Technology Acceleration – 2022

Subprogram Overview

Introduction

The Technology Acceleration subprogram aims to enable the H2@Scale vision and support the Hydrogen Energy Earthshot through targeted hydrogen and fuel cell system integration and demonstration activities. To achieve this mission, Technology Acceleration focuses on:

- Identifying hydrogen applications and system configurations that can provide affordable and reliable clean energy.
- Validating and testing integrated energy systems.
- Bridging the gaps between component-level research, development, and demonstration (RD&D) and commercialization by integrating technologies into functional systems, reducing costs, and overcoming barriers to deployment.

Demonstrations conducted during verification and validation activities provide valuable data and feedback to research and development (R&D) conducted through the U.S. Department of Energy's (DOE) Hydrogen Program subprograms. The data are also used in techno-economic assessments of various market scenarios to provide essential information regarding market readiness to manufacturers, investors, and potential end users. The remaining subprogram activities—including manufacturing RD&D; safety, codes and standards; and workforce development—fill out an integrated portfolio that addresses other significant barriers.

The Technology Acceleration subprogram focuses its activities on key emerging markets and technology applications based on preliminary findings of the Systems Analysis subprogram, which identifies technologies and markets with the potential to enable economies of scale for hydrogen and fuel cell systems in alignment with the H2@Scale vision. Based on this analysis, the Technology Acceleration subprogram is currently focused on four technology application areas:

- **Grid energy storage and power generation** applications focus on grid integration and direct coupled renewable and nuclear hybrid systems, as well as distributed and backup power generation. Projects are designed to produce low-cost clean hydrogen from intermittent and curtailed renewable sources, provide grid reliability, demonstrate dynamic response to match grid demands, support market penetration of renewable energy systems such as wind and solar, and provide additional revenue streams for nuclear power plants.
- **Chemical and industrial processes** are focused on decarbonizing hard-to-decarbonize industrial sectors through integration of hydrogen technologies. These end uses include iron- and steelmaking and ammonia, fuel, and chemical production, among others. The integration of clean hydrogen will reduce greenhouse gas emissions, add jobs, and provide environmental justice in these energy-intensive processes.
- **Transportation** includes medium- and heavy-duty trucks, maritime, rail, off-road equipment, and other heavy-duty applications requiring significant power, range, and up-time. The focus for heavy-duty transportation applications is to demonstrate and validate fuel cell durability and performance under real-world conditions. Projects will also demonstrate and validate high-flow fueling to support these transportation modes. Analysis will also be conducted to determine total cost of ownership (TCO) and future targets needed to compete with incumbent technologies.
- **Enabling activities** include manufacturing RD&D; safety, codes and standards; and workforce development. Manufacturing RD&D projects aim (1) to identify and pursue high-value processing routes to accelerate scaling and (2) to develop techniques to produce advanced components and sub-systems to enable multi-megawatt-scale hydrogen systems at high production volumes. These demonstrations also focus on developing technology and analysis tools for quality control and reliability issues. The Safety, Codes and Standards activity area develops codes and standards to enable bulk utilization of hydrogen, as well as safety and permitting guidance to enable deployment of hydrogen for novel applications (see the Safety, Codes and Standards section of this report for more details). Workforce development activities support the development of training programs to enable the safe and effective deployment, use, and maintenance of hydrogen and fuel cell technologies across various applications.

Goals

The overarching goals of the Technology Acceleration subprogram are to identify and demonstrate new and promising integrated hydrogen production and end uses, expedite private-sector commercialization of hydrogen and fuel cell systems, validate the performance of these systems, and achieve economies of scale as envisioned in the H2@Scale initiative.

Key Milestones

Key milestones for the Technology Acceleration subprogram are summarized below.

Grid Energy Storage and Power Generation

- Validate large-scale electrolysis systems for energy storage, grid stabilization, resilience, and dispatch management of electric grid systems with high renewable energy penetration.
- Validate efficiency, costs, and benefits of hydrogen production systems directly integrated with nuclear and renewable power sources with the goal of achieving clean hydrogen production at <$1/kg.
- Validate 90% efficiency (based on high heating value of hydrogen) for high-temperature electrolysis (HTE) systems operating at nuclear plants utilizing onsite waste thermal energy.
- Validate an integrated distributed and backup power generation system in real-world operations for power demands up to 2 MW.
- Demonstrate integrated electrolyzer systems at the megawatt level using multiple electrical sources and targeting hydrogen end uses across transportation, industrial/chemical processing, and power generation.

Chemical and Industrial Processes

- Validate 80,000-hour electrolyzer lifetime and verify clean hydrogen system cost and technical performance comparable with incumbent technologies for metals production.
- Validate 80,000-hour electrolyzer lifetime and demonstrate green ammonia production processes for emission reductions; verify costs and validate technical performance.
- Integrate emerging concepts with industrial processes for production of synthetic fuels and chemicals; verify costs and validate technical performance.
- Initiate transition to clean hydrogen for hard-to-decarbonize industrial applications and identify specific locations for potential scale-up (e.g., ammonia, refineries, steel).

Transportation

- Validate 25,000-hour durability and 68% peak efficiency for fuel cells in in heavy-duty truck applications.
- Validate integrated portside power systems and a 35,000-hour durability target for ferry boat shipboard applications.
- Validate onboard hydrogen storage and locomotive power systems for long-distance trains, including a 35,000-hour durability target.
- Validate technical and economic potential of hydrogen and fuel cells for off-road applications.
- Deploy scalable hydrogen fueling stations to support early fleet markets, such as heavy-duty trucks and buses capable of 10 kg H_2/min (average) fueling.

Enabling Activities

- Develop manufacturing and supply innovations to commercialize multi-megawatt-scale electrolyzers that can produce hydrogen at <$1/kg.
- Develop crosscutting low-cost manufacturing processes with scalability in mind to support domestic supply chains.
- Identify opportunities for standardization of components, reduce dependence on critical materials, and foster a robust supply chain.

- Establish a skilled workforce to respond effectively to the expected growth in hydrogen-supported industries.
- See the Safety, Codes and Standards section of this report for additional enabling activity targets.

Fiscal Year 2022 Accomplishments

Subprogram-Level Accomplishments

Technology Acceleration Fiscal Year (FY) 2022 accomplishments are summarized below.

Overall

- Released the $7 billion Regional Clean Hydrogen Hub Funding Opportunity Announcement in collaboration with DOE's Office of Clean Energy Demonstrations, along with extensive stakeholder engagement, public webinars, a request for information, and a notice of intent.

Grid Energy Storage and Power Generation

- Completed over 7,000 cumulative hours of high-temperature electrolyzer system testing and commissioned a simulated integration of an HTE test facility with a nuclear power plant (Idaho National Laboratory [INL]).
- Completed the procurement and design for a 1.25 MW electrolyzer installation at the Nine Mile Point nuclear plant (Constellation).
- Awarded a new project to demonstrate a high-temperature solid oxide electrolyzer integrated with a simulated nuclear plant using electricity and waste heat (FuelCell Energy and INL).
- Awarded two Small Business Innovation Research (SBIR) Phase 2 wind-to-hydrogen projects to model pathways and optimize designs for coupling hydrogen electrolyzers to offshore wind turbines (Giner, Inc. and Alchemr, Inc.).
- Facilitated international collaboration between the United States and Netherlands, including a techno-economic analysis and assessment of knowledge gaps for multiple pathways for offshore-wind-to-hydrogen.
- Commenced building out megawatt-scale hydrogen infrastructure and capabilities at the National Renewable Energy Laboratory's (NREL's) Flatirons campus to enable integrated hydrogen energy system RD&D (e.g., to demonstrate grid services, energy storage, renewable hydrogen production, and innovative end-use applications).
- Awarded four H2@Scale cooperative research and development agreement (CRADA) projects that will leverage NREL's Advanced Research on Integrated Energy System (ARIES) facilities and capabilities to perform integrated hydrogen energy system testing and validation (NREL and industry partners).
- Awarded a new project to develop and demonstrate a grid-forming fuel cell inverter for a microgrid with the potential to enable higher solar photovoltaic penetration and replace the current diesel-powered backup generators at a disadvantaged community in Borrego Springs, California (NREL and San Diego Gas and Electric).

Chemical and Industrial Processes

- Designed and began constructing a direct iron reduction pilot plant facility that will have a production rate of one tonne of iron per week. The pilot system will be capable of operating with hydrogen, natural gas, and various mixtures and will be used to evaluate using hydrogen to decarbonize iron and steelmaking processes to help de-risk industrial investments (Missouri University of Science and Technology).
- Developed system models for hydrogen direct reduction, integrating a solid oxide electrolysis cell (SOEC) module with a direct reduced iron (DRI) furnace, indicating potential energy intensity of less than 8 GJ/ton (crude steel) compared to 19–20 GJ/ton for a traditional blast furnace and basic oxygen furnace (University of California, Irvine).
- Initiated a new modeling and analysis effort focused on reducing cost, improving efficiency, and accelerating renewable energy penetration for integrated clean hydrogen pathways that include hydrogen production from solar or wind energy, optimized to support industrial end-use applications for hydrogen (NREL).

Transportation

- Awarded three SuperTruck 3 projects (Daimler North America, General Motors, and Ford), which will demonstrate a total of 11 medium-/heavy-duty hydrogen fuel cell electric trucks with driving ranges, payloads, and fueling times competitive with incumbent technologies.
- Built ten fuel cell hybrid electric United Parcel Service (UPS) delivery vans entering service in disadvantaged communities in California to reduce local air pollution (Center for Transportation and the Environment).
- Modeled the TCO for hydrogen fuel cell passenger ferry and rail, multiple medium-duty applications, and mining trucks to provide the basis for developing targets necessary to meet incumbent technology performance (Argonne National Laboratory [ANL]).
- Through Mission Innovation Clean Hydrogen, co-hosted the Hydrogen Fuel Cell Off-Road Equipment and Vehicles Workshop focused on mining, construction, and agriculture equipment and established the International Off-Road Working Group for hydrogen and fuel cell vehicles.
- Demonstrated the >10 kg/min average hydrogen fueling rate necessary for heavy-duty transportation applications (NREL).

Enabling Activities

- Engaged in SOEC manufacturing workshops to identify quality assurance/quality control (QA/QC) gaps and performed post-mortem stack characterization on commercial stacks to identify operational and manufacturing issues (Pacific Northwest National Laboratory [PNNL]).
- With the European Commission, co-hosted the Clean Hydrogen JU [Joint Undertaking] Expert Workshop on Environmental Impacts of Hydrogen to identify technical needs and next steps for monitoring and mitigating hydrogen releases into the atmosphere.
- Through Hydrogen Education for a Decarbonized Global Economy (H2DGE) (Electric Power Research Institute [EPRI]), launched five professional workforce development courses, covering basic hydrogen science as well as production, storage, end use, and safety.
- Accelerated progress on safety, codes and standards (see Safety, Codes and Standards section for specific program- and project-level accomplishments).

Project-Level Accomplishments

Grid Energy Storage and Power Generation

Constellation Corporation is integrating a 1.25 MW polymer electrolyte membrane (PEM) electrolyzer at the Nine Mile Point nuclear power plant in New York to provide cost-effective supply of in-house hydrogen. The initial engineering design is 60% complete, while an electrolyzer supplied by Nel Hydrogen has gone through acceptance testing (NREL), demonstrating less than 0.1% degradation over 500 hours of operation. Initial market demand analysis for similar deployments at various sites has been conducted by ANL, and INL developed a front-end controller for optimal electrolyzer dispatching.

Idaho National Laboratory is advancing the state of the art of HTE technology. Over the past year, this project commissioned an HTE test stand integrated with a nuclear power plant emulator and initiated testing of a 100 kW Bloom Energy system, attaining over 7,000 hours to date of cumulative HTE stack testing. INL continues to work with several industry partners—including Bloom Energy, Nexceris, OxEon, FuelCell Energy, Xcel Energy, and Haldor Topsoe—to independently validate stack performance and provide nuclear-simulated integration and testing with the goal of over 10,000 hours of stack and system testing to be completed by the end of 2022.

Pacific Northwest National Laboratory, in collaboration with INL, is addressing important HTE manufacturing issues that adversely affect stack performance and durability and reduce stack manufacturing costs. Over the past year, PNNL developed a process to produce 300 cm^2 active-area SOECs. The project team tested single cells over 2,800 hours at 750°C with minimal degradation, established a stack repeat unit fabrication process, and assembled and tested two 1 kW short stacks with a goal of building and testing a 5 kW stack. SOEC manufacturing workshops were conducted to identify QA/QC gaps, and post-mortem stack characterization on commercial stacks was performed to identify operation and manufacturing issues.

FuelCell Energy is completing design, engineering, procurement, assembly, integration, and demonstration of a solid oxide steam electrolysis system integrated with a simulated nuclear plant at INL. Although newly under way, the project has acquired all materials and the tooling for stack assembly and has initiated stack assembly and factory acceptance testing.

Frontier Energy is determining how hydrogen production costs can be minimized by using multiple generation sources, including steam methane reforming units that use renewable natural gas and electrolysis that uses wind and solar power. Over the course of the last year, Frontier Energy completed the site plans and engineering, began site installation of utilities, and procured major equipment and systems. In support of the plan for the Port of Houston, the team conducted workshops and developed a preliminary techno-economic model with supply and demand hubs.

Caterpillar Inc. is demonstrating hydrogen-fueled backup power for a Microsoft data center. A techno-economic analysis has been completed, and the system and component simulations showed a power capability similar to diesel gensets currently used for backup power.

Giner, Inc. is modeling and validating an integrated energy system designed to produce clean hydrogen using offshore wind power. The modeling performed over the past year predicts hydrogen can be produced at ~$2.20/kg from offshore wind. Researchers determined a tolerance of baseline Pt and Ir loading for common seawater ions, and the design process was initiated for the integrated 250 kW electrolyzer stack with the simulated wind turbine input.

Alchemr, Inc. is developing a low-cost anion exchange membrane water electrolyzer (AEMWE) that can operate using seawater as a feedstock, enabling direct coupling with offshore wind farms. The project has already demonstrated long-term performance of 5 cm^2 AEMWE cells with non-platinum-group-metal anode and cathode catalysts at 0.3 A/cm^2 at 60°C with membrane electrode assembly degradation of 400 µV/h over 1,000 hours.

Chemical and Industrial Processes

University of California, Irvine is showing the technical and economic feasibility of the thermal and process integration between an SOEC module and a DRI furnace, paving the way for production of green steel. Over the past year, the project has developed system models that indicate potential energy intensity of less than 8 GJ/ton (crude steel) compared to 19–20 GJ/ton for a traditional blast furnace and basic oxygen furnace. In addition, SOEC modeling predicts electric-to-hydrogen efficiency less than 35 kWh/kg.

Missouri University of Science and Technology leads the Grid-Interactive Steelmaking with Hydrogen (GISH) project, aiming to de-risk industrial investment in infrastructure for hydrogen-based direct reduction of iron and steelmaking in an electric arc furnace by closing critical knowledge gaps in the current RD&D landscape. Over the past year, the project completed preliminary techno-economic analysis of the GISH process; developed and verified a kinetic model for hydrogen, natural gas, and mixed gas reduction and a DRI melting model; completed the GISH pilot reactor design; and initiated construction.

National Renewable Energy Laboratory is creating a hydrogen scenario analysis tool by developing new models and integrations for the NREL Hybrid Optimization and Performance Platform (HOPP). Although recently launched, the project has already developed the H2OPP analysis tool, which shows potential for renewable hydrogen at less than $2.50/kg in both near- and long-term scenarios.

Transportation

Center for Transportation and the Environment, in partnership with UPS and others, is demonstrating fuel cell hybrid electric delivery vans with fuel cell range extenders. To date, ten delivery vans have been built, five more are currently in various stages of assembly, and a 169-mile max range test was completed. The UPS delivery vans are entering service at UPS service centers, including operation in disadvantaged communities in California.

Cummins has partnered with the U.S. Army Engineer Research and Development Center's Construction Engineering Research Laboratory to develop and demonstrate a hydrogen fuel cell hybrid emergency disaster Class 7 relief truck. The project has completed final vehicle design, and vehicle assembly is currently under way.

Argonne National Laboratory is analyzing the TCO for various transportation applications. Results thus far indicate that fuel cost dominates TCO for passenger rail and ferries. In one example, it was determined that achieving a fuel cell cost of $60/kW and liquid hydrogen bunkered cost of $4/kg H_2 would likely make hydrogen fuel cell ferries cost-competitive with incumbent technologies. In another example, ANL found that a fuel cell cost of $60/kW and liquid hydrogen cost of $3.50/kg H_2 would likely make hydrogen electric multiple-unit passenger rail cost-competitive.

National Renewable Energy Laboratory is collecting and evaluating fuel cell electric bus (FCEB) performance to validate performance and cost using real-world data. Of the 38 FCEBs tracked, 12 surpassed 25,000 hours of operation, while one FCEB demonstrated over 32,000 hours of durability. The average fuel economy of these FCEBs was found to be approximately 9 miles per diesel gallon equivalent (up to two times greater than fuel economy for compressed natural gas or diesel buses), surpassing the target of 8 miles per diesel gallon equivalent. A range of approximately 280 miles was achieved with the buses, documenting progress toward the 300-mile-range target.

Hornblower Energy, LLC is establishing a hydrogen production and distribution facility onboard a barge at the San Francisco Waterfront. The facility will be used to refuel hydrogen vessels with renewable hydrogen and recharge the batteries of diesel–electric hybrid vessels. Within the project's first year, Hornblower has been collaborating with the Port of San Francisco, Sandia National Laboratories, and various industry stakeholders to evaluate the performance, efficiency, and feasibility of such a system, while developing related safety protocols. The project has completed evaluation of equipment required for marine environments and design of the hydrogen barge.

Electricore, Inc. is developing, testing, and demonstrating a hydrogen fuel dispenser and nozzle assembly capable of fueling heavy-duty vehicles. Over the last year, the project team has completed the design work and manufacturing of the prototype nozzle components, computational fluid dynamics analysis, and failure modes and effects analysis. External assembly parts were procured, and the setup for dispenser manufacturing was completed.

Electricore has completed design, assembly, and initial testing of an advanced mobile hydrogen refueler capable of fueling 20–40 vehicles per day. The refueler is currently undergoing an upgrade to enable medium- and heavy-duty fueling. It will soon to be available for a fueling demonstration at the Foothill Transit bus station in Pomona, California.

Enabling Activities

National Renewable Energy Laboratory is developing, validating, and transferring technology to support QC diagnostics of membrane electrode assembly manufacturing. Over the past year, this project completed the demonstration and validation of optical transmission imaging of the electrode (IrO_x and Pt/C) loading. Chromatic confocal detectors for electrode thickness measurement were also explored, and the development and hardware fabrication of spatial in situ diagnostic tools for low-temperature electrolyte membrane electrode assembly testing was continued. NREL's partner on this project, Lawrence Berkeley National Laboratory, continued predictive finite element model development on performance impacts of membrane compression and electrode variations.

National Renewable Energy Laboratory is addressing the unknown high-volume scaling costs associated with roll-to-roll processing technologies and the effects on cell and stack manufacturing cost estimates. Over the past year, the project team explored the relationship between applied shear and degree of agglomeration for the coated catalyst layer in gas diffusion electrodes. The team also researched and documented the impact of different support structure types and Pt weighting amounts on ink properties and coating thicknesses for Pt/C fuel cell catalysts.

New Project Selections

In FY 2022, the subprogram added projects through a funding opportunity announcement (FOA) and a CRADA call, as noted below. In addition, FY 2022 selections are pending from the Office of Nuclear Energy industry FOA, jointly funded by the Hydrogen and Fuel Cell Technologies Office (HFTO), and the FY 2022 HFTO Annual Appropriations FOA.

FY 2022 selections included the following:

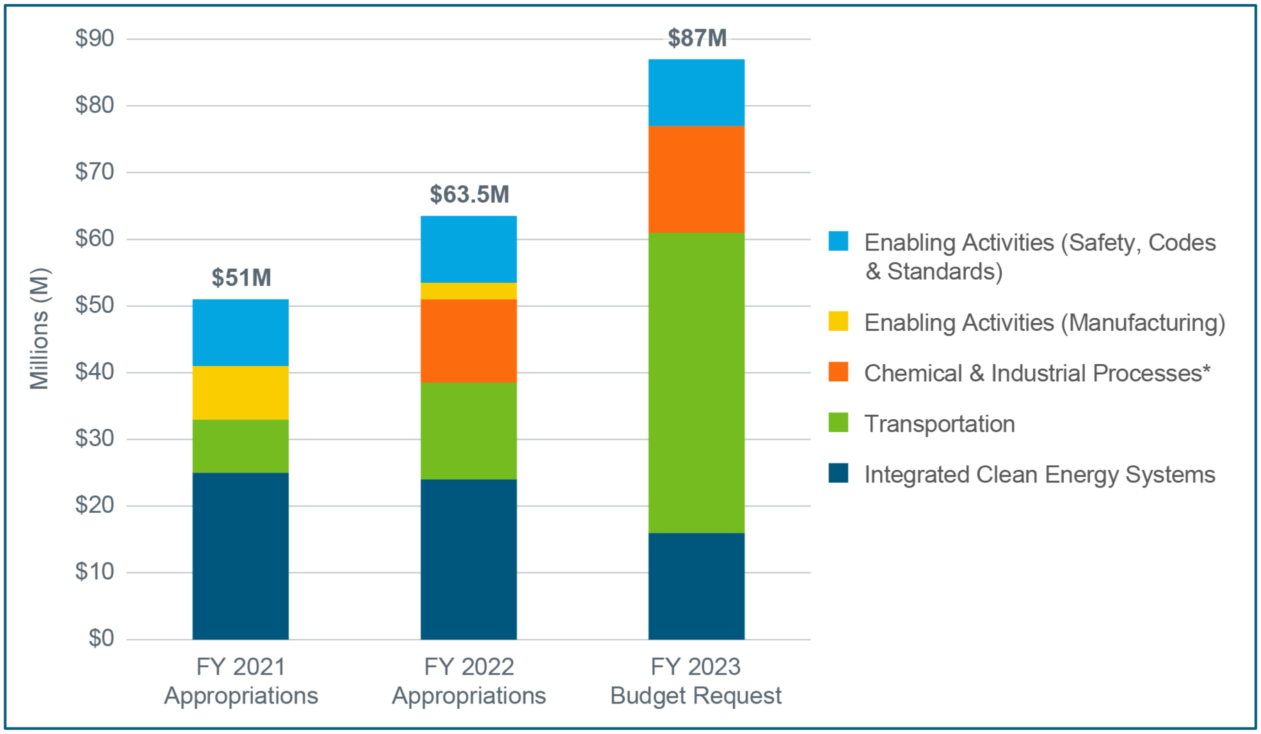
- Projects selected under the H2@Scale CRADA call supporting ARIES:
  - NREL, GE Renewable Energy, Nel Hydrogen: Optimal Wind Turbine Design for Hydrogen Production (TA-061)
  - NREL, Southern California Gas Company (SoCalGas), University of California, Irvine: Validation of Interconnection and Interoperability of Grid-Forming Inverters Sourced by Hydrogen Technologies in View of 100% Renewable Microgrids (TA-062)

- NREL, GKN Powder Metallurgy, SoCalGas: Metal Hydride Bulk (520 kg H_2) Storage System Coupled with Electrolysis and Fuel Cell Systems (TA-063)
- NREL, EPRI**:** Optimize Hydrogen Production Via PEM Electrolysis with Grid Integration and Variable Renewables (TA-064)

- Projects selected under the SuperTruck 3 FOA:
  - Daimler Trucks North America: Ultra-Efficient Long-Haul Hydrogen Fuel Cell Tractor (TA-056)
  - General Motors: Freight Emissions Reduction via Medium-Duty Battery Electric and Hydrogen Fuel Cell Trucks with Green Hydrogen Production (TA-057)
  - Ford Motor Company: High-Efficiency Fuel Cell Application for Medium-Duty Truck Vocations (TA-058)

Budget

The budget for the Technology Acceleration subprogram increased from $51 million in FY 2021 to $63.5 million in FY 2022. The FY 2023 budget request of $87 million includes a significant increase of $23.5 million to continue accelerating efforts to demonstrate and validate low-cost hydrogen production integrated with various hydrogen end uses to enable decarbonization and support the H2@Scale vision. Additionally, $8 billion in funds over five years has been congressionally approved for Clean Hydrogen Hubs through the Office of Clean Energy Demonstrations, in collaboration with HFTO and the Hydrogen Program.



**Includes $7.5 million to fulfill congressional language requirement in coordination with Advanced Manufacturing Office*

Project Summaries

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

Project #TA-001: Membrane Electrode Assembly Manufacturing Research and Development

Michael Ulsh, National Renewable Energy Laboratory

DOE Contract #	WBS 10.1.0.501	
Start and End Dates	7/1/2007	
Partners/Collaborators	• General Motors • Mainstream Engineering • Gore, 3M • Nel/Proton • Giner, Inc. • Plug Power	• AvCarb • Lawrence Berkeley National Laboratory • Colorado School of Mines • National Research Council–Canada • Fraunhofer-ISE

Project Goal and Brief Summary

The objectives of this project are to (1) understand QC needs from industry partners and forums, (2) develop diagnostics by using modeling to guide development and in situ testing to understand the effects of defects, (3) validate diagnostics in-line, and (4) transfer technology to industry partners.

Project #TA-018: High-Temperature Electrolysis Test Stand

Micah Casteel, Idaho National Laboratory

DOE Contract #	WBS 7.2.9.1
Start and End Dates	9/30/2020
Partners/Collaborators	• Idaho National Laboratory • Strategic Analysis, Inc. • Bloom Energy • FuelCell Energy • Nexceris, Energy • Xcel Energy • OxEon

Project Goal and Brief Summary

The project objective is to advance the state of the art of HTE technology by discovering, developing, improving, and testing thermal–electrical–control interfaces for highly responsive operations. The project will (1) develop an infrastructure to integrate support systems for 25–250 kW HTE testing units, (2) support HTE research and system integration studies, (3) measure cell stacks, performance, and materials health under transient and reversible operation, (4) characterize dynamic system behavior to validate transient process control models, (5) demonstrate integrated operation with co-located dynamic thermal energy distribution/storage systems, and (6) operate the system with co-located digital real-time simulators for dynamic performance evaluation and hardware-in-the-loop simulations.

Project #TA-028: Demonstration of Electrolyzer Operation at a Nuclear Plant to Allow for Dynamic Participation in an Organized Electricity Market and In-House Hydrogen Supply

Uuganbayar Otgonbaatar, Exelon Corporation

DOE Contract #	DE-EE0008849
Start and End Dates	10/1/2019–4/1/2023
Partners/Collaborators	• Idaho National Laboratory • National Renewable Energy Laboratory • Argonne National Laboratory • Nel Hydrogen

Project Goal and Brief Summary

This project aims to demonstrate cost-effective supply of in-house hydrogen consumption at an Exelon nuclear power plant. A 1 MW PEM electrolyzer and supporting infrastructure will be installed at an Exelon plant, providing an in-house supply of hydrogen. Researchers will also simulate the scale-up of electrolyzer participation in power markets. The project will demonstrate the potential for hydrogen production to increase the value of nuclear power plants, both by supplying plants' onsite hydrogen needs and by providing hydrogen to regional markets.

Project #TA-037: Demonstration and Framework for H2@Scale in Texas and Beyond

Rich Myhre, Frontier Energy, Inc.

DOE Contract #	DE-EE0008850
Start and End Dates	1/10/2019–1/31/2024
Partners/Collaborators	• Air Liquide • CenterPoint Energy • Chart Industries • Chevron • ConocoPhillips • GTI Energy • Low-Carbon Resources Initiative (LCRI) • McDermott • Mitsubishi Heavy Industries Americas • OneH2, Inc. • ONE Gas, Inc. • ONEOK, Inc. • Shell • Southern California Gas Company • Texas Council on Environmental Quality (TCEQ) • Toyota • University of Texas at Austin • Waste Management

Project Goal and Brief Summary

This project will determine how hydrogen production costs can be minimized by using multiple generation sources, including steam methane reforming units that use renewable natural gas and electrolysis that uses wind and solar power. The project will also demonstrate hydrogen end uses, including using a 100 kW fuel cell to power a computing center. Base-load stationary power generation will be co-located with hydrogen vehicle fueling. The project will also develop a five-year plan for the Port of Houston area that considers existing hydrogen generation, distribution, and infrastructure assets to enable deployment of stationary fuel cell power and hydrogen-fueled vehicles. The plan will identify key barriers and partners, as well as the economic and environmental benefits of hydrogen deployment for the region.

Project #TA-039: Solid Oxide Electrolysis System Demonstration

Hossein Ghezel-Ayagh, FuelCell Energy

DOE Contract #	DE-EE0009290
Start and End Dates	10/1/2020–8/31/2023
Partners/Collaborators	• Versa Power Systems • Idaho National Laboratory

Project Goal and Brief Summary

The project will complete design, engineering, procurement, assembly, integration, and demonstration of a solid oxide steam electrolysis hydrogen generation system. The project will validate the technology's potential as a high-efficiency, low-cost alternative for hydrogen production at nuclear plants. Researchers will design, build, and test a 250 kW (input) steam electrolysis system using hardware-in-the-loop simulation of light water reactor operation. Objectives include validating SOEC technology performance and reliability for steam electrolysis and hydrogen production in a packaged system; developing system operational and control strategies specific to the nuclear industry; demonstrating key features of SOEC electrolysis systems, including high electric efficiency and waste heat utilization, in a 250 kW class unit prototypical of larger-scale systems suitable for integration with nuclear plants; and acquiring the data necessary to valorize the integration of SOEC systems in light water reactor facilities for increasing their operational flexibility and profitability by switching between electricity production and hydrogen generation.

Project #TA-043: Electrolyzer Stack Development and Manufacturing

Olga Marina, Pacific Northwest National Laboratory

DOE Contract #	WBS 7.2.9.2
Start and End Dates	10/1/2019
Partners/Collaborators	• Pacific Northwest National Laboratory • Idaho National Laboratory

Project Goal and Brief Summary

PNNL and INL are collaborating to address important electrolyzer manufacturing issues that adversely affect stack performance and durability. The project team assists U.S. manufacturers in identification of manufacturing and operational issues by performing post-mortem stack characterization work. In addition, the team is developing and demonstrating an in operando stack health monitoring system, employing advanced manufacturing approaches (e.g., thin film deposition, electroplating, and 3D printing) to reduce stack manufacturing costs, and identifying QA/QC manufacturing gaps for SOEC systems.

Project #TA-044: System Demonstration for Supplying Clean, Reliable, and Affordable Electric Power to Data Centers Using Hydrogen Fuel

Paul Wang, Caterpillar, Inc.

DOE Contract #	DE-EE0009252
Start and End Dates	10/1/2020–3/31/2024
Partners/Collaborators	• Microsoft, Ballard • National Renewable Energy Laboratory

Project Goal and Brief Summary

This project aims to conduct a first-of-its-kind demonstration of hydrogen-fueled backup power for a data center. The project team will scale a proton exchange membrane fuel cell to megawatt scale. Performance targets include a full load rating of 1.5 MW and 48 hours of liquid hydrogen storage. All aspects of the complete power delivery system will be addressed, including (but not limited to) hydrogen production and delivery, site layout design, safety planning, component sizing, controls development, and permitting. The equipment will be installed, tested, and debugged, and data will be collected. Project completion will entail system decommissioning. This project supports the U.S. Department of Energy goal of reducing greenhouse gas emissions by heightening the viability and expanding the capabilities of a green fuel source, namely hydrogen.

Project #TA-045: San Francisco Waterfront Maritime Hydrogen Demonstration Project

Narendra Pal, Hornblower Energy LLC

DOE Contract #	DE-EE0009251
Start and End Dates	10/1/2021–6/30/2025
Partners/Collaborators	• Sandia National Laboratories • Port of San Francisco • Air Liquide • Nel Hydrogen US • IGX Group, Inc. • Glosten • Moffett Nichol

Project Goal and Brief Summary

This project will establish a hydrogen production and distribution facility onboard a barge at the San Francisco Waterfront. The facility will be used for refueling hydrogen vessels with renewable hydrogen and recharging the batteries of diesel–electric hybrid vessels. This renewable hydrogen infrastructure will also support a land-based hydrogen network, creating an ecosystem of zero-emission mobility and resilience. This project will establish robust science-based protocols, procedures, operating parameters, and attendant training materials for the safe and routine generation and storage of electrolyzed hydrogen, creating a blueprint for optimally designing such a hydrogen barge and showcasing how the infrastructure can be replicated at other ports and similar locations across the United States. In addition, the demonstration will stimulate increased demand for hydrogen; advance the development of safety, codes and standards for barge-based hydrogen technology; and promote the development of a hydrogen customer base along the San Francisco Waterfront, in the city of San Francisco, and in the greater Bay Area.

Project #TA-048: Advanced Research on Integrated Energy Systems (ARIES)/Flatirons Facility – Hydrogen System Capability Buildout

Daniel Leighton, National Renewable Energy Laboratory

DOE Contract #	WBS 7.2.9.9
Start and End Dates	5/6/2020–9/30/2022
Partners/Collaborators	• Nel Hydrogen • Toyota Motor North America

Project Goal and Brief Summary

This project will design and commission a megawatt-scale electrolyzer, storage system, and fuel cell generator at the NREL Flatirons Campus. The system is designed with flexibility to demonstrate system integration, grid services, energy storage, direct renewable hydrogen production, and innovative end-use applications. If successful, this project will support H2@Scale goals by enabling integrated systems R&D to study the science of scaling for hydrogen energy systems.

Project #TA-049: High-Pressure, High-Flow-Rate Dispenser and Nozzle Assembly for Heavy-Duty Vehicles

Spencer Quong, Electricore Inc.

DOE Contract #	DE-EE0008817
Start and End Dates	10/1/2019–8/31/2022
Partners/Collaborators	• WEH Technologies Inc. • Bennett Pump Company • Quong & Associates Inc. • National Renewable Energy Laboratory

Project Goal and Brief Summary

This project team will develop, test, and demonstrate a hydrogen fuel dispenser and nozzle assembly (nozzle, receptacle, hose, and breakaway) capable of fueling heavy-duty vehicles. Based on industry feedback, the assembly's fuel transfer rate will be 100 kg in 10 minutes at a nominal pressure of 70 MPa. If successful, this project will accelerate the development and adoption of sustainable transportation technologies.

Project #TA-051: Lowering Total Cost of Hydrogen by Exploiting Offshore Wind and Polymer Electrolyte Membrane Electrolysis Synergies

Hui Xu, Giner, Inc.

DOE Contract #	DE-SC0020786
Start and End Dates	8/23/2021–8/22/2023
Partners/Collaborators	• National Renewable Energy Laboratory • GE Research • Hygro • Plug Power, Inc.

Project Goal and Brief Summary

This project aims to model and validate an integrated energy system designed to produce clean hydrogen using offshore wind power. A model will be developed to study offshore wind integrated with electrolyzers and its performance based on location (wind speed, intermittency, water depth, and distance to shore). The model will be used to calculate the levelized cost of hydrogen produced and how varying conditions affect that cost. Researchers will also determine the impact of seawater impurities on electrolyzer performance with the goal to optimize solutions for obtaining sufficiently pure water for electrolysis offshore. With modeling results in hand, the project will design and build a 250 kW PEM electrolyzer and integrate it with directly coupled emulated wind power at NREL. This stage entails determining system process and instrumentation needs for offshore wind with electrolyzers and designing power electronics and control systems for integration. These efforts will serve the Hydrogen Shot goals of reducing hydrogen production costs ($1 for 1 kilogram in 1 decade, or "1 1 1"), lowering greenhouse gas emissions, building clean energy infrastructure, and providing pathways to private-sector uptake.

Project #TA-052: Solid Oxide Electrolysis Cells Integrated with Direct Reduced Iron Plants for Producing Green Steel

Jack Brouwer, University of California, Irvine

DOE Contract #	DE-EE0009249
Start and End Dates	3/10/2021–3/31/2024
Partners/Collaborators	• FuelCell Energy • Versa Power Systems • Hatch Associates Consultants, Inc. • Politecnico di Milano • Laboratorio Energia Ambiente Placenza • Southern California Gas Company

Project Goal and Brief Summary

The main goal of the project is to show the technical and—at scale—the economic feasibility of the thermal and process integration between an SOEC module and a DRI furnace, paving the way for production of green steel. The SOEC system will be designed to produce enough hydrogen (>10 kg/day H_2) to supply a shaft furnace of an equivalent size of one ton per week of DRI product. The best-performing configuration will be scaled up via a feasibility design at a production capacity of 2 Mton/year of DRI. The project comprises the following phases: plant conceptualization and thermodynamic analysis, SOEC module sizing and nominal load design, testing in relevant conditions for DRI operation, design and commissioning of a DRI simulator, and techno-economic assessment of a full-scale system. The proposed hydrogen direct reduction system has the potential to reduce specific energy consumption up to 35% compared to conventional DRI and ensure the product specifications of a conventional DRI plant (metallization 96%).

Project #TA-053: Grid-Interactive Steelmaking with Hydrogen

Ronald J. O'Malley, Missouri University of Science and Technology

DOE Contract #	DE-EE0009250
Start and End Dates	10/1/2020–4/30/2024
Partners/Collaborators	• Arizona State University • National Renewable Energy Laboratory • Danieli, Voestalpine • Nucor • Steel Dynamics • Gerdau • Linde • Air Liquide

Project Goal and Brief Summary

This project aims to de-risk industrial investment in infrastructure for hydrogen-based direct reduction of iron and steelmaking in an electric arc furnace by closing critical knowledge gaps in the current research, development, and deployment landscape. The project includes four main activities: (1) documenting the effects of mixed hydrogen and natural gas reduction kinetics for iron oxide and use of plasma to enhance reduction rates; (2) modeling scale-up of an innovative direct reduction pilot reactor to production scale, capturing the characteristics of the materials flow and the thermal profile; (3) developing models for electric arc furnace operation with variable carbon-based and carbon-free feedstocks; and (4) conducting a techno-economic assessment to quantify the economic opportunity of the project steelmaking process. These efforts have the potential to incentivize the use of clean hydrogen in one of the nation's most CO_2 emissions-intensive industries, expanding hydrogen demand and thereby decreasing costs.

Project #TA-054: Anion Exchange Membrane Water Electrolyzer for Hydrogen Production from Offshore Wind

Gholamreza Mirshekari, Alchemr, Inc.

DOE Contract #	DE-SC0020712
Start and End Dates	8/23/2021–8/22/2023
Partners/Collaborators	• University of Connecticut

Project Goal and Brief Summary

The main goal of this project is to develop a low-cost AEMWE that can operate using seawater as a feedstock, enabling direct coupling with offshore wind farms. To improve cell performance and durability in a marine environment, researchers will develop high-performance oxygen evolution reaction selective electrodes and modify the anode flowfield/current collector. Based on the architecture of the small single cell, the project team will construct a three-cell single stack to increase hydrogen production. In addition to developing an improved marine-based system, the project will reduce capital costs associated with hydrogen storage and transmission as well as the power electronics required for grid integration.

Project #TA-060: U.S. Wind-to-Hydrogen Modeling, Analysis, Testing, and Collaboration

Aaron Barker and Sam Spirik, National Renewable Energy Laboratory

DOE Contract #	7.2.9.15
Start and End Dates	8/1/2021–6/30/2022
Partners/Collaborators	• Netherlands Organization for Applied Scientific Research • Giner, Inc. • GE Research

Project Goal and Brief Summary

A key barrier to industry adoption of hydrogen production using renewable energy sources is certainty that the approach is economically viable. This project aims to create a hydrogen scenario analysis tool by developing new models and integrations for the NREL HOPP. The tool provides rapid, high-resolution insights into optimized green hydrogen pathways and alternatives. The tool will be equipped with modeling capabilities for on- and off-grid systems, electrolyzer configurations and operation, compatibility with renewables, and design and sizing optimization. The tool can be used to reveal pathways to achieving the Hydrogen Shot goal ("1 1 1"). The project will provide visualization sets, with accompanying data files, for hydrogen production across the United States, using land-based wind (under on- and off-grid scenarios) and offshore wind. Cost data will span 2020–2035.

Project #TA-065: Total Cost of Ownership Analysis of Hydrogen Fuel Cells in Off-Road Heavy-Duty Applications – Preliminary Results

Rajesh Ahluwalia, Argonne National Laboratory

DOE Contract #	9.3.0.6
Start and End Dates	10/1/2020–9/30/2022
Partners/Collaborators	• Argonne National Laboratory

Project Goal and Brief Summary

Construction, mining, and agriculture equipment are the largest contributors to off-road greenhouse gas emissions within the transportation sector. This project will determine the fuel cell and hydrogen storage performance needed to make fuel cells in off-road vehicles economically competitive with more commonly used technologies, such as diesel engines. Fuel cell systems being developed for heavy-duty trucks will be adapted for tractors, wheel loaders, and excavators; for example, systems will be resized for power requirements, and degradation will be reduced through voltage clipping. Researchers will determine the TCO, considering the uncertainties of critical powertrain design (e.g., degree of hybridization), parameters (e.g., vehicle miles traveled), and driving cycles. This project has the potential to pave the way for a green fuel alternative to power the nonroad sector.

Annual Merit Review of the Technology Acceleration Subprogram

Summary of Technology Acceleration 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.

Goals, Strategy, Targets, and Metrics

The Technology Acceleration subprogram recognizes—and acts on—the importance of demonstrating and de-risking integrated hydrogen systems, fostering community engagement, developing technology deployment strategies, developing regional markets and supply chains, and advancing domestic manufacturing to accelerate the commercialization of both current and future hydrogen and fuel cell technologies at large scales. The Technology Acceleration subprogram has a clearly articulated mission and strategy and appropriate goals, milestones, and quantitative metrics. However, it could be argued that there are differences between the stated materials and performance goals of industry and national laboratories, as different manufacturers use different approaches and national laboratory experts are not sufficiently engaged with industry. Other suggestions for improvement are having the subprograms add goals to ensure their technologies are manufactured in the United States, having the subprograms ensure alignment of the metrics down to the individual project level, and developing metrics and equity program principals that translate into improved outcomes for communities and the workforce.

The Program might build on the Technology Acceleration subprogram's achievements by conducting a study to identify the most successful projects and the critical elements and technical goals that led to their success.

Technology Acceleration Subprogram Portfolio

The Technology Acceleration subprogram's portfolio of projects is appropriately balanced across research areas to help achieve its mission and goals. There is also an appropriate balance between near-, mid-, and long-term R&D. The subprogram has increased funding for demonstration projects of high-technology-readiness-level technologies, especially the funding that will be available through the Bipartisan Infrastructure Law, to help move hydrogen and fuel cell technologies from R&D to commercial markets. Although this funding increase is appropriate, mid- and long-term research should remain in the future portfolio. Projects of particular note are the hydrogen and fuel cell systems at NREL's ARIES facility in Boulder, Colorado, and recent demonstration projects within H2@Scale. Technology Acceleration is an important stepping stone to higher technology readiness levels that will lead to manufacturing; however, there is some concern as to the extent to which data generated from pilot- and demonstration-scale activities is shared with domestic and international industry stakeholders.

Reviewer comments and recommendations relating to the Technology Acceleration subprogram's portfolio of projects were offered in the following four areas: transportation, manufacturing, grid integration, and industrial hydrogen use. In the transportation area, a thorough assessment is needed of hydrogen and hydrogen-derived non-fossil liquid fuels for long-haul trucks, as hydrogen may not succeed as a direct-use fuel in freight and maritime applications. Additionally, there is a need for work on how to maintain reliable supply of fuel and electricity during the transition to alternative fuels and longer-term dependence on fewer sources of energy (e.g., common mode failure).

In the manufacturing area, funding of manufacturing R&D must be increased to lower technology cost and address a gap in high-speed, low-cost manufacturing technologies in the United States. The use of domestic materials should be prioritized in projects funded by the subprogram, and the projects' impacts on the domestic supply chain should be considered. In addition, more attention should be paid to ensure safe, secure, economical, and reliable sources of materials within industry.

In the grid integration area, the subprogram could increase the number of neighborhood-level microgrid demonstrations and minimize hydrogen cost for grid energy storage through multiple generation sources. One possibility is to investigate opportunities to integrate renewable power, grid capacity, and hydrogen production at the point of use to minimize hydrogen transport.

Regarding industrial hydrogen use, training on the Greenhouse Gases, Regulated Emissions, and Energy Use in Technologies (GREET) model could be helpful in integrating non-carbon energy facilities or upgrades with facilities that use or produce fossil fuels.

Challenges

The Hydrogen Program's strategy has been formulated to meet the challenges of integrating hydrogen-based technologies into the overall renewable energy portfolio in a timely, cost-effective, and impactful way, in part thanks to the Program's strong collaboration with industry. The Program has not always had the budget to address all the important challenges, particularly for demonstration, deployment, education, and outreach. The Bipartisan Infrastructure Law will provide adequate funds to address the challenges, but DOE may not have sufficient staff to manage the increased efforts. The Program might consider increasing staff and identifying management tools and approaches to provide effective oversight of the hydrogen hubs and other projects.

The Program did not present a clear path to implementing its technologies in the market; the current frameworks will not ensure a smooth transition from lab-scale innovation to benchtop to prototype to pilot to large-scale manufacturing. Engagement with a wide variety of stakeholders, including demonstrated technology disruptors and innovators, is encouraged for rapid progress. International collaboration is also encouraged to leverage the knowledge and progress being made in other countries.

Hydrogen demand projections are needed for various applications, taking into account potential cost increases resulting from the transition to hydrogen-based processes. One reviewer's recommendations included (1) requiring technology validation projects to collect and supply data and (2) identifying or developing an inventory of existing facilities that could utilize hydrogen, including their ages and their replacement/upgrade costs, for use in developing demand projections and populating "e-learning" systems to train the workforce. In contrast, however, another reviewer recommended reducing the administrative burden of reporting and data collection requirements for projects funded under the Bipartisan Infrastructure Law.

Discussion was lacking in terms of quantifying/controlling greenhouse gas and air pollutant emissions from hydrogen projects; there is a need to identify the challenges in overcoming the extent of energy and greenhouse gases related to producing hydrogen at larger scales. Furthermore, there is a need for adequate materials, at reasonable prices and from reliable sources, to meet future alternative energy needs. One reviewer observed insufficient involvement and support for (1) the smooth transition of energy technologies without significant disruption and (2) economic and secure supply chains that benefit all stakeholders.

Collaborations/Stakeholder Engagement

While the Program has a well-organized structure for collaborating and gathering feedback from stakeholders, coordination with these stakeholders could be improved and increased. There is alignment between the Program and the hydrogen and fuel cell industry and energy stakeholders. The Program's engagement with American Indian Tribes, the Native Hawaiian community, and other underserved and disadvantaged communities is noteworthy and important. The Program is to be commended for its coordination and co-funding with DOE's Advanced Manufacturing Office, such as on the Roll-to-Roll Advanced Materials Manufacturing DOE Laboratory Collaboration. However, there should be more direct engagement with local officials/municipalities, state agencies, community groups, leaders of distressed communities, workforce development organizations, environmental justice organizations, manufacturing and supply chain stakeholders, technology incubators and startups, non-governmental organizations, community-based organizations, non-profits, and education and outreach programs such as Clean Cities. Such alliances would enable effective technology deployment, community acceptance of the technologies, expansion of domestic manufacturing, workforce development, and timely market transformation.

Specific recommendations regarding collaborations and stakeholder engagement include the following:

- Assess the validity of concerns of environmental non-governmental organization stakeholders before basing decisions on these concerns.

- Provide guidance to community leaders, municipalities, and workforce development organizations on siting and deployment of hydrogen and fuel cells in stationary, transportation, and utility markets, including combined heat and power, mission-critical facilities, microgrids, reversible fuel cells, light- and heavy-duty vehicle fleets, materials-handling, aircraft, decarbonization of electric and natural gas infrastructure, and refueling.
- Provide guidance for hydrogen production to identify and coordinate with renewable feedstock producers, including offshore wind and solar developers.
- Provide guidance to facilitate community siting and investment to help identify and address concerns of distressed communities, underserved cities, and opportunity zones consistent with state policies and goals, goals for community investment, and the requirements of the Bipartisan Infrastructure Law.
- Provide guidance to encourage alliance-building with local industry, supply chain, and community resources.
- Provide guidance to local community stakeholders on environmental performance (to identify carbon offsets, greenhouse gas equivalent reductions, air quality improvements, community siting impacts, and potential impacts from hydrogen production and leakage), safety, and economic projection of the impact to consumer energy costs and the utility rate base.
- Coordinate with non-hydrogen stakeholders on overall integration with other technologies, including battery storage, battery electric vehicles, gas blending and decarbonization, production of hydrogen with renewable energy project developers (biomass, wind, and solar energy), utility-based energy storage and dispatch, and direct consumer use.