021, https://www.nrel.gov/storage/storefast.html.

[2] Chad Hunter, Michael Penev, Evan P. Reznicek, Joshua Eichman, Neha Rustagim and Samuel F. Baldwin, "Techno-Economic Analysis of Long-Duration Energy Storage and Flexible Power Generation Technologies to Support High Variable Renewable Energy Grids," *Joule* (2020) https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3720769.

[3] Pacific Northwest National Laboratory, "User Guide: Hydrogen Energy Storage Evaluation Tool (HESET)," from *Energy Storage Evaluation Tool (ESET)* website, accessed September 2021, https://eset.pnnl.gov/document/heset.

[4] Chad Hunter, Michael Penev, Evan Reznicek, Jason Lustbader, Alicia Birky, and Chen Zhang, "Spatial and Temporal Analysis of the Total Cost of Ownership for Class 8 Tractors and Class 4 Parcel Delivery Trucks," NREL Technical Report NREL/TP-5400-71796, September 2021, https://www.nrel.gov/docs/fy21osti/71796.pdf.

Supply and Demand Potential for Hydrogen

In support of DOE's H2@Scale initiative, NREL, Argonne National Laboratory (ANL), Idaho National Laboratory (INL), and Lawrence Berkeley National Laboratory (LBNL) completed three comprehensive analyses of hydrogen supply and demand potential in the United States.[5] These analyses characterized the technical potential of hydrogen supply in the United States, assessed price points and market potential for hydrogen demand in eight sectors, and identified the economic growth potential for hydrogen supply and demand in five scenarios to be at least two to four times current consumption.

Other Highlights

The subprogram is also supporting the development of internationally agreed-upon methods of lifecycle analysis, working with the Hydrogen Production Analysis Task Force of the International Partnership for Hydrogen and Fuel Cells in the Economy.

Project-Level Accomplishments

Annual Technology Baseline (ATB)

The ATB provides a consistent set of technology cost and performance data (based on annual DOE analysis) that may be used as modeling input for energy analyses. In 2020, a transportation module of the ATB was launched through a collaboration between HFTO, the Strategic Analysis Team, the Vehicle Technologies Office, and the Bioenergy Technologies Office. The platform characterizes cost and emissions data for 10 different light-duty vehicle powertrains, under user-specified scenarios of technology progress and scale.[6] The 2021 update will include expansion to MDVs, HDVs, and aviation.

Hybridized Nuclear Plants Producing Hydrogen

State-of-the art analysis tools were used by NREL, INL, and ANL to estimate the value of integrating hydrogen production at two Xcel Energy nuclear power plants, given regional demands for hydrogen. Grid prices with and without hydrogen were estimated, and the operating strategy for a hybrid energy system was optimized. Future work may evaluate sensitivities of these conclusions to key assumptions, such as the cost of hydrogen storage infrastructure.

Industrial Applications for Hydrogen

ANL led analysis characterizing the potential for clean hydrogen to reduce emissions from liquid fuels and iron refining.

- Preliminary analysis indicates that hydrogen use in iron refining can reduce lifecycle emissions by 30%–50% compared to iron refining using coke or natural gas via blast furnaces or direct reduction of iron.
- Per analysis funded by the Advanced Research Projects Agency–Energy (ARPA-E), clean hydrogen use in ammonia production can reduce lifecycle emissions by over 80% compared to conventional ammonia production using natural gas without carbon capture and sequestration.
- It was determined that hydrogen and carbon dioxide synthesized into synthetic fuels can achieve over 70% lower lifecycle emissions than conventional diesel, assuming end uses that burn the fuel (e.g., vehicles, turbines).[7]

New Projects Launched FY 2020–2021

- PNNL, ANL, NREL – Updates to GCAM
- OnLocation – Development of Hydrogen Module for National Energy Modeling System

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[5] Reports available at "H2@Scale" on the DOE website (accessed September 2021): https://www.energy.gov/eere/fuelcells/h2scale.

[6] https://atb.nrel.gov/transportation/2020/index

[7] https://pubs.acs.org/doi/10.1021/acs.est.0c08237

- NREL – Annual Technology Baseline – Transportation
- ANL, NREL – Analysis of Hydrogen Export Potential
- LBNL, NREL – Advanced Network Analysis of Hydrogen Fuel Cell Automated Vehicles for Goods Delivery (ATLAS)
- NREL – Long duration energy storage cost analysis

Budget

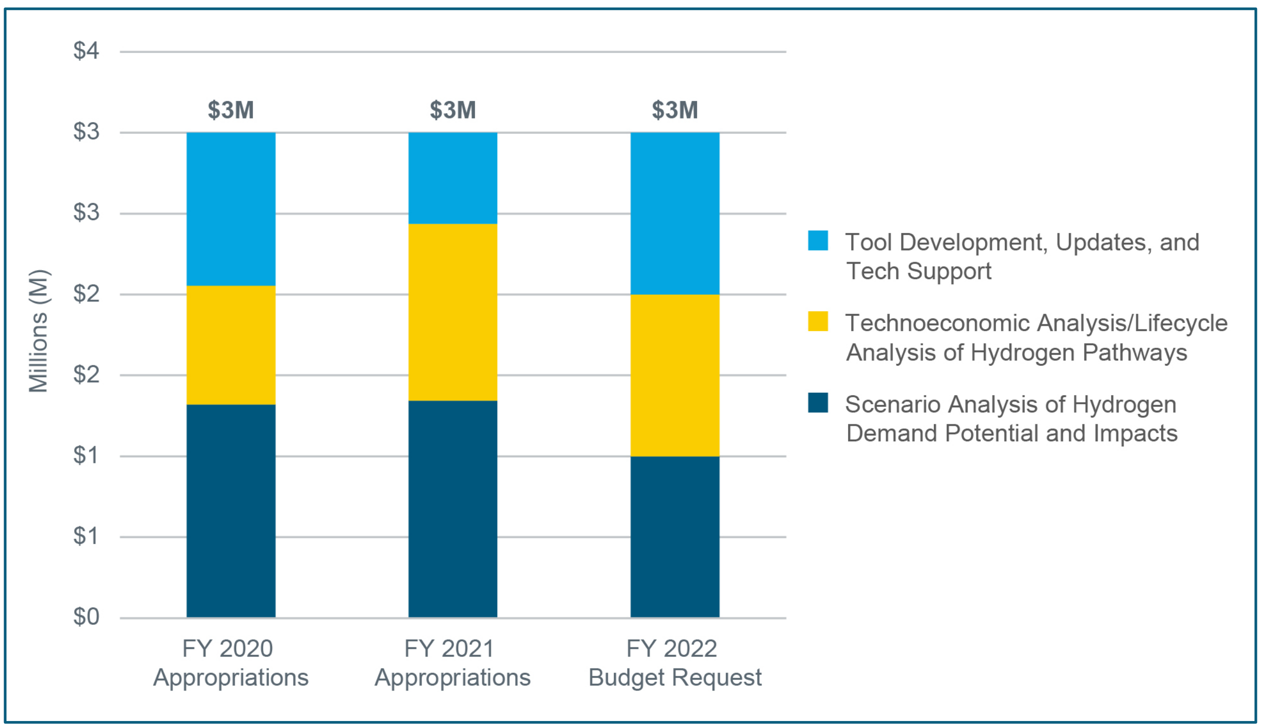
The FY 2021 appropriation for the Systems Analysis subprogram was $3 million. In FY 2021, the subprogram funded efforts in three key areas: scenario analysis of hydrogen demand potential and impacts; technoeconomic and lifecycle analysis of hydrogen pathways; and tool development, updates, and technical support.

Funding for scenario analysis focused on areas such as sustainability metrics, hydrogen market sizes in different energy system scenarios (e.g., high-renewable grids), and the value proposition of hydrogen energy storage. Technoeconomic and lifecycle analyses explored industrial applications, synthetic fuels and biofuels, and medium- and heavy-duty transportation applications. The subprogram also continues to fund annual updates to its portfolio of diverse models, while developing new tools to characterize the value proposition of hydrogen and fuel cells.

The FY 2022 budget request for the Systems Analysis subprogram is also $3 million. Activities planned for FY 2022, subject to appropriations and congressional direction, include:

- Assessment of potential large-scale deployments of hydrogen and fuel cells to address viability and benefits, such as decarbonization, sustainability, and environmental justice
- Assessment of climate impacts of hydrogen production and use
- Completion of ongoing analyses from FY 2021, such as updates to GCAM and evaluation of the total cost of ownership of fuel cells in autonomous fleets.

Systems Analysis RD&D Funding



Annual Merit Review of the Systems Analysis Subprogram

Summary of Systems Analysis Subprogram Reviewer Comments

The reviewers commended increased focus on environmental justice and the shift to considering hydrogen as a way to decarbonize carbon-intensive industries. The subprogram's ability to provide tools for analyzing hydrogen applications without actually investing in the applications, essentially testing out and de-risking ideas, was seen as invaluable to achieving the Hydrogen Energy Earthshot goal. An overall funding increase was recommended for the subprogram, reasoning that it can be essential in better guiding where research, development, and demonstration (RD&D) efforts in other subprograms should be targeted.

To better articulate HFTO's RD&D strategy, reviewers suggested use of more waterfall charts and investigations into total cost of ownership sensitivities, as well as linking these findings to the portfolio of projects. It was also suggested that multiple analyses could be integrated and some of them expanded to include additional emerging applications (e.g., mining, construction equipment, refuse trucks). Moreover, it was suggested that concepts such as sustainability, circular economy, recycling, eco-design, and just-in-time hydrogen production (producing hydrogen based on anticipated demand) could be considered.

Reviewers also pointed out that some stakeholders were interested in becoming self-sufficient in running the models but may hesitate, as they are not certain of the skill set required to run the models. Thus, reviewers suggested that an explanation conveying the level of expertise needed be added both to the models' websites and to the merit review presentations.

Market segmentation of MDVs and HDVs was seen as a comprehensive, nuanced, and insightful analysis that filled major data gaps and was informative to a variety of stakeholders, meeting needs as transportation moves toward zero-emission vehicles. Reviewers suggested that the scope could be expanded to consider infrastructure, operator perspective, factors such as dwell time and payload, and new data sets.

Technoeconomic analysis of the use of hydrogen in steelmaking and in producing synthetic fuels was regarded as an important step in reducing carbon dioxide emissions and a building block toward meeting the Hydrogen Energy Earthshot goal. Reviewers suggested that carbon utilization and capture also be evaluated.

The annual technology baseline work was commended for providing data that many stakeholders can reliably and easily find and reference. Coordination with industry and users outside of DOE was recommended as a way to validate the data.

The cradle-to-grave transportation analysis conducted by the subprogram was viewed as demonstrating tangible improvements in modeling, data, and assumptions. Industry verification and additional sensitivity analyses (for types of vehicles) were recommended.

For H2@Scale, the following were observed:

- Coordinating with state and regional entities could be a value-add for H2@Scale.
- As H2@Scale is focused on modeling, it might be worth validating findings through demonstrations.
- The technology readiness levels of various analysis components and pathways could be incorporated into the H2@Scale effort.
- There is a need to have a more nuanced understanding of the roles hydrogen can play, given the heavy interest and push toward battery technologies (i.e., more detailed information, rather than evaluation of general economic sectors).
- More clarity is needed about what it would take to build an upstream supply chain to support the vision of H2@Scale.
- Climate-change-induced droughts affect current energy systems and have sometimes led to increased use of fossil fuels, further exacerbating the issue. Perhaps H2@Scale could serve as a platform for investigating hydrogen's role in short-circuiting this kind of feedback loop.

During the 2021 Annual Merit Review, eight Systems Analysis projects were reviewed, receiving scores ranging from 3.0 to 3.8, with an average score of 3.5. Project reviewers were impressed with specific project-level highlights and accomplishments. Following this subprogram introduction are individual project reports for each of the projects reviewed. Each report contains a project summary, the project's overall score and average scores for each question, and the project-level reviewer comments.

Project Reviews

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

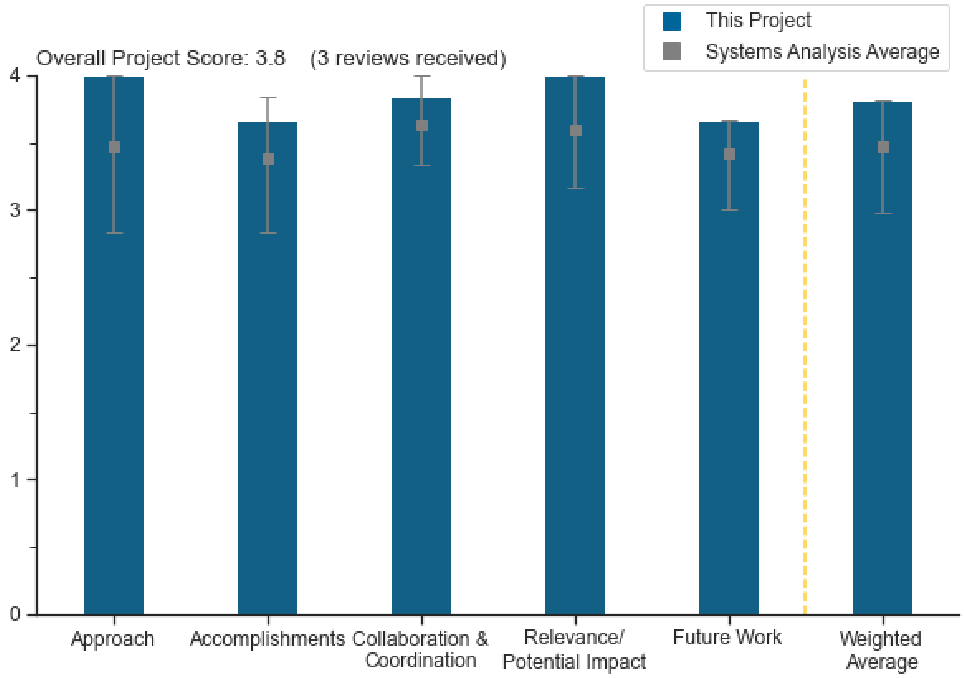
Chad Hunter, National Renewable Energy Laboratory

DOE Contract #	5.3.0.502
Start and End Dates	10/01/2018–08/30/2021
Partners/Collaborators	External peer reviewers: Argonne National Laboratory, Bosch, California Air Resources Board, Center for Transportation and the Environment, Cummins, Eaton, Energy Independence Now, FedEx, Toyota, DOE Vehicle Technologies Office
Barriers Addressed	• Future market behavior: assessing competitiveness of fuel cell medium- and heavy-duty vehicles • Inconsistent data, assumptions, and guidelines: developing a consistent modeling methodology using established U.S. Department of Energy cost/price and performance targets • Insufficient suite of models and tools: expanding spatial and temporal analysis tools to the medium- and heavy-duty vehicle sector

Project Goal and Brief Summary

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

Project Scoring



The vertical hash-lines represent the highest and lowest average scores received by Systems Analysis projects.

Question 1: Approach to performing the work

This project was rated 4.0 for identifying and addressing objectives and barriers and for project design, feasibility, and integration with other relevant efforts.

- The methodologies used in this project, leveraging the national laboratories' suite of transportation modeling tools, are comprehensive, logical, and well-designed. One of the major barriers this project aims to overcome is inconsistent data or lack of existing data, and this project provides results that will fill major data gaps. It is comprehensive in its analysis of many possible future drivetrain technologies, and it is nuanced in its evaluation of many different use cases and possible trajectories for future development.
- There is a clear understanding of the key pain points for truck operators, and the project seeks to quantify an appropriate mix of scenarios. The project leverages and improves upon existing tools and data sets as much as possible, as well. The project not only adds core TCO components (truck cost, fuel, etc.) but also accounts for the financial impact of operations to capture the full return on investment (e.g., dwell time and payload), which is especially appreciated.
- The project makes very good use of existing tools and methods to accomplish goals. Also, it is nice to see that payload capacity and dwell time are two cost components/drivers.

Question 2: Accomplishments and progress

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

- It appears that much work has been done over the last year and that previous Annual Merit Review comments and peer review feedback were taken seriously and addressed. The results are starting to indicate challenges and opportunities in the zero-emission truck market.
- The results to date are very insightful. Using the market segmentation effort to help bound the Class 8 market is excellent for seeing the full picture. It will be interesting to see more.
- The project already appears to be providing several novel data points that will be informative to hydrogen and MD/HD transport stakeholders. While it is a bit outside the project's control, the continued reliance on 2002 Vehicle Inventory and Use Survey (VIUS) data is a concern. The project could have potentially sought some other alternative or even developed a new and verified data set that could have stood as

comparable to VIUS. While an updated VIUS data set is expected to be released sometime soon, it stands as a potential weakness of the project to be so reliant on this update for more accurate or up-to-date data as a critical model input.

Question 3: Collaboration and coordination

This project was rated **3.8** for its engagement with and coordination of project partners and interaction with other entities.

- The project has engaged several relevant institutions for collaboration and review of the project, which likely provided valuable and relevant insight into project development. In addition, the incorporation of models across national laboratory teams and other projects is a core strength of this project.
- The establishment and verification of assumptions required significant coordination with industry partners, which appears to be sufficient and effective. Continuous updating and verification will be important for the rapidly changing battery and fuel cell technologies.
- There is great coordination with other groups at DOE and industry partners. The inclusion of the North American Council for Freight Efficiency is good, as it allows getting closer to the truck operators, and it is suggested that the project engage in even more direct conversations with operators to fully understand how they use the vehicles and what affects their truck purchase decisions. That may inform how to present new insights that consider the voice of the customer. Also, coordination with hydrogen infrastructure stakeholders may be somewhat out of scope, but it will help confirm assumptions on fuel cost.

Question 4: Relevance/potential impact

This project was rated **4.0** for supporting and advancing progress toward the Hydrogen and Fuel Cell Technologies Office goals and objectives delineated in the Multi-Year Research, Development, and Demonstration Plan.

- This work is exactly the type of information and modeling that is needed today, as government agencies are starting to develop regulations and requirements of fleets to move toward zero-emission technologies. Government and industry stakeholders alike need this type of information to understand the potential impact of new and proposed requirements, as well as the most cost-effective way to meet these requirements. There is a good deal of early-stage misinformation and misunderstanding that this project can directly address with authoritative and comprehensive scientific evaluation.
- This work is critical to understanding where and how efforts should be directed to achieve commercialization for the zero-emission truck market.
- This is an extremely relevant project, both to the DOE Hydrogen Program and the broader industry. A publicly available model is highly anticipated so fleets and the industry can further explore.

Question 5: Proposed future work

This project was rated **3.7** for effective and logical planning.

- Now that the methodology, approach, and assumptions have been refined, future work must continue to include solicitation and incorporation of any assumption updates, as well as modeling of all other truck markets. The development and release of the TCO tool will be very useful for the industry but should include validation, verification, and communication activities.
- It is good to see that consideration of hydrogen station placement has been added to the scope for potential future work. However, there may also need to be some consideration of charging infrastructure to provide the kind of apples-to-apples comparison many stakeholders will expect. The project team may need to expand collaboration to complete this work.
- Sharing a published model will be a major value-add from this project. The project team seems to have a good understanding of what gaps and improvements remain, but it is not clear what will be prioritized or performed under separate projects to build from this work. Engagement with fleet operators, a deeper dive on market segmentation, and more focus on the supporting infrastructure are examples that should be explored.

Project strengths:

- There is much to like about this project, with some key strengths:
    - Relevance and value: Industry, operators, and policymakers understand how important TCO is to driving the freight movement sector to zero emissions. This work provides a great reference that compiles reputable data and modeling to inform better decision-making and quantifies the value of fuel cell electric trucks.
    - Public model: There is always value when the results do not have to be static and stakeholders can dive as deep as they please to understand scenarios and options.
    - Cost-effectiveness: This project provides a great bang for the buck. Other multiyear, multi-million-dollar initiatives have provided much less value than this project already has.
- Overall project strengths include the ability to simulate and quantify critical drivers for commercialization of the zero-emission truck market. The approach is great and provides a robust framework for building in and updating use cases and being used as a decision-making tool in the development of zero-emission vehicles and projects. Further, the planned development and release of the comprehensive reports and tools will be important to driving the use and understanding of the work.
- This project's greatest strengths are its timeliness, comprehensive nature, and the well-structured methodology that leverages multiple transportation modeling tools available across DOE and the national laboratories.

Project weaknesses:

- A wide stakeholder group will take interest in this project, given the focus on TCO in the HD space, where there is currently somewhat limited information. How this information is presented, published, shared, and expanded will be very important. It is recommended that the team connect with more stakeholders (operators, infrastructure providers, and policymakers) to ensure the team understands what stakeholders are looking for and help tailor the message to add value. There is a good deal of potential with this project, so more effort on the dissemination piece is encouraged.
- It would be good to have a better understanding of the source, conditions, and values for critical input assumptions used, such as fuel cell density by weight and volume, fuel cell cost, comprehensiveness of Fleet DNA duty cycles, electric vehicle charge times, and battery density. This understanding would give users more confidence in the results and tools, as well as increase acceptance.
- The project weaknesses are (1) the potential delay or roadblock that can occur if the VIUS data are delayed and (2) the project's current structure of not investigating sensitivity to infrastructure development.

Recommendations for additions/deletions to project scope:

- The project scope should keep expanding. Some ideas are already mentioned in previous comments, but a few thoughts are below:
    - Infrastructure: Comparing the infrastructure experience is equally important. Some of this is already captured indirectly, yet much more work could be done here.
    - Operator perspective: This would help address the question of "designing to the average." It would add more reality to the project if the team found out how much of the market would really purchase a truck for single-shift, volume-limited cargo operation. If that is not the case all of the time, it would be good to know what happens.
    - More data: It sounds like a new VIUS study is coming in a couple years, but perhaps there are ways to collect data or expand new data sets to create even better insights.
- Overall, this is fantastic work done by Chad Hunter and the team, and they should keep up the good work.
- Recognizing that a prior year's reviewer already commented about infrastructure and the project team responded that it is out of scope, this still feels like it is the largest remaining gap in the project. Given the project scope, it is appropriate to use outside projections of hydrogen price for the estimates. However, infrastructure (in addition to TCO) is a large part of the fleets' consideration regarding adopting these vehicles and of the public sector's consideration regarding the impacts of requirements or the necessary support. In addition, the project already incorporates SERA, which has more than enough capability to investigate this aspect. A full investigation with multiple sensitivity evaluations may be beyond the scope of this work, but even a case study or a small set of representative studies could be an immensely useful addition in the near term. This type of information, even just as an example or two, is a major need right now for stakeholders. It could also provide a strong basis for a future project that could be more detailed and comprehensive in its analysis.
- An addition could include tying simulations and results to various scenario inputs related to specific charging and fueling methods and/or other expected industry advancements and breakthroughs. For instance, the project might show how the results change based on liquid hydrogen (LH2) delivery versus onsite electrolysis, or with LH2 fueling, or with a battery chemistry breakthrough such as a solid-state lithium battery.

Project #SA-174: Technoeconomic and Lifecycle Analysis of Synthetic Fuels and Steelmaking

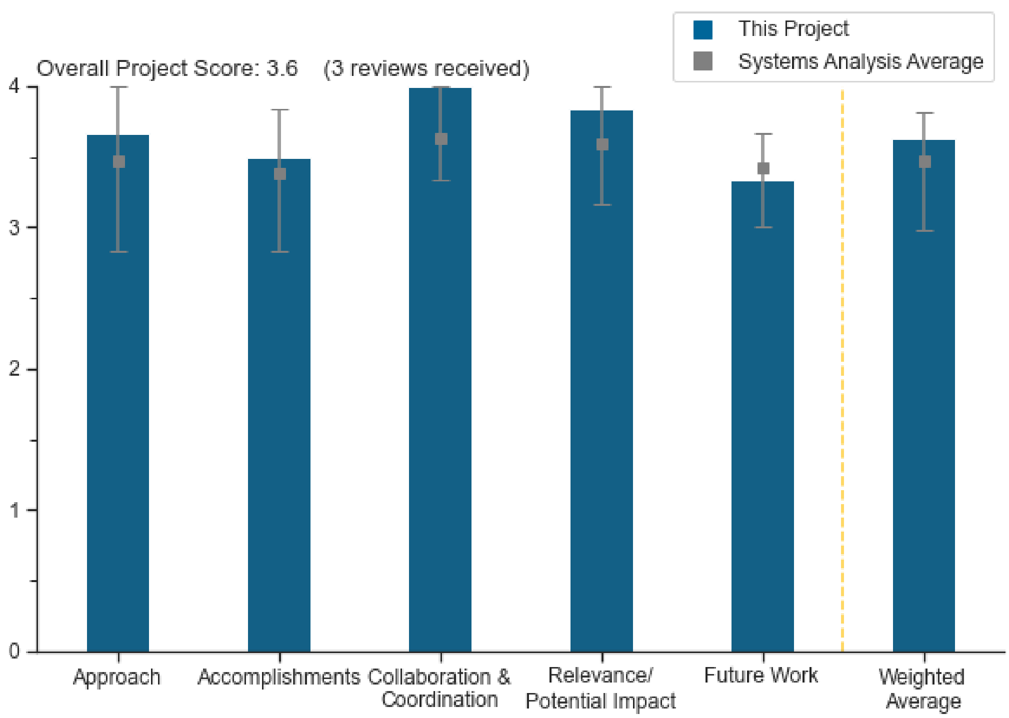
Amgad Elgowainy, Argonne National Laboratory

DOE Contract #	5.1.0.6
Start and End Dates	10/1/2019
Partners/Collaborators	National Renewable Energy Laboratory, Lawrence Berkeley National Laboratory, University of California, Irvine
Barriers Addressed	• Future market behavior: Potential hydrogen markets beyond fuel cell vehicles • Insufficient suite of models and tools • Unplanned studies and analysis: Cost and environmental impacts of hydrogen use in new applications

Project Goal and Brief Summary

Hydrogen is being considered for new markets, including as a means of producing synthetic fuel and of manufacturing steel from iron ore using hydrogen to reduce iron oxides. This project aims to evaluate the technoeconomics and environmental implications of hydrogen use in these applications, providing estimates of associated costs and greenhouse gas (GHG) emissions. Argonne National Laboratory is collaborating on this project with the U.S. Department of Energy's (DOE's) Strategic Analysis Office, DOE's Advanced Manufacturing Office (AMO), the National Renewable Energy Laboratory (NREL), Lawrence Berkeley National Laboratory (LBNL), and the University of California, Irvine (UCI).

Project Scoring



The vertical hash-lines represent the highest and lowest average scores received by Systems Analysis projects.

Question 1: Approach to performing the work

This project was rated **3.7** for identifying and addressing objectives and barriers and for project design, feasibility, and integration with other relevant efforts.

- This project has an excellent understanding of the problem(s) to be solved, namely balancing GHG emissions and hydrogen cost requirements (with and without incentives). It has a sound approach on how to resolve the technoeconomic barriers through the development of a technoeconomic analysis (TEA) model, interviews with key partners, and the assessment of current and new technologies.
- The project goals and barriers addressed are clearly described. The project design is well-organized, precise, and comprehensive. This work is highly relevant to advancing H2@Scale goals.
- The scope is clearly defined and addressed in the project. The scope is also manageable in the sense that it is not vague or ambiguous. Therefore, the findings can provide discrete value to the DOE Hydrogen Program.

Question 2: Accomplishments and progress

This project was rated **3.5** for its accomplishments and progress toward overall project and U.S. Department of Energy (DOE) goals.

- The presentation and background material showed significant progress toward the goals and offered key conclusions. For example, the breakeven cost of hydrogen necessary to achieve low-CO2 steelmaking at $1.2/kg is consistent with other publications and the reviewer's personal (albeit much less sophisticated) evaluation. Of course, such TEA models can always be further refined with more detailed calculations, improved assumptions, and more case scenarios, but the work showed that all the building blocks are in place.
- The methodology employed in the analysis was comprehensive and yielded a good result. However, further background should be made available to provide better context of the results. For example, the steelmaking scenarios looked at various production technologies and energy sources. However, each of the technologies examined were at various levels of commercial readiness and deployment. More accurate costs for carbon capture and CO2 are available.
- The proposed work plan was completed.

Question 3: Collaboration and coordination

This project was rated **4.0** for its engagement with and coordination of project partners and interaction with other entities.

- The project has leveraged a range of expertise across DOE, national laboratories, and academia. The team also seemed to care about the end use of the product, a very important aspect in applied analysis.
- The collaboration partners—the DOE Strategic Analysis Office, DOE AMO, NREL, LBNL, and UCI—constitute a very strong team.
- The work presented displayed all the evidence of extensive collaboration with laboratories (LBNL in particular), universities (UCI), and industrial partners.

Question 4: Relevance/potential impact

This project was rated **3.8** for supporting and advancing progress toward the Hydrogen and Fuel Cell Technologies Office goals and objectives delineated in the Multi-Year Research, Development, and Demonstration Plan.

- This work is a building block toward the ultimate goal of reducing CO2 emissions by using green hydrogen (from nuclear and/or renewable energy). The study aims at setting goals and necessary conditions to achieve decarbonization; however, the project is not intended to "solve" the problem but rather to indicate pathways, such as using hydrogen in ironmaking. In that respect, the project's relevance is outstanding. It is the kind of work that sets clear targets, such as the Hydrogen Energy Earthshot announced earlier in the week.

- The DOE Hydrogen Program's success turns in large part on the economic validation provided by the models, tools, analyses, and studies performed by this team. This effort is necessary for sound policy development and business decision-making. It saves substantial amounts of time and resources.
- The team has a strong understanding of the H2@Scale initiative and its goal and is receptive to input from the initiative. The growing interest in decarbonized, hard-to-abate emissions, plus the Hydrogen Energy Earthshot, makes TEA of the project's suite of technologies very important.

Question 5: Proposed future work

This project was rated **3.3** for effective and logical planning.

- The lifecycle assessment (LCA) aspect of the work is fundamentally important, as accurate carbon reductions may drive newer technology forward more than economic competitiveness over the incumbent technologies. The presentation did not highlight the importance of the LCA and details (i.e., viability and economics) of the CO2 sources, CO2 capture, and CO2 infrastructure adequately. However, the future work based on the other aspects, such as steelmaking, were well-laid-out areas of logical growth.
- The proposed future work makes sense based on the earlier findings and conclusions presented. Economics of CO2 capture and transportation definitely ought to be included, but it is also suggested that "scale" be included as a consideration. The CO2 emissions from the steel industry are tremendous, and it is not clear that storage is feasible beyond a limited time before we run out of space. Decarbonization should be promoted, rather than giving the steelmakers an option to delay. Documentation, publication, and access to the model are critical to disseminating the message of this excellent work.
- Proposed future work is comprehensive and important. However, the list should be longer.

Project strengths:

- The approach and relevance are logical and of interest. The analysis is constructed in a way to provide tangible benefit for industry, DOE, and the broader research and development community. The scope is contained, and the methodology is comprehensive.
- The project's strengths are its analytical rigor, well-conceived tools, detailed analyses, relevant and useful results, and excellent outreach.
- The project's understanding of the problem areas, approach to solutions, and clear and concise results are its strengths.

Project weaknesses:

- The analysis could benefit from additional background for context, especially if these findings were to be used by a policymaker. Additional details should be provided, and consideration should be given to the carbon utilization and capture component of the project, as models such as Greenhouse Gases, Regulated Emissions and Energy use in Transportation (GREET) are not specifically designed for carbon use. Also, CO2 costs, ranging from capture to delivery costs (CO2 is not free, as there are capital expenditures and operating expenses even from compression), should be used in the analysis.
- The project's modeling can always be improved.

Recommendations for additions/deletions to project scope:

- No deletions are needed. The project's focus on steelmaking is a welcome improvement. It is only suggested that the team dive a little deeper into the TEA of building new steelmaking infrastructure and abandoning the existing one. For example, waste gases from blast furnace/basic oxygen furnace steelmaking are often used for other applications (including power/heat) that will have to be replaced. This can have a significant impact on companies and local communities.
- The project should consider adding the metric "dollars per ton of CO2e emissions avoided or offset" wherever possible. This could provide a common basis for comparison of disparate technologies and approaches.
- Overall, this is a good project and has shown good progress.

Project #SA-175: Regional Hybrid Energy Systems Technoeconomic Analysis

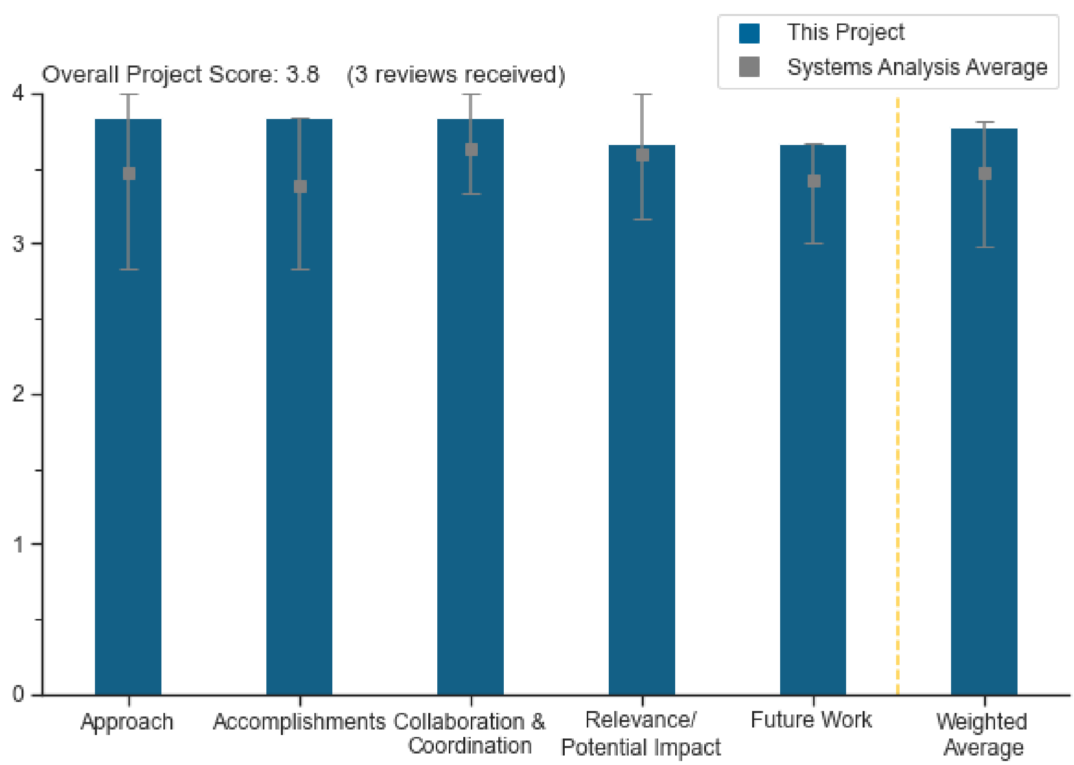
Mark Ruth, National Renewable Energy Laboratory

DOE Contract #	5.3.0.502
Start and End Dates	8/22/2019
Partners/Collaborators	Idaho National Laboratory, Argonne National Laboratory, Xcel Energy Inc., Electric Power Research Institute (EPRI)
Barriers Addressed	• Hydrogen production cost of $2/kg • Insufficient suite of models and tools

Project Goal and Brief Summary

This project aims to quantify the potential financial impact of hybridizing Xcel Energy's Prairie Island and Monticello nuclear power plants to produce hydrogen. This project will provide investment-grade information to support Xcel Energy's greenhouse gas reduction efforts, improve understanding of the potential for hybridized nuclear power plants to produce hydrogen at $2/kg or less, and develop tools and capabilities to better characterize hybridized hydrogen production on the grid so that new opportunities can be analyzed.

Project Scoring



The vertical hash-lines represent the highest and lowest average scores received by Systems Analysis projects.

Question 1: Approach to performing the work

This project was rated **3.8** for identifying and addressing objectives and barriers and for project design, feasibility, and integration with other relevant efforts.

- The project team is developing a unique figure-of-merit-based approach to optimizing hydrogen production for a nuclear power plant. This approach is commercially relevant and useful for nuclear utilities.
- The capabilities of the national laboratories in complex scenario modeling are excellent, and leveraging them in concert with each other adds even more value.
- The project goals and objectives are very clear (e.g., as shown on slide 3). Barriers are identified, but how they are being addressed could be more clearly articulated in the presentation. For example, new tools are described well, but the linkage of these efforts to addressing the $2/kg barrier is not as clear. The project appears to be feasible and integrated well with both industry and government needs.

Question 2: Accomplishments and progress

This project was rated **3.8** for its accomplishments and progress toward overall project and U.S. Department of Energy (DOE) goals.

- Within the scope of the project, the progress indicated shows that the goals have been addressed very well and good insights into the different market points have been provided. The existing project focuses on high-temperature electrolysis (HTE), but this approach could likely be extended to low-temperature electrolysis and hybrid systems.
- The accomplishments are consistent with the DOE H2@Scale initiative goals by enabling low-cost hydrogen produced from nuclear power for various end-use applications.
- The presentation provides an excellent display of aspects of the project (e.g., as shown on slide 10) and accomplishments for each. Preliminary results show that the project objectives are being met. Specific performance indicators are not as clear as they could be, as they read more as qualitative progress toward the outcome. The project appears to be on track to overcoming the barrier related to tools and techniques, but, as noted in Question 1, the linkage to the $2/kg barrier could be emphasized more.

Question 3: Collaboration and coordination

This project was rated **3.8** for its engagement with and coordination of project partners and interaction with other entities.

- The project involves modeling capabilities across multiple laboratories and is grounded by industry participation and review. Having the Electric Power Research Institute (EPRI) on the project with access to multiple utilities, as well as a specific utility partner, provides both specific and general validation of the models and direction.
- The presentation shows outstanding collaboration between industry, laboratory, and government partners. In particular, the many portions of the Xcel Energy organization that are involved demonstrates the effort in this area.
- Additional input directly from hydrogen end users or industrial gas companies might be helpful.

Question 4: Relevance/potential impact

This project was rated **3.7** for supporting and advancing progress toward the Hydrogen and Fuel Cell Technologies Office goals and objectives delineated in the Multi-Year Research, Development, and Demonstration Plan.

- The project aligns very well with the DOE Hydrogen Program by exploring both the supply and demand sides of one means of producing hydrogen in a way that may be economical for multiple parties. As the various nuclear-related projects advance toward approval and implementation, they do have the potential to show more progress; however, at this early stage, it is difficult to say they are critical or will show significant progress.
- The project aligns very well with DOE Hydrogen Program objectives in HTE. With some additional work, the framework could also likely be very useful to other water-splitting pathways.

- The project supports the goals of the research and development subprograms and is impactful in enabling carbon-free hydrogen production from nuclear power.

Question 5: Proposed future work

This project was rated **3.7** for effective and logical planning.

- Since future work is dependent on future funding, it is not totally clear what commitments can be made. The ideas discussed toward adding additional relevant factors, analyzing different demand scenarios, and looking at co-optimization are all aligned with overcoming the barriers for deployment.
- The future work is clearly identified and impactful in quantifying the hydrogen production future compared to business as usual or flexible operations scenarios.
- The project has clearly planned its future (e.g., as shown on slide 24) and is well on its way to accomplishing each of its objectives.

Project strengths:

- The strength of the team and presenter are key attributes of the project. The potential for expansion to other scenarios and connection to other projects that touch on similar topics can provide additional value.
- This project integrates partners from multiple sectors. It advances the suite of analytical tools available. It bridges the gap between hydrogen and nuclear efforts with practical applications.
- The project is commercially relevant and impactful for the utilities thinking about hydrogen production from nuclear power and enables scale-up.

Project weaknesses:

- The project could demonstrate greater use of risk identification and mitigation. For example, the team could determine what would happen if HTE is not available when needed, if "guesses" about the demand curve (as stated in the oral presentation) turn out not to be correct, or if the dynamic functioning of the plant and electrolyzer do not operate as planned.
- The project could benefit from input from hydrogen end users.
- No major weaknesses were noted.

Recommendations for additions/deletions to project scope:

- Expanding the analysis to additional cases and technologies would help define which technologies might best fit different energy scenarios while achieving different price targets.
- The project could benefit from input from hydrogen end users such as natural gas-fired power plants. Also, next year's presentation could include a figure on the intersection of supply and demand curves.

Project #SA-176: Annual Technology Baseline – Transportation

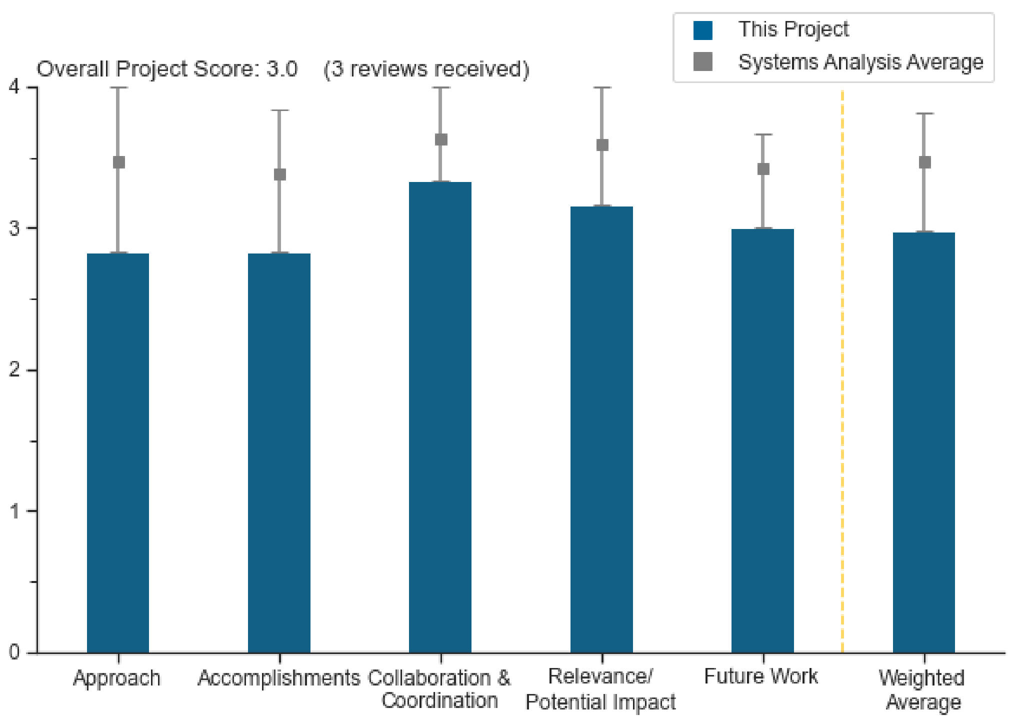
Laura Vimmerstedt, National Renewable Energy Laboratory

DOE Contract #	WBS 5.3.0.502
Start and End Dates	10/1/2017
Partners/Collaborators	U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy, Argonne National Laboratory
Barriers Addressed	• Inconsistent data, assumptions, and guidelines • Stove-piped/siloed analytical capability • Unplanned studies and analysis

Project Goal and Brief Summary

This project will maintain the Annual Technology Baseline (ATB), an energy analysis dataset that provides current, credible, and consistent information on technology cost and performance across energy sectors. The ATB is updated annually and reviewed for consistency. The National Renewable Energy Laboratory, the U.S. Department of Energy's (DOE's) Office of Energy Efficiency and Renewable Energy, and Argonne National Laboratory will work together to review data sets, online publications, and documentation.

Project Scoring



The vertical hash-lines represent the highest and lowest average scores received by Systems Analysis projects.

Question 1: Approach to performing the work

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

- The development of the ATB vehicle portal and downloadable information seems to be very well-suited to the intended project goals. The variety of ways to access the data, with varying levels of detail and variation, is a useful aspect, as it allows the website to be useful for a wide variety of stakeholders that have different levels of need in terms of data nuance and detail. Two areas are less clear in the project. First, it is not entirely clear how the project might resolve differing data points for similar projections that come from different projects across DOE and the national laboratories. Second, the project so far includes only midsize light-duty vehicles (LDVs), and it is unclear why a larger set of vehicles was not included in the first launch of the portal, given that information is available at least for more classes of LDVs from the same resources that are used for the mid-size vehicles. It seems some modifications during early project planning could have allowed more vehicle classes to be available in the initial release.

- While the goals and objectives are clear and much needed in the industry, the input, or aggregated data, seems narrow and confusing to decipher. It appears that the input data consist solely of mined information from DOE reports that involve select, scenario-driven case studies. It is hard to figure out the cases and conditions on which the results are based. Most case studies appear to utilize DOE tools, which are great but are limited. Perhaps the tools could be used to do parametric sweeps across all conditions that could then be aggregated. There did not appear to be any empirical data that were used (only simulated projections), which would also be valuable. Also, there is no mention of the approach to how input data are validated, verified, and normalized. This is especially important, given that one of the objectives is to address inconsistent data, assumptions, and guidelines.
- There is a good deal of different information within separate DOE offices, but it is unclear exactly how much of a gap there really is and whether this project sufficiently addresses it. The approach was defined and presented in some detail, yet there were no accomplishments to show after the methodology had been presented.

Question 2: Accomplishments and progress

This project was rated **2.8** for its accomplishments and progress toward overall project and U.S. Department of Energy (DOE) goals.

- The project team has put together a large collection of tools so many stakeholders can easily access important transportation system data. The amount of work required to develop these several tools and formats is large, and the project team has made significant progress.
- There is good progress in publishing the results in various formats usable by the public. Some of the products could use clarification of source data, categorization of source data, explanation of parameters, and definition of units.
- The very brief accomplishments, which mentioned only publication and a couple webinars, were a bit confusing. There is potential to leverage a compiled data set to share useful insights, but this project does not currently take that step. If this really is a pure compilation of existing data, the scope and costs could be greatly reduced going forward.

Question 3: Collaboration and coordination

This project was rated **3.3** for its engagement with and coordination of project partners and interaction with other entities.

- The amount of coordination and collaboration appears to be well-suited to the project. The project leverages multiple DOE and national laboratory project teams. It is also good to see that the project has engaged a panel of outside reviewers to provide feedback and direction on the development of the ATB portal and data materials.
- Collaboration with internal sustainable transportation offices is good. Perhaps they are the primary consumers of this effort and tools. However, this project could benefit from coordination with outside users, researchers, and industry to better validate the usefulness and understanding of the work being produced.
- Clear collaboration has been established with the appropriate offices at DOE to compile data. Considering this does not include new modeling efforts, the role of the Technical Review Committee (TRC) is not clear since there does not appear to be any new content to review. It would also be interesting to learn who is already part of the TRC.

Question 4: Relevance/potential impact

This project was rated **3.2** for supporting and advancing progress toward the Hydrogen and Fuel Cell Technologies Office goals and objectives delineated in the Multi-Year Research, Development, and Demonstration Plan.

- This type of resource, especially one that is as authoritative as the one this project provides, is something that stakeholders need very much right now. This project fills a gap in usable and accessible data that many stakeholders can reliably reference and find quickly and easily.
- Finding credible and consistent data is absolutely needed in the industry, and this project can provide that with the right approach.
- The idea of compiling siloed information can be a value add, but the relevance to broad stakeholders is not clear. This appears more like an internal check within DOE to ensure that analyses and targets are not misaligned.

Question 5: Proposed future work

This project was rated **3.0** for effective and logical planning.

- The proposed future work will address one of the largest limitations of the current version of the ATB, namely, that results and data are currently available only for midsize LDVs. It is also extremely encouraging to see the intended scope of additions expanded beyond on-road vehicles to address the infrastructure side of zero-emission transportation.
- The project appears as though it would benefit from a focus on source data validation, normalization, characterization, and explanation.
- The scope of future work will determine the value of this project. As proposed during the presentation, it appears that more analyses will be compiled to refine the set of assumptions used to make the plots. This may increase the accuracy of the ATB without much significant change from its current state. A larger directional shift to add more insight from the data or even additional analysis of some kind is suggested.

Project strengths:

- The greatest strength of this project is its ability to provide consolidated and authoritative data via several formats that speak to many different types of stakeholders. There are many information needs across zero-emission stakeholders today, each with its own interest in levels of detail and nuance, and this resource will be useful to many of these different perspectives.
- Project strengths are the aggregation of LDV levelized costs of driving and well-to-wheels emissions that are predicted through reports created by DOE laboratories and energy offices.
- Having the awareness to leverage existing and sometimes siloed expertise is a project strength.

Project weaknesses:

- It appears that the input data consist solely of mined information from DOE reports that involve select, scenario-driven case studies. It is hard to figure out the cases and conditions on which the results are based. Most case studies appear to utilize DOE tools, which are great but limited. Also, there is no mention of the approach to how input data are validated, verified, and normalized. This is especially important given that one of the objectives is to address inconsistent data, assumptions, and guidelines. Some of the products could use clarification of source data, categorization of source data, explanation of parameters, and definition of units.
- There are a number of areas for improvement:
    - The project needs a clearer “why.” It is unclear what problem is really being solved here. There are other projects that compare technologies and investigate a new problem.
    - Clarification of the scenarios is needed. The assumptions for the constant, mid, and advanced cases need more description. This project probably does not involve new analysis or assumptions, so perhaps there is a consistent reference that is used by all offices. It would be good to have more insight into what affects these curves, whether it is public policy/funding, private research and development investment, DOE investment, or a likelihood of hitting DOE targets.

  - The project is missing the punchline. This scope frames up the background for what should be a new project that builds on this information. The value is currently limited.
- So far, the project's weakness has been the limited scope of the data available through the ATB portal. However, the project team provides confidence that the scope will soon expand significantly, which will make this project much more useful.

Recommendations for additions/deletions to project scope:

- Other than improvements mentioned previously (if out of current project scope), the aggregation, normalization, and addition of historical data would be beneficial to analysts and researchers.
- Perhaps the full intent of this project is not being realized. If all this information already exists, then future projects are expected to directly reference that work as needed and build new analysis from there rather than starting from the ATB as a baseline. This project seems to be setting up the framework for an expanded scope that offers new analysis and insight of some kind. If that is not the intent, then a much simpler work scope is recommended to make sure information is shared internally with DOE offices.
- There are no recommendations other than to ensure that the proposed future expansions of scope do occur.

Project #SA-177: Analysis of Hydrogen Export Potential

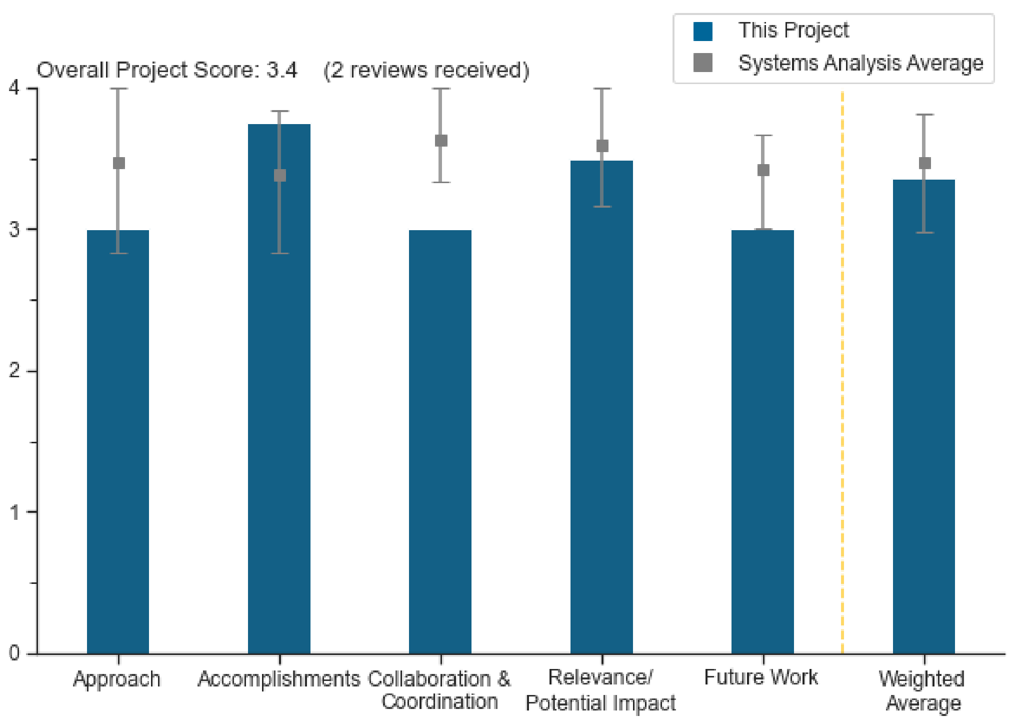
Amgad Elgowainy, Argonne National Laboratory

DOE Contract #	5.1.0.6
Start and End Dates	10/1/2020
Partners/Collaborators	Analysis of Hydrogen Storage Options (ST-001), National Renewable Energy Laboratory
Barriers Addressed	• Insufficient suite of models and tools: Extend suite with export model • Stove-piped/siloed analytical capability for evaluating sustainability • Inconsistent data, assumptions, and guidelines: Leverage the Hydrogen Delivery Scenario Analysis Model (HDSAM) and ST-001

Project Goal and Brief Summary

Argonne National Laboratory and the National Renewable Energy Laboratory are evaluating the economic potential for liquid hydrogen (LH2) export. Team members will identify regions near ports with potential for LH2 production, work with ST-001 to determine the cost of terminals and tankers for LH2 transport, and estimate current and future global hydrogen demand. The project will provide information needed to assess the value proposition of exported hydrogen, identify technology barriers to hydrogen export by identifying cost drivers, and expand opportunities for hydrogen export.

Project Scoring



The vertical hash-lines represent the highest and lowest average scores received by Systems Analysis projects.

Because of late reviewer withdrawals and conflict of interest notifications, the minimum number of reviewers for a complete review panel (three reviewers) was not achieved for this project. The results are included here to inform future work and reviews, but the scores for this project are not included in the subprogram average.

Question 1: Approach to performing the work

This project was rated **3.0** for identifying and addressing objectives and barriers and for project design, feasibility, and integration with other relevant efforts.

- The approach leverages external studies, as well as past U.S. Department of Energy efforts and modeling frameworks. An important aspect of the work is that the analysis specifies the assumptions in variables such as liquefaction cost across different studies so that it is clear where differences may arise (lower technology readiness level projections versus current technology, etc.). Otherwise, it is very difficult to assess the value of the different analyses.
- The current approach is reasonable but does not seem to address the costs of hydrogen distribution/transport domestically. That is reasonable if it is assumed that the hydrogen is being produced near a port, for example, in the Gulf Coast. However, there are comments about the demand for green hydrogen in Europe, and in that scenario, there could be additional transmission costs associated with renewable hydrogen production, say, in the middle of the country, where renewables may be cheaper and more abundant. It also seems like the data gathered on current and future hydrogen demand include hydrogen as mixed gases, which does not seem relevant here. Also, it is unclear what the point of analyzing future global demand is if the study is not complemented with a supply analysis (in this project, it appears the team is actually just using projections from others). It seems the point should be identifying net importers of hydrogen, but this approach does not take it to that step.

Question 2: Accomplishments and progress

This project was rated **3.8** for its accomplishments and progress toward overall project and U.S. Department of Energy (DOE) goals.

- The project made substantial progress, despite a very small budget. As the shipping scenario has been discussed for a few years now, having a grounded analysis of the related costs is important. The work also lays the framework for continued analyses to compare different generation and transportation scenarios.
- The team seems to have made good progress on completing its tasks. However, the scope should be expanded so that the work better answers the question of what the potential is for the United States to export hydrogen.

Question 3: Collaboration and coordination

This project was rated **3.0** for its engagement with and coordination of project partners and interaction with other entities.

- There is some collaboration with the National Renewable Energy Laboratory, but it was not discussed in detail. For a small project, there is not much room for collaboration across multiple institutions, but it would be interesting/valuable to get perspective from the stakeholder industries (Kawasaki, port authorities, shipping companies, etc.).
- More engagement with NASA would be beneficial. It seems there could also be mutual benefit to collaborating with the International Energy Agency, particularly on export/import potential.

Question 4: Relevance/potential impact

This project was rated **3.5** for supporting and advancing progress toward the Hydrogen and Fuel Cell Technologies Office goals and objectives delineated in the Multi-Year Research, Development, and Demonstration Plan.

- Managing renewable hydrogen costs in areas where renewable energy costs are high is an important part of understanding the balance between transportation modes and distances versus generating at the point of use. This project starts that analysis and should help to highlight potential regulatory issues that may arise.
- The research and analysis on LH2 storage costs can be leveraged to better understand the potential role for hydrogen in maritime and commercial aviation applications.

Question 5: Proposed future work

This project was rated **3.0** for effective and logical planning.

- It is unclear whether this modeling/functionality is being added to the Hydrogen Delivery Scenario Analysis Model (HDSAM). This seems important to addressing the "insufficient suite of models and tools" barrier.
- The future work description is somewhat generic but logically comes after the current tasks.

Project strengths:

- The project's strengths include good coordination with other projects, use and extension of modeling tools, and leveraging of external studies.
- The biggest strength is that the project builds off of HDSAM.

Project weaknesses:

- Better data are needed on the scalability of LH2 storage, as well as potential for boil-off during hydrogen transfer (boil-off considerations were removed, but it appears they were based on boil-off solely during storage).
- The lack of direct industrial feedback/participation could be a weakness.

Recommendations for additions/deletions to project scope:

- Ultimately, the lowest-cost solution will be the most successful. Now that the framework has been developed, it would be valuable to compare the different segments versus geography (generation, transportation, storage) to determine the best location for electrolyzer deployment for specific geographies (whether we should be exporting hydrogen or electrolyzers, how far away from point of use electrolysis should be placed based on delta in electricity cost, etc.).
- The project should include the analysis of which countries may be net importers of hydrogen, as well as which other countries are positioned to be net exporters (e.g., Chile). HDSAM should be expanded so that there is a public tool to evaluate LH2 shipping costs.

Project #SA-178: Cradle-to-Grave Transportation Analysis

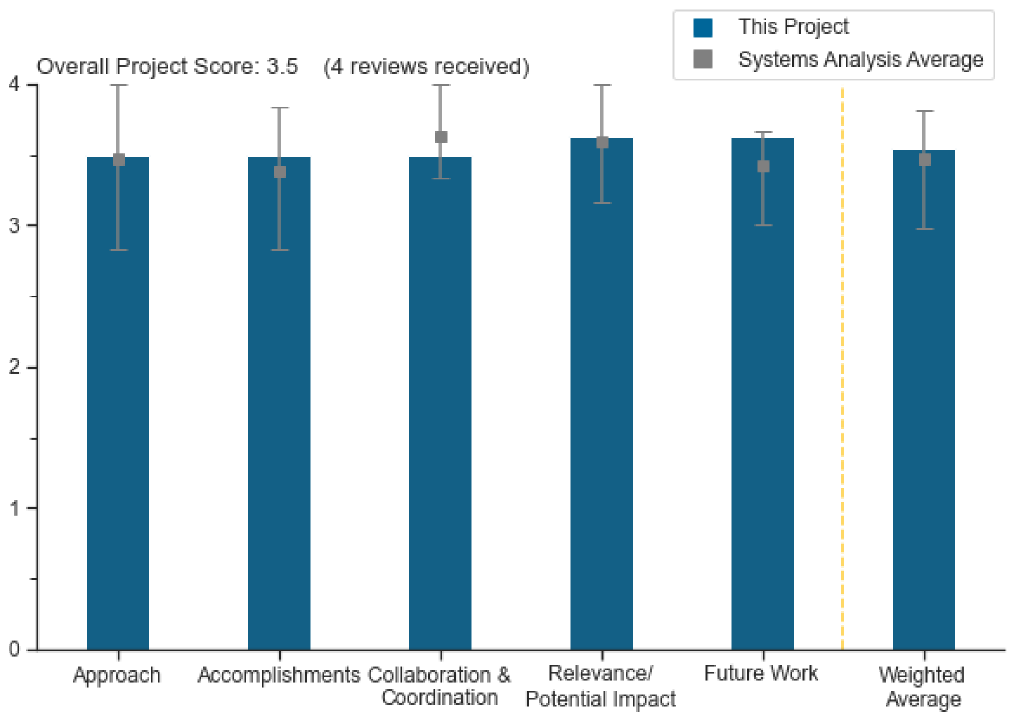
Amgad Elgowainy, Argonne National Laboratory

DOE Contract #	5.1.0.6
Start and End Dates	10/1/2020
Partners/Collaborators	U.S. DRIVE Partnership, Integrated Systems Analysis Tech Team, Strategic Analysis, Inc., Argonne National Laboratory Autonomies Team
Barriers Addressed	• Insufficient suite of models and tools • Indicators and methodology for evaluating economic and environmental sustainability • Inconsistent data, assumptions, and guidelines

Project Goal and Brief Summary

This project will deliver information about anticipated cradle-to-grave (C2G) greenhouse gas (GHG) emissions and costs of different vehicle technology pathways. Argonne National Laboratory will employ the lab's Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET®) and Autonomie modeling tools to evaluate C2G economic and environmental vehicle technology impacts. The analyses will examine fuel production, vehicle operation, and vehicle manufacturing for different vehicle classes and powertrains.

Project Scoring



The vertical hash-lines represent the highest and lowest average scores received by Systems Analysis projects.

Question 1: Approach to performing the work

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

- The comments apply only to Task 1 and Task 2, as information from Task 3 was not presented. The project seems generally well-designed for addressing the barriers and objectives identified. Some improvements to

Task 1 would include consideration of larger light-duty vehicles (LDVs). Including small sport utility vehicles (SUVs) makes sense, given their large market share, but larger light-duty (LD) trucks and SUVs may be the most difficult segments to decarbonize and would benefit from additional analysis. Duty cycles for these vehicles may also differ from those of midsize cars and small SUVs, as the former are more frequently used as commercial vehicles. For Task 1, cost sensitivity results were not presented, though the presenter indicated that such analyses are under way. It is recommended that cost sensitivities be integrated into the levelized-cost-of-driving results. This was done well on the GHG emissions impact side of the project. For Task 2, it would be useful to present updated vehicle lifecycle assessment (LCA) results in the context of existing fuel LCA estimates. In addition, fuel cell sizing sensitivities could be illustrative. This can be parsed to some extent from slide 19 results but could be more clearly presented.

- The team used a proven approach to evaluate and compare advanced vehicle concepts versus baseline concepts, and the approach focused on estimates of the key contributors to differences peculiar to specific technologies (carbon fiber impacts).
- The approach appears consistent with the needs of the industry and builds on previous model development in this area.
- The approach is illustrated in the slides, and GREET is expanded and updated to evaluate fuel and vehicle cycles. It is suggested that the appendix be used to describe the approach in more detail.

Question 2: Accomplishments and progress

This project was rated **3.5** for its accomplishments and progress toward overall project and U.S. Department of Energy (DOE) goals.

- The project has clearly resulted in tangible improvements in DOE's ability to estimate costs and environmental impacts associated with these technologies. This includes valuable modeling improvements and improved data and assumptions useful to a wide range of applications. Significant gaps remain to be addressed by future work, but the project shows solid progress toward overcoming identified barriers. As discussed under Question 1, additional sensitivity analyses and expansions, in terms of the types of vehicles studied, would further contribute to overcoming these barriers.
- The project started in October 2020, and progress is commensurate with funding, helping DOE to achieve the goal of enabling improved technologies to contribute to national objectives. It is good that work has started on both medium-duty vehicles (MDVs) and heavy-duty vehicles (HDVs).
- The project has achieved excellent progress, with comprehensive analysis of various scenarios and significant technical accomplishments. The project could be further improved from the points of view below:
    - Comparing slides 9 and 10, the differences among midsize sedans with different types of fuels are similar to those differences among SUVs with the same types of fuels. The comparison between slides 11 and 12 also led to similar conclusions for the GHG analysis; however, should some preferences of SUVs over midsize sedans to certain types of fuels be expected, the project should review the assumption for midsize sedans and SUVs and provide some explanations.
    - In addition to slides 11 and 12, the project should show the breakdown of total GHG for midsize sedans and SUVs into vehicle manufacturing and operation, and feedstock and fuel production.
    - Slide 7 should include the explanations on the error bar.
    - It seems there is a jump from slide 12 to slide 13 on carbon fiber LCA. Some background introduction should be provided before slide 13.
- The accomplishments to date are very good. The quantitative results are clear so far, and qualitative justification make sense. The only questionable item is for the degree of hybridization being used for fuel cell medium-duty and heavy-duty trucks. Recent and near-term Class 8 fuel cell drayage truck battery sizes have been anywhere from 12 kWh up to 100 kWh. Even at the lower end, slide 18 shows that battery mass for fuel cell trucks is less than for diesel configurations.

Question 3: Collaboration and coordination

This project was rated **3.5** for its engagement with and coordination of project partners and interaction with other entities.

- Collaboration with the U.S. DRIVE Partnership team, Strategic Analysis, Inc. (Strategic Analysis), and another national laboratory project team (Autonomie) who have the needed expertise is excellent, as a result of prompt and thorough input provided by the collaborators.
- This project engaged several excellent partners to improve success. There is little to criticize here. One potential improvement might be to compare and contrast the impact estimates from this work with those of other groups working in this space. This might help to further illustrate where key cost and emissions impact uncertainties remain across methodologies. This is perhaps a stretch goal.
- The collaboration is good. The project could benefit from the industry/original equipment manufacturer review of assumptions and preliminary results to provide a reality check, especially for vehicle composition for both material and drivetrain configuration.
- This project has good teamwork with other partners and collaborators. It collaborated with U.S. DRIVE members on C2G analysis, with Strategic Analysis on material composition of fuel cell system and onboard hydrogen storage, and with the Autonomie team on fuel economy and vehicle cost and composition. Nonetheless, it will be better to have some auto companies included in this study to validate the assumptions on vehicle composition and cost.

Question 4: Relevance/potential impact

This project was rated **3.6** for supporting and advancing progress toward the Hydrogen and Fuel Cell Technologies Office goals and objectives delineated in the Multi-Year Research, Development, and Demonstration Plan.

- C2G economic and environmental analysis is critical to evaluating these options on the table. The project aligns well with DOE Hydrogen Program and DOE objectives, and the project has the potential to advance progress toward DOE research, development, and demonstration (RD&D) goals and objectives.
- The project aligns well with DOE RD&D objectives and has the potential to advance progress toward DOE goals and objectives because critical component costs are still a barrier in the midterm.
- This project has great information for decision-making purposes. There certainly is a need for reliable and consistent C2G economic and emissions information.
- The project clearly contributes to advancing Hydrogen Program goals and objectives. The outputs of this project would have applications across several other workstreams presented at this Annual Merit Review. This project could improve its relevance by emphasizing areas of key uncertainty in cost and emissions impacts. This would assist the Hydrogen Program and other projects by identifying important focus areas for future work.

Question 5: Proposed future work

This project was rated **3.6** for effective and logical planning.

- There is nothing to criticize here. The planned and proposed future work seems like a logical and effective path.
- The proposed activities are very logical continuations of this year's activities.
- The proposed future work is right on track.
- The project has an effective proposed future work plan that incorporates key decision points and considers barriers. However, the following points could be considered in the future work, if not included in this or other studies: (1) evaluation of GHG emissions associated with the manufacturing of fuel cell stack and balance of plant for LDVs and SUVs; (2) evaluation of GHG emissions associated with the manufacturing of carbon fiber overwrapped tanks for 350 bar and 700 bar onboard hydrogen storage for LDVs and SUVs; and (3) cost analysis for various MDVs and HDVs.

Project strengths:

- Overall, the project demonstrated an excellent study on the C2G transportation analysis, with comprehensive analysis on various scenarios and significant technical achievements.
- The analysis topic is outstanding. There is a sound approach and a highly qualified principal investigator and partners. Progress is excellent, as are collaborations with experts.
- The overall project strengths are the focused approach and ability to build on existing methods and tools.
- The project has tangible and impactful project outputs, with highly rigorous technical work.

Project weaknesses:

- The project could be further improved from the points of view below:
    - Comparing slides 9 and 10, the differences among midsize sedans with different types of fuels are similar to those differences among SUVs with the same types of fuels. The comparison between slides 11 and 12 also led to similar conclusions for the GHG analysis; however, should some preferences of SUVs over midsize sedans to certain types of fuels be expected, the project should review the assumption for midsize sedans and SUVs and provide some explanations.
    - In addition to slides 11 and 12, the project should show the breakdown of total GHG for midsize sedans and SUVs into vehicle manufacturing and operation, and feedstock and fuel production.
    - Slide 7 should include the explanations on the error bar.
    - It seems there is a jump from slide 12 to slide 13 on carbon fiber LCA. Some background introduction should be provided before slide 13.
    - The appendix should show how the GREET model will be expanded and updated.
    - Some automotive companies should be included in this study to validate the assumptions on vehicle composition and cost.
    - Future work or other studies could consider the following: evaluation of GHG emissions associated with the manufacturing of fuel cell stack and balance of plant for LDVs and SUVs; evaluation of GHG emissions associated with the manufacturing of carbon fiber overwrapped tanks for 350 bar and 700 bar onboard hydrogen storage for LDVs and SUVs; and cost analysis for various MDVS and HDVs.
- The suite of market segments considered could be improved. More emphasis is needed on cost uncertainty and sensitivity analysis.
- The project appears to need some industry verification of assumptions and results.

Recommendations for additions/deletions to project scope:

- The project could consider larger LD SUVs and trucks. It is recommended that the project integrate Task 2 findings with existing fuel LCA literature to give a fuller context.
- Potential additions to the project could be empirical testing (where possible, related to mass and cost) to validate some of the results. Also, the development of a publicly available tool would be helpful.
- A forward-looking analytic plan developed in conjunction with partners may be useful.

Project #SA-179: Transportation Benefits Analysis

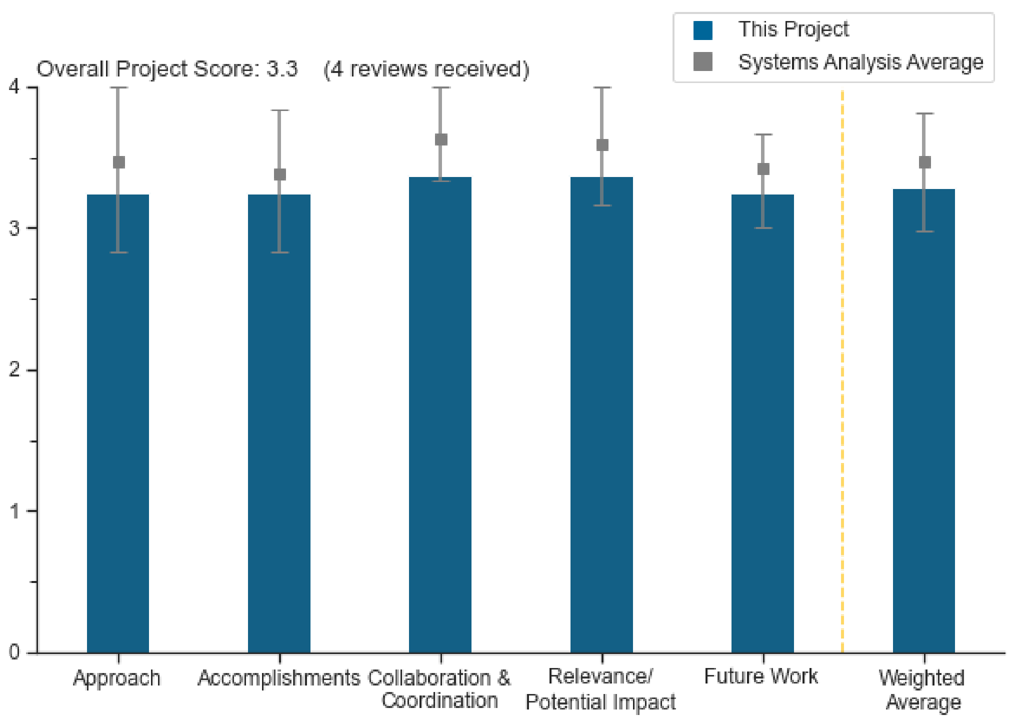
Aaron Brooker, National Renewable Energy Laboratory

DOE Contract #	5.3.0.2.502
Start and End Dates	10/1/2019
Partners/Collaborators	21st Century Truck Partnership
Barriers Addressed	• Future market behavior: Assessing impact of Hydrogen and Fuel Cell Technologies Office (HFTO) research, development, and demonstration targets on future fuel cell and battery electric vehicle adoption • Inconsistent data, assumptions, and guidelines: employ consumer choice models validated with real-world data, and coordinate across U.S. Department of Energy offices (HFTO, Vehicle Technologies Office, Bioenergy Technologies Office) and analysis efforts (Annual Technology Baseline) to use consistent data and assumptions • Insufficient suite of models and tools: expand vehicle choice models to the medium- and heavy-duty sector

Project Goal and Brief Summary

The National Renewable Energy Laboratory (NREL) is collaborating with the 21st Century Truck Partnership to quantify the benefits of U.S. Department of Energy research into alternative powertrain technologies. The project team will model future light-duty (LD), medium-duty (MD), and heavy-duty (HD) vehicle deployment and adoption, emissions reductions, and petroleum consumption reductions associated with the achievement of U.S. Department of Energy (DOE) research and development targets. Researchers will then develop cost and performance scenarios for various levels of DOE contribution. The results will help to identify key targets that drive tipping points in technology adoption.

Project Scoring



The vertical hash-lines represent the highest and lowest average scores received by Systems Analysis projects.

Question 1: Approach to performing the work

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

- The team intends to use capable models (Automotive Deployment Options Projection Tool [ADOPT], Future Automotive Systems Technology Simulator [FASTSim], and TRUCK) to analyze vehicle technologies in the Program Success Case and the No Program Case [Fiscal Year (FY)] 2020. The interface between analysis tools is sound.
- The approach appears to be good, and there is good use of existing tools and approaches to updating tools for MD/HD use. However, results are so dependent on assumptions, and there should be a little more insight into their establishment and impact. In addition to more background on how assumptions are established, it is suggested that the project perform sensitivity analyses and determine the drivers and needs for areas of focus. This may be part of future work, but that was not completely clear.
- Good efforts have been made to leverage modeling tools and data to provide useful insight. It could be greatly improved by adding more real-world adoption metrics and the impact of policy levers. This could include the impact of longer charging/fueling time, access to overnight home charging (multi-unit dwellings), impact of limited payload capacity, etc. Policy levers could include vehicle sales and purchase mandates (only zero-emission vehicles [ZEVs] become viable options in certain years), tax incentives, and different vehicle purchase incentives, to name a few.
- Using models such as ADOPT, FASTSim, TRUCK, and HDStock to help estimate the energy and emissions benefits of achieving DOE targets makes sense. However, looking at this from the perspective of what would be ideal, it seems that NREL would ideally consider ADOPT results within the context of a broader suite of analysis. It does not seem that these frameworks are capturing all of the dynamics needed to fully characterize energy and emissions benefits. There are a few critical examples of why this is the case.
    - First, the sales volumes of fuel cell electric vehicles (FCEVs) and battery electric vehicles (BEVs) that would be achieved if DOE targets were met would have a substantial impact on U.S. petroleum consumption, more than enough to affect global prices.
    - Second, achievement of these goals would have substantial implications for the electricity grid, including infrastructure needs and regional and nationwide electricity prices. The price multiplier for the *Annual Energy Outlook* electricity prices helps somewhat on this front, but it does not describe how we would expect the composition of the grid to change under conditions of elevated electricity demand. It is a good start, but it could be much more robust.
    - Third, depending on how expensive or inexpensive these vehicles are relative to conventional vehicles, potentially significant changes would be expected in household and firm costs of passenger and freight transport. These impacts could also move markets, leading to changes in national passenger vehicle miles traveled and freight ton miles.
    - Ideally, NREL would be incorporating the perspective of global economic modeling in some form. This could be from technologically rich integrated assessment, partial equilibrium, or general equilibrium frameworks—but the global economic perspective should be represented in some way to get a more complete assessment of benefits.
    - Incorporating dispatch or other electricity market modeling would also improve the robustness of this methodology.
    - This is not to say that the NREL approach is subpar, only that it could be improved. Admittedly, incorporating additional large and complex modeling frameworks into this methodology may be outside the scope of what has been funded for this project. A middle ground, then, would be to conduct a robust set of sensitivity analyses that explore alternative petroleum and electricity prices for the program success scenario, as well as alternative assumptions about passenger and freight transportation service demand levels. These would at least put some bounds around how we might expect DOE transportation program benefits to vary, given uncertainty in how other markets would respond to these rather transformational changes in the transportation sector. This will be especially critical for the decarbonization scenarios the project contemplates.

- It was noted that sensitivity analysis of this type is discussed on slide 21, but the materials do not describe the nature of this analysis or what methods would be used to conduct it. Slide 22 includes a reference to TEMPO being leveraged in FY 2022, but if this benefits analysis and decarbonization scenario work is being conducted in FY 2021, it is unclear how TEMPO will inform those results. Further, some of these sensitivity questions would seem to be outside the capabilities of TEMPO, though this reviewer's knowledge of that framework is limited.

Question 2: Accomplishments and progress

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

- With the approach set up the way it is, the results make sense; they show that both BEV and FCEV penetration are very low for both LD and HD applications since adoption curves are heavily based on pure cost competitiveness. This is an extremely valuable insight, especially for policymakers that are pushing for 100% ZEVs within one to two decades. Even if the technology reaches technoeconomic targets, adoption will only start to occur many years after targets have passed. The data as presented create a good baseline to really add value for stakeholders when new adoption models (as suggested in the comments above) are explored.
- The project has been meeting its milestones, such as the March 2021 milestone, an important priorities' assessment and plan. The charts show that technology assumptions are consistent with DOE transportation program input. Legacy analysis approach improvements were discussed.
- There is good progress for a project that perhaps is more complex than originally anticipated.
- It is hard to fully evaluate progress on the updated 2021 analysis since, as the presenter noted, most of the results being presented are from the older FY 2020 analysis. That being said, the 2020 results are a useful characterization of where DOE believes technologies may penetrate U.S. markets under conditions of program success and what the benefits of this penetration might be. Updated analysis with better characterization of MD/HD vehicles should only improve this. The updates to ADOPT to handle MD/HD vehicles are well-defined and demonstrate good progress toward the project goals. These improvements seem very likely to contribute to reducing barriers to our understanding of the benefits of FCEVs once they are brought to bear to update the FY 2020 analysis. During the presentation, there was not enough time to discuss the intuition behind the FY 2020 MD/HD truck results presented on slides 16 and 17. Perhaps the report does so, but that was not noted anywhere in the presentation. Such a discussion would be perhaps the most valuable output from this project, as it would help to characterize the key drivers of expected market penetration, or the lack thereof.

Question 3: Collaboration and coordination

This project was rated **3.4** for its engagement with and coordination of project partners and interaction with other entities.

- DOE connections are good, as is the 21st Century Truck Partnership. Gathering feedback—especially from key policymakers, truck operators, and LD vehicle manufacturers—would add great value for vehicle adoption assumptions and the role that policy could play. The project should look especially to California stakeholders that are setting aggressive ZEV targets that will likely be re-created in other states.
- Collaboration with the U.S. DRIVE Partnership and coordination across Office of Energy Efficiency and Renewable Energy program offices are outstanding.
- There is great collaboration and use of existing DOE groups and industry working groups. Reviewing results and drivers with industry working groups to inform and provide validation is recommended.
- The project participants seem to be making good efforts to gather the most up-to-date modeling inputs for their analyses. Gathering industry perspectives through the 21st Century Truck Partnership is good, though how applicable that perspective is to vocational vehicles is not clear. There do not appear to be any similar information-gathering efforts on the LD side of the analysis. Therefore, there seems to be room for improvement in terms of the scope of industry outreach.

Question 4: Relevance/potential impact

This project was rated **3.4** for supporting and advancing progress toward the Hydrogen and Fuel Cell Technologies Office goals and objectives delineated in the Multi-Year Research, Development, and Demonstration Plan.

- This project is of critical importance to the DOE Hydrogen Program's goals and objectives. Characterizing the potential impacts and benefits of program success not only helps to justify the program, but also can help to guide program goals and priorities. This work helps to clarify the transportation applications in which fuel cells are most likely to succeed. The relevance of this project could be improved only by expanding the universe of estimated benefits. Work to estimate criteria emissions benefits, in addition to greenhouse gas emissions benefits, would have a strong impact. Estimating jobs impacts and impacts on overall household/firm expenditures would also be welcome.
- This project provides a method of evaluation and really good feedback on impacts of DOE funding initiatives. Also, the project can be used to set areas of focus and prioritize funding initiatives.
- The project aligns well with DOE's research, development, and demonstration objectives and has the potential to advance progress toward DOE goals and objectives in the transportation sector.
- The relevance and impact could be huge, but it is not there yet. However, there is great potential to add significant value with some of the earlier changes suggested.

Question 5: Proposed future work

This project was rated **3.3** for effective and logical planning.

- Overall, the planned work for the remainder of FY 2021 seems logical and is likely to help address critical program barriers. Per comments on the approach above, a more holistic consideration of economic impacts could enhance these benefits, but the planned work is good. The project participants are right to identify market disruptions and interactions as an area of future work in FY 2022. However, it is unclear that the planned methods will fully address this need. Per comments above on TEMPO, it is unclear that this framework can address all of these types of questions. It may make sense to supplement these methods with electricity sector modeling and global economic modeling. It is encouraging to see that work in non-road and aviation sectors is under consideration for FY 2022. DOE and NREL are strongly encouraged to conduct this work. Especially in the context of fuel cells, many of the most critical applications may be in these types of non-road applications. This is work that should go forward with full funding.
- The proposed activities are very logical continuations of this year's activities. Non-road and off-road analysis would be interesting.
- The future work appears to hit all the areas in need of refinement of assumptions and tools being used.
- Proposed future work focuses a bit too much on refinement, rather than taking a step back to ensure the overall direction provides the highest value. More stakeholder engagement and inclusion of new high-level metrics will add more value than detailed refinement of assumptions at this stage.

Project strengths:

- The overall project strength is the development of a structured approach to evaluating the impacts of DOE funding. Once it is defined, then stakeholders can evaluate input assumptions to better understand funding priorities based on cost and emissions impacts.
- The scope of work is highly impactful. There is good use of collaboration to identify modeling inputs. Outputs so far contribute strongly to program goals. Plans to expand beyond on-road vehicles are taking this project in a good direction.
- The overall project is set up well to address key questions and issues for reducing the environmental impact of the transportation sector.
- There is a sound approach and a highly qualified principal investigator and partners. There is excellent progress and collaboration or coordination with DOE and external/internal experts.

Project weaknesses:

- The project weakness currently appears to be the complexity of the project and the ability to process and present the "take-aways." For instance, it is unclear how many variations in assumptions affect the results, and it is unclear which assumptions are the biggest drivers. It is unclear which inputs present the most risk for not meeting DOE goals. It is likely all there but appears to be difficult to present.
- Lack of dynamics for fuel prices and transportation service demand could limit usefulness of benefit estimates. This is especially true for transformational decarbonization scenarios that would be expected to have significant impacts on petroleum prices and the structure of the energy sector. Sensitivity analysis plans need to carefully consider how to characterize these impacts. Characterization of the intuition behind market penetration estimates could be improved. That messaging is not very clear so far, at least for the MD/HD results. The project could benefit from broader industry outreach in LD and MD/HD vocational sectors.
- Keeping a refined scope to quantifying impacts only from DOE-funded research could be a major missed opportunity. It is concerning that the project researchers do not understand their assumptions and analysis well enough to form basic insight. Even with two panelists supporting the question-and-answer session, simple questions and confirmations were met with confusion.
- There are no weaknesses.

Recommendations for additions/deletions to project scope:

- Current results have shown that much more support outside DOE is needed to accelerate ZEV adoption for on-road transportation. This should be framed as a call to action, as the typical pathway to cost competitiveness is not acceptable, given global environmental targets. The project should find ways to incorporate the voice of the customer to inform vehicle adoption and explore a number of different policy scenarios (for example, if policy support created a total cost of ownership parity tomorrow and if ZEV was the only option by a certain year). The project should take a look at policies in California for specific examples of these policy frameworks. Also, the recent proposed awards from a combined California Air Resources Board/California Energy Commission grant supporting drayage trucks in California now has public information for commercial Class 8 truck costs in about the 2023 timeframe, with multiple reference points for both battery and fuel cell trucks. A copy of the full proposals to help establish a baseline can be requested (spoiler: they are not cheap).
- The project should improve robustness of planned sensitivity analysis methods and ensure these methods include global economic modeling and electricity market modeling. For future project cycles, the team should consider expanding the scope of benefits to include criteria air pollutants and other economic metrics.
- In addition to more background on how assumptions are established, it is suggested that the project perform sensitivity analysis and determine the drivers and needs for areas of focus.

Project #SA-180: Advanced Network Analysis of Hydrogen Fuel Cell Automated Vehicles for Goods Delivery (ATLAS) – Total Cost of Ownership of Autonomous Fuel Cell Fleet Vehicles

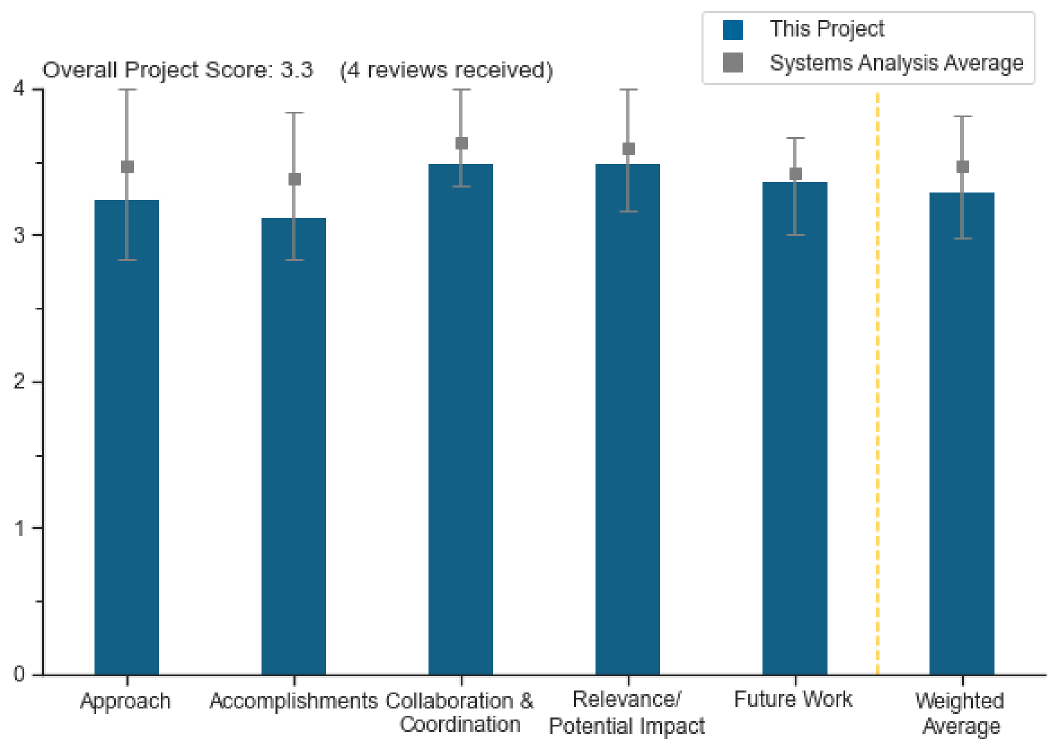
Tim Lipman, Lawrence Berkeley National Laboratory

DOE Contract #	5.3.0.2.502
Start and End Dates	9/1/2020
Partners/Collaborators	National Renewable Energy Laboratory, Center for Transportation and the Environment
Barriers Addressed	• Future Market Behavior – Economic and environmental value of FCEVs in MDV applications • Insufficient Suite of Models and Tools –MDV fleet level analysis, early adopters, H2 refueling infrastructure roll-out, economics and emissions analysis

Project Goal and Brief Summary

The Advanced neTwork anaLysis of hydrogen fuel cell Automated vehicleS (ATLAS) seeks to help directly reduce harmful emissions of both greenhouse gases (GHGs) and criteria air pollutants (CAPs) through implementation of zero-tailpipe-emission technologies. In this project, ATLAS aims to enable future regional goods delivery networks, with fleets comprising medium-duty fuel-cell-powered delivery vans and heavy-duty short-haul hydrogen trucks. The project team is developing delivery network analysis tools that will help evaluate routing optimization, vehicle duty cycles and drive-cycle dynamics, vehicle energy use, and the impacts of vehicle automation. Researchers will also calculate costs for these networks and compare them to those of conventional fuel systems.

Project Scoring



The vertical hash-lines represent the highest and lowest average scores received by Systems Analysis projects.

Question 1: Approach to performing the work

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

- The team has a thorough, systematic approach to conducting a challenging analysis involving steps such as routing and fueling facility siting. The approach is being used on an initial site. The choice of GraphHopper mapping for routing analysis is good for what this project needs to accomplish.
- This is a good approach, in theory. The project will likely run into challenges with process and need to remain flexible in finding solutions and modifying the approach. For instance, the team will likely need to complete simulations for case studies and evaluate results for effectiveness and utility before applying them broadly. The station deployment approach is unclear, i.e., it is not clear whether the project will consider only private stations that are commonly found at distribution sites or also private or shared station deployments. The distribution facility approach is also unclear, i.e., it is not clear whether the project will consider existing package distribution facilities, future unconstrained locations, or both. It will be important to accurately characterize the duty cycles for various delivery schemes, as they are unique and differ depending on whether they are commercial, residential, urban, rural, etc. Results from the study will be valuable to better understanding the benefits for a holistic approach to parcel delivery using zero-emission vehicles/fuels and autonomous technology.
- The project developed a systematic approach that combines a fuel cell delivery van and drayage truck vehicle route modeling, detailed simulation of vehicle energy use, hydrogen station planning/design trade-offs, and calculation of vehicle ownership and hydrogen fuel costs. It is suggested that the project add some more description of the use of GraphHopper, such as required input and output.
- The project aims to model the incorporation of hydrogen-powered fuel cell electric vehicles (FCEVs) in autonomous driving modes. Based on the work presented so far, there did not seem to be a clear connection in the approach to this aspect of the project goals. It is not clear how the routing behavior or the needs assessment, as presented so far, would be specific to the automated vehicle use case. In addition, it seems as though the geographic scope of modeling will necessarily be limited to smaller regions and/or smaller numbers of routes. The project approach was not clear in terms of how useful this could be in implementation or how potential future users of the project results or tools could utilize this more limited geographic result for larger or broader system considerations. It is unclear whether it would need to be piece by piece for individual regions or whether a multi-regional approach could be implemented in a single run, somewhere down the line.

Question 2: Accomplishments and progress

This project was rated **3.1** for its accomplishments and progress toward overall project and U.S. Department of Energy (DOE) goals.

- The project has been meeting its milestones, such as demonstrating initial success with GraphHopper. Development of H2Plan, an infrastructure analysis platform, began recently, and it is not yet time to assess progress.
- The project has reached several accomplishments so far. However, there are still gaps between these accomplishments and the milestone deliverables, as shown in progress toward DOE targets or milestones. In addition, there are a few points for further improvement. On slides 12 and 13, the project should add the assumed hydrogen refueling station into the simulation map, show the number of delivery vans for the simulations, and explain how the five distinct routes are calculated with 80 van stop locations, as some routes are intertwined with each other. It is suggested that the project do some more studies to investigate the relationships between the number of vans, distinct routes, van stop locations, and number of package drops. It will be interesting to see the timeline of the delivery along the routes on the map. The project is asked to provide some explanations on how the approach could realistically reflect the actual traffic situations.
- There is good accomplishment to date. It is still early in project. The project has done good work in finding an open-source solution to routing, but it would be good to verify its effectiveness and accuracy with a parcel delivery industry representative.

- The project team has spent significant time implementing and developing a routing process that will be central to the project's overall goals; however, it is not entirely clear why this new development is necessary. Several off-the-shelf options are available, even in open-source software. The significant amount of time that was put into this routing routine could have been spent more on other, later modeling steps in the project.

Question 3: Collaboration and coordination

This project was rated **3.5** for its engagement with and coordination of project partners and interaction with other entities.

- The project is co-led by Lawrence Berkeley National Laboratory (LBNL) and the National Renewable Energy Laboratory (NREL), in collaboration with the Center for Transportation and the Environment (CTE). The project teams demonstrated strong expertise in modeling and analysis in past projects.
- Collaboration with CTE is a major plus, in addition to the excellent partnership between LBNL and NREL.
- Several relevant and potential collaboration and coordination opportunities have been identified. The project should also consider collaborating with other ongoing hydrogen fuel station siting activities that have been ongoing in California at the state government level and other research and education institutions. At the least, the project should coordinate with these other ongoing works for lessons learned and potentially to provide some points of comparison or identify opportunities to capitalize on the work that is being done today in terms of siting hydrogen fueling stations. There may be opportunities for co-location that should at least be evaluated.
- The collaboration is good but will benefit from having an industry partner to collaborate and verify the assumptions. It would be good to have that partner provide the requirements and operational constraints since that can be unique to logistics and parcel delivery.

Question 4: Relevance/potential impact

This project was rated **3.5** for supporting and advancing progress toward the Hydrogen and Fuel Cell Technologies Office goals and objectives delineated in the Multi-Year Research, Development, and Demonstration Plan.

- The project is definitely timely and will provide valuable insights, based on the project goals. As the project team notes, there are already multiple demonstration projects on the ground that have similar operations, and this work could be a very valuable resource for translating those demonstration projects' findings into improved implementation for more commercial-ready projects in the next phase of deployment.
- The goal of the project is to enable future regional goods delivery networks based on hydrogen fuel and medium-duty fuel-cell-powered delivery vans and heavy-duty short-haul hydrogen trucks; the project will work toward this with a unique and detailed analysis that combines and advances hydrogen system modeling capabilities. The project aligns well with current DOE objectives.
- Depending on the effectiveness of the model, this project will be very relevant and impactful. The project can inform funding decisions, industry needs, funding program characteristics, and industry blind spots.
- The project aligns well with DOE's research, development, and demonstration (RD&D) objectives and has the potential to advance progress toward DOE goals and objectives in these segments of the transportation sector.

Question 5: Proposed future work

This project was rated **3.4** for effective and logical planning.

- The proposed future expansion of scope to additional vehicle classes and use cases is a very good addition to the project. In addition, expanding the number of routes/geographic extent is necessary. It would be helpful if the project team were to provide some vision of even further expansion and what will be necessary to implement the project on an even larger scale. This question of scale will be critical for growth of commercial implementation.
- The project aligns well with DOE's RD&D objectives and has the potential to advance progress toward DOE goals and objectives in these segments of the transportation sector.
- Future work is on target. However, the project would benefit from some validation steps along the way.

- Highlighted at beginning of the presentation is the intent to help reduce GHG and CAP emissions, especially in highly impacted communities. However, the proposed future work on slide 18 did not include any GHG and CAP emission analysis for the environmental benefits of FCEV goods delivery. How the highly impacted communities are identified should also be included in the scope of the future work.

Project strengths:

- The project's strengths are its timeliness, its applicability to real-world operations and near-term demonstration or commercialization, and its structure to consider many aspects of delivery vehicle operations, including drive cycles and infrastructure development.
- The project has developed an excellent systematic approach that integrates and extends modeling capabilities developed at three national laboratories with collaboration activities. The approach is well-illustrated in the slides. The project demonstrated the successful application of GraphHopper on route simulations.
- This is an outstanding analysis topic. The project has a sound approach and a highly qualified principal investigator and partners. Progress is excellent, as is collaboration or coordination with experts.
- This is a complex project but can have some very impactful results that are both qualitative and quantitative. It will be exciting to start seeing some results.

Project weaknesses:

- The project should be further improved in terms of the following points:
  - The progress of the project seems to have fallen behind the expected milestone deliverables, possibly because of COVID-19.
  - It is suggested that the project add some more description of the use of GraphHopper, such as required input and output.
  - On slides 12 and 13, it is suggested that the project add the assumed hydrogen refueling station into the simulation map, show the number of delivery vans for the simulations, and explain how the five distinct routes are calculated with 80 van stop locations, as some routes are intertwined with each other.
  - The project should do some more studies to investigate the relationships between the number of vans, distinct routes, van stop locations, and number of package drops.
  - It will be interesting to see the timeline of the delivery along the routes on the map.
  - The project is asked to provide some explanations of how the approach could realistically reflect the actual traffic situations.
- This is a complex project that could benefit from some industry validation and verification of operational requirements constraints. There is a very broad range of possible inputs and scenarios that will need to be narrowed down and focused through industry needs in order to provide useful results.
- Currently, the project seems to be potentially narrow in its practical applicability. Also, there is not a well-defined methodology for making this work specifically applicable to the automated vehicle application.
- There are no weaknesses.

Recommendations for additions/deletions to project scope:

- The project needs either to develop a way to expand the geographic region and routes that can be modeled within this project or to develop a more complete vision and recommendations for enabling this kind of large-scale modeling in a future project. Also, the project needs to develop more concrete methodologies for application to the autonomous operation case specifically.
- GHG and CAP emissions analysis for the environmental benefits of FCEV goods delivery and the identification of the highly impacted communities should be added to the project scope.
- There are no current recommendations for additions/deletions. There is a good deal of challenging work to be done with the scope as is.