Systems Analysis – 2022

Subprogram Overview

Introduction

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

Crosscutting 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, Advanced Manufacturing Office, and others
- State and local government organizations
- Other federal agencies (e.g., the 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 (2022–2027)

- Develop models and analyses to support the implementation of the Bipartisan Infrastructure Law (BIL) and the Inflation Reduction Act (IRA).
- Conduct state-of-the-art assessments of technology cost, performance, and value proposition to help guide the research, development, demonstration, and deployment (RDD&D) portfolio.

Mid-Term (2027–2035)

- 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; assess job potential, including impacts on disadvantaged communities.

Fiscal Year 2022 Technology Status and Accomplishments

Activities Supporting the Bipartisan Infrastructure Law and the Inflation Reduction Act

HFTO has continued funding analyses of the cost and emissions benefits of hydrogen use in industry and transportation relative to other decarbonization solutions, in collaboration with offices across DOE and the federal government. These analyses informed the draft DOE National Clean Hydrogen Strategy and Roadmap[1] and the Clean Hydrogen Production Standard Draft Guidance,[2] both of which were released in September 2022 in support of the BIL. The draft roadmap identified sectors in which hydrogen could have a strong potential role in decarbonization: long-haul heavy-duty trucks, production of clean biofuels for aviation, chemicals production and iron ore refining in industry, high-temperature heat generation for industry, and long-duration energy storage for a clean grid. DOE is currently also supporting the U.S. Department of the Treasury's implementation of the IRA provisions, including Section 45V Credit for Production of Clean Hydrogen, which relies on Argonne National Laboratory's (ANL's) Greenhouse Gas Regulated Emissions, and Energy Use in Technologies (GREET) model.

Market Segmentation in Medium- and Heavy-Duty Transportation

The transportation offices within DOE (HFTO, Vehicle Technologies Office, and Bioenergy Technologies Office) collaboratively completed an analysis project, led by the National Renewable Energy Laboratory, that evaluates market adoption of medium- and heavy-duty vehicles, with varying ranges and operating conditions. The analysis leveraged a newly developed vehicle choice model at the National Renewable Energy Laboratory (NREL), Transportation Energy and Mobility Pathway Options (TEMPO), which estimates how segments of the trucking sector could transition to new powertrains as a function of fuel cost, vehicle cost, and assumptions around driving behavior, such as annual vehicle miles traveled within each segment of the market.[3] If DOE targets for the cost of hydrogen fuel, fuel cells, and storage are achieved, modeling shows that the trucking sector would start to adopt fuel cells over the next several decades and that 10%–14% of trucks could be using hydrogen fuel cells in 2050.

User-Friendly Model Development

HFTO routinely funds the development of tools that characterize the cost, emissions, and performance of hydrogen and fuel cell technologies. In 2022, HFTO and other DOE offices provided ANL with funding to complete an annual update to the GREET model, which is already used by 50,000 stakeholders worldwide to characterize emissions of hundreds of fuel pathways, including hydrogen. As part of this update, ANL developed a user-friendly interface to characterize the well-to-gate emissions of hydrogen production from diverse feedstocks.[4] Additionally, NREL developed the Hydrogen Analysis (H2A) Lite Production tool (H2A-Lite), which characterizes the levelized cost of hydrogen production from systems with user-defined assumptions (e.g., cost of electricity, efficiency, cost of fuel). H2A-Lite is pre-populated with configurations of key hydrogen production technologies, including electrolyzers, steam methane reforming with and without carbon capture and sequestration (CCS), and coal gasification with CCS.[5]

In addition, HFTO led DOE's first Hydrogen Business Case Prize competition in 2021, inviting teams to develop models that quantify the value proposition of hydrogen deployments in specific regions of the country. During this nine-month challenge, competing teams were asked to develop user-friendly Excel-based tools and supplemental final reports characterizing business cases for hydrogen. Team members received access to mentors across industry

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[1] DOE, *DOE National Clean Hydrogen Strategy and Roadmap* (draft), September 22, 2022, https://www.hydrogen.energy.gov/pdfs/clean-hydrogen-strategy-roadmap.pdf.

[2] DOE, U.S. Department of Energy Clean Hydrogen Production Standard (CHPS) Draft Guidance, September 22, 2022, https://www.hydrogen.energy.gov/pdfs/clean-hydrogen-production-standard.pdf.

[3] NREL, "TEMPO: Transportation Energy & Mobility Pathway Options Model," accessed 2022, https://www.nrel.gov/transportation/tempo-model.html.

[4] ANL, "GREET with H2 User Interface," accessed 2022, https://greet.es.anl.gov/greet_hydrogen.

[5] For more information on H2A-Lite, see NREL, "H2A-Lite: Hydrogen Analysis Lite Production Model," accessed 2022, https://www.nrel.gov/hydrogen/h2a-lite.html.

and national laboratories. Four winning teams received cash prizes of $20,000–$50,000, and the top two teams also received offers for paid internships at companies and the national labs.[6]

International Collaborations

HFTO's Systems Analysis team led U.S. engagement in the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE) Hydrogen Production Analysis (H2PA) task force. Members of H2PA include representatives from 10 countries, working to develop methods of life cycle analysis of hydrogen production and distribution; application of the mutually agreed upon methodology will help to inform global trade. Last year, HFTO supported the H2PA in completion of guidance around emissions analysis of electrolysis, steam methane reforming, and coal gasification, led by representatives from France and Australia.[7] In 2021–2022, HFTO led the H2PA in completing additional guidance on emissions analysis of hydrogen carriers and liquefaction, and contributed to guidance on hydrogen production from biomass and autothermal reforming.

Assessing Decarbonization Potential of Hydrogen Across Sectors

HFTO is currently funding updates to Pacific Northwest National Laboratory's Global Change Analysis Model (GCAM)[8] and the National Energy Modeling System (NEMS)[9] to represent the cost and emissions of hydrogen production from diverse resources, for use in industry, transportation, and the grid. These updated tools can then be used to characterize market potential of hydrogen in various sectors, relative to other decarbonization tools, such as electrification and CCS.

New Project Selections

- ANL is developing GREET+, a version of the GREET tool including pathways and assumptions of interest worldwide, in collaboration with the International Energy Agency.
- NREL, in collaboration with Mission Innovation, is developing guidance on how to characterize the sustainability of hydrogen deployments.
- DOE's Strategic Analysis team is launching several projects involving multiple entities across the Office of Energy Efficiency and Renewable Energy. These initiatives aim to characterize the decarbonization potential of a range of technology options, including clean fuels such as hydrogen, energy efficiency, electrification, and CCS. ANL and NREL are leading sprint studies, and longer-term projects are currently under development.

Budget

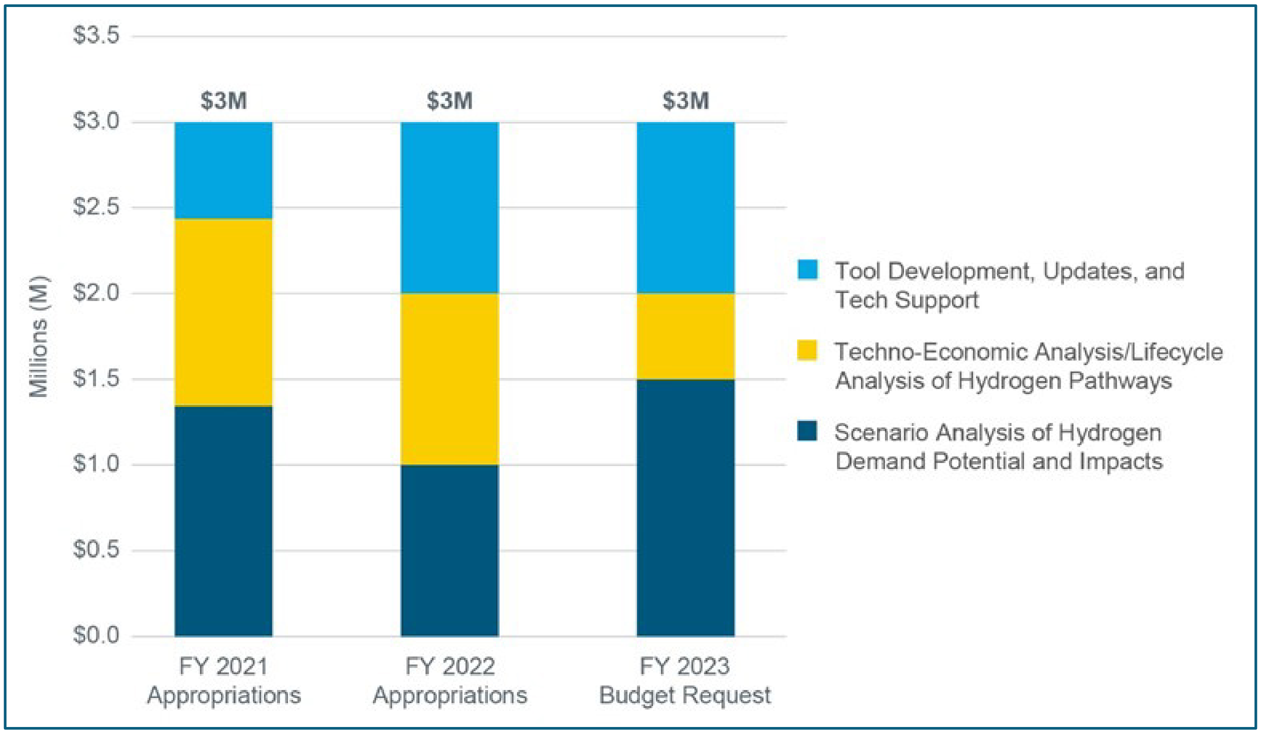
The Fiscal Year 2022 appropriation for Systems Analysis was $3 million. The program's budget was focused largely on scenario analyses evaluating priority sectors for hydrogen and key market drivers, techno-economic and life cycle analysis evaluating cost and benefits of hydrogen production from different pathways and hydrogen use, and the development of user-friendly platforms to characterize the cost and benefits of hydrogen technologies.

[6] American-Made Challenges, "Hydrogen Business Case Prize," accessed 2022, https://www.herox.com/h2businesscase/teams.

[7] IPHE, "Release of the IPHE Working Paper Ver1 Oct 2021: Methodology for Determining the Greenhouse Gas Emissions Associated with the Production of Hydrogen," https://www.iphe.net/iphe-working-paper-methodology-doc-oct-2021.

[8] Global Change Intersectoral Modeling System, "GCAM: Global Change Analysis Model," accessed 2022, https://gcims.pnnl.gov/modeling/gcam-global-change-analysis-model.

[9] U.S. Energy Information Administration, "Documentation of the National Energy Modeling System (NEMS) Modules," accessed 2022, https://www.eia.gov/outlooks/aeo/nems/documentation/.



Project Summaries

Below are brief Systems Analysis project summaries of oral presentations given during the 2022 Annual Merit Review (AMR). The full list of projects, including oral and poster presentations, is provided in Appendix D.

Project #SA-174: Life Cycle Analysis of Hydrogen Pathways

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

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 techno-economics and environmental implications of hydrogen use in these applications, providing estimates of associated costs and greenhouse gas emissions. Argonne National Laboratory is collaborating on this project with DOE's Strategic Analysis Office, DOE's Advanced Manufacturing Office, NREL, Lawrence Berkeley National Laboratory, and the University of California, Irvine.

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)

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 #SA-181: Global Change Analysis Model Expansion – Hydrogen Pathways

Page Kyle, Pacific Northwest National Laboratory

DOE Contract #	5.2.0.107
Start and End Dates	05/1/2021–10/31/2022
Partners/Collaborators	• Argonne National Laboratory • National Renewable Energy Laboratory

Project Goal and Brief Summary

This project seeks to add a hydrogen module to a configuration of GCAM in an effort to improve hydrogen representation in the tool, which allows researchers to explore the interplay of energy, agriculture, and climate systems. The work will include analyses of various hydrogen technologies that offer insight into their role and importance in facilitating system-wide emissions mitigation. By updating cost, performance, and emissions mitigation information on hydrogen production technologies, the project aims to increase hydrogen consumption in the industrial, transportation, refining, and building sectors, helping them to achieve decarbonization goals.

Project #SA-182: Biomass Gasification Optimal Business Case Analysis Tool

Bridger Cook, Oregon State University

DOE Contract #	5.3.0.502
Start and End Dates	10/5/2021–5/20/2022
Partners/Collaborators	• U.S. Department of Agriculture • Sun Grant Program (Western Region)

Project Goal and Brief Summary

Wildfire mitigation efforts create large amounts of potential biomass feedstock. Woody biomass gasification could potentially take advantage of this waste product to provide low-carbon hydrogen and enable the co-location of hydrogen supply and demand. However, the capital costs are high, and stakeholders considering these systems lack the proper analytical tools to make informed decisions. This project will develop an Excel tool to evaluate the economic, social, and environmental potential of a woody biomass-based hydrogen production facility. In addition to optimizing plant scale and production levels to maximize net present value, the tool will provide environmental and social impact metrics, offering further insight into the overall impact of a business venture, with cost and performance data being sourced from the H2A and GREET models. Access to such a business case analysis tool will decrease investment risk while promoting environmental and social justice, as well as supporting DOE's goal of supporting private-sector uptake of hydrogen production.

Project #SA-183: H2X Tool: Technoeconomic Modeling for Utilizing Curtailed Solar Power in California for Green Hydrogen Generation

Sharun Kumar and Amanda Wonnell, Pure Hydrogen

DOE Contract #	5.3.0.502
Start and End Dates	10/5/2021–5/20/2022
Partners/Collaborators	N/A

Project Goal and Brief Summary

By creating a techno-economic modeling tool, this project aims to enable the utilization of curtailed solar power for green hydrogen generation in California. The H2X model will evaluate end uses for green hydrogen generated from curtailed electricity. Hydrogen can be used to power manufacturing, transportation, and residences, and excess electricity can be sold back to the grid during peak demand. Tool users will input the following site-specific information: facility (plant capacity, depreciation, and hydrogen transport), technology (electrolyzer and fuel cell type, storage method), costs (electricity, water, and KOH), and end users (allocation of hydrogen sales to different industries). Once inputs are processed, the model will output the following: income statement information (including cost breakdown over the lifetime of the plant), carbon dioxide savings (per industry as a result of green hydrogen usage), and socioeconomic justice factors (i.e., jobs created).

Project #SA-185: Hydrogen Business Appraisal Tool

Nicolas Alfonso Vargas, University of Southern California

DOE Contract #	5.3.0.502
Start and End Dates	10/5/2021–5/20/2022
Partners/Collaborators	• Pacific Northwest National Laboratory • Los Alamos National Laboratory • National Renewable Energy Laboratory • Carnegie Institution for Science, Plug Power, Inc.

Project Goal and Brief Summary

This project aims to develop a user-friendly computational tool for DOE's Hydrogen Business Case Prize Competition. The tool will characterize business cases for hydrogen in user-defined scenarios and will also model four sectors of the hydrogen supply chain (production, storage, transportation, and end use) to produce comparable financial, environmental, and societal reports. This model was designed not only to provide assessments of hydrogen business cases but also to serve as an exploratory tool, exposing users to emerging methods of hydrogen production, storage, and transportation for various end uses to optimize parameter and technology selection.

Annual Merit Review of the Systems Analysis Subprogram

Summary of Systems Analysis Subprogram Reviewer Comments

This section provides a summary of the reviewers' remarks. The content reflects those inputs only and not the views of Program management. The complete set of review comments received is provided as Appendix A.

The Systems Analysis subprogram is managed well, with clearly articulated goals, milestones, and quantitative metrics. Suggested next steps included systems analysis efforts aimed at accelerating the transition of research to commercialization, while also engaging the community and advancing domestic manufacturing to meet demand. The Hydrogen Program (the Program) could more clearly define and communicate the research and development pathways to reduce costs, including the remaining risks or barriers along each pathway and the probability of achieving the goals. In addition, there could be more Program efforts to support transition to a hydrogen-based infrastructure, including analysis of the workforce needed, more training on the GREET model, and macroeconomic and system-wide economic studies. While Systems Analysis cannot easily foster innovation, analyses provide value by showing how the innovations might fare if they do in fact succeed.

Hydrogen Shot Goal

Specific pathways to achieving the Hydrogen Shot goal were not sufficiently articulated. The Program would be better served with more analysis to relate the goal to what is achievable in different timeframes. Technology innovations could be explained as part of a total cost of ownership model, helping stakeholders to better understand the impacts of these innovations on the Hydrogen Shot goal.

Analysis Needs

The subprogram has appropriately kept its focus on overall energy efficiency and environmental protection. This emphasis should continue so that hydrogen and fuel cell technologies can have meaningful impacts in transportation electrification and the broader energy transition to cleaner and more sustainable options. More specifically, while maintaining the strong focus on greenhouse gas emissions is important, local air pollutants also need further evaluation, as they are a key factor in addressing communities' environmental and health concerns. Hydrogen is considered a powerful avenue for global decarbonization, and the hydrogen community must ensure the credibility and transparency of environmental impact analysis. Investigating details of all the environmental impacts of hydrogen pathways on a life cycle basis—such as carbon footprint, land use, and materials needs—could contribute to building that trust.

Quantifying the projected demand for hydrogen is important, and continued analysis in this area is encouraged. Related activities could include developing an inventory of existing facilities, with their replacement/upgrade cost potential.

While Program cost status and goals were clearly articulated during the AMR, more analysis is needed to go deeper on a systems level, into the entire value chain, and to go beyond viability analysis. For electricity cost, the value of 3 cents/kWh used in some of the analyses and modeling seems questionable, since this does not include costs for transmission and distribution, and the lowest industrial electricity prices in the United States are now near 6 cents/kWh.

Analyses should incorporate some additional factors, such as the impacts of the war in Ukraine and the recent drought conditions. Technology comparative analyses could be beneficial in evaluating whether funding levels in each area are appropriate.

Given the plans for regional hydrogen hubs, the Program could perform more state- and region-specific analyses to assist states and regions in planning hydrogen and fuel cell demonstrations and deployments.

Regarding diversity and inclusion-related issues, discussions usually were more qualitative, as compared to the quantitative and clear metrics laid out for technology. Perhaps the Program could support development of a model (like the H2A and GREET models) that could provide more quantitative insights.