H2@Scale CRADA Call Projects

An H2@Scale cooperative research and development agreement (CRADA) call was issued in August 2017 to seek qualified partners to participate in projects with the H2@Scale national laboratories consortium. The selected collaborative projects address key challenges associated with wide-scale production and use of hydrogen to address critical issues such as enabling grid resiliency, energy security, and domestic job creation and leadership in manufacturing. As of the end of fiscal year (FY) 2018, there were 24 selected CRADA call projects moving forward. Each project is receiving between $25,000 and $1,786,000 in Fuel Cell Technologies Office funding as a match of industry funding.

Table 1 lists the H2@Scale CRADA call projects, followed by brief descriptions of each project.

Table 1. H2@Scale CRADA Projects Active in FY 2018

Title	Industry Lead	Lab Lead
Development, Validation, and Benchmarking of Quantitative Risk Assessment Tools for Hydrogen Refueling Stations	Air Liquide	Sandia National Laboratories
Methane Pyrolysis for Base-Grown Carbon Nanotubes and CO_2-Free Hydrogen over Transition Metal Catalysts	C4-MCP, LLC	Pacific Northwest National Laboratory
California Hydrogen Infrastructure Research Consortium	California Governor's Office of Business and Economic Development	National Renewable Energy Laboratory
Hydrogen Safety Outreach by the Hydrogen Safety Panel to Expedite Hydrogen Fueling and Energy Project Deployment	Connecticut Center for Advanced Technology	Pacific Northwest National Laboratory
Hydrogen Safety Panel Evaluation of Hydrogen Facilities	California Energy Commission	Pacific Northwest National Laboratory
Valuation of Hydrogen Technology on the Electric Grid Using Production Cost Modeling	Electric Power Research Institute	National Renewable Energy Laboratory
Merchant Hydrogen at Scale: A Technical-Economic Case Study of the Potential for Nuclear Hydrogen Production	Exelon Corporation	Idaho National Laboratory
Holistic Fuel Cell Electric Vehicle / Hydrogen Station Optimization Model	Frontier Energy	National Renewable Energy Laboratory
Megawatt-Scale Proton Exchange Membrane-Based Electrolyzers for Renewable Energy Source Applications	Giner ELX, Inc.	National Renewable Energy Laboratory
Scalable Electrolytic Systems for Renewable Hydrogen Production	GTA, Inc.	National Renewable Energy Laboratory
Validating an Electrolysis System with High Output Pressure	Honda R&D Americas, Inc.	National Renewable Energy Laboratory
Turboexpander: Alternative Fueling Concept for Fuel Cell Electric Vehicle Fast Fill	Honda R&D Americas, Inc.	National Renewable Energy Laboratory
Membrane Electrode Assembly Manufacturing Automation Technology for the Electrochemical Compression of Hydrogen	HyET Hydrogen USA LLC	National Renewable Energy Laboratory
Membrane Technology for the Electrochemical Compression of Hydrogen	HyET Hydrogen USA LLC	Lawrence Berkley National Laboratory
Hydrogen Materials Compatibility of Low-Cost, High-Pressure, Polymer Hydrogen Dispensing Hoses	NanoSonic, Inc.	Pacific Northwest National Laboratory

Title	Industry Lead	Lab Lead
Develop a Tool to Estimate the Benefits of Tube-Trailer Consolidation Scheme for Station Builders	PDC Machines, Inc.	Argonne National Laboratory
Optimizing an Integrated Renewable-Electrolysis System	PG&E Corporation	National Renewable Energy Laboratory
Risk Analysis and Modeling to Improve Hydrogen Fuel Cell Vehicle Repair Garages Codes and Standards	Quong & Associates, Inc.	Sandia National Laboratories
Hydrogen Component Performance Diagnostic Testing	RIX Industries	National Renewable Energy Laboratory
Innovating High-Throughput Hydrogen Stations	Shell	National Renewable Energy Laboratory
Region-Specific Merchant Hydrogen Market Assessment and Techno-Economic Assessment of Electrolytic Hydrogen Generation	Southern Company	Idaho National Laboratory
Hybrid Electrical/Thermal Hydrogen Production Process Integrated with a Molten Salt Reactor Nuclear Power Plant	Southern Company	Idaho National Laboratory
Tatsuno Coriolis Flow Meter Development Testing in High-Pressure Hydrogen	Tatsuno	National Renewable Energy Laboratory
Evaluate High-Temperature Steam Electrolysis Coupled to PWR/MCFR/TWR for Hydrogen Production and Energy Storage	TerraPower, LLC Inc.	Idaho National Laboratory

H2@SCALE CRADA PROJECTS

Development, Validation, and Benchmarking of Quantitative Risk Assessment Tools for Hydrogen Refueling Stations

Air Liquide
9807 Katy Freeway
Houston, TX 77024

This project incorporates two tasks for a CRADA between Air Liquide and Sandia National Laboratories. The first task comprises a validation and benchmark comparison of risk and consequence software between Air Liquide and Sandia National Laboratories for the support of advancing quantitative risk assessment and improving the safety of hydrogen refueling stations. The second task involves developing a diagnostic tool for capturing three-dimensional data for large-scale hydrogen experiments to support code development for liquefied hydrogen refueling stations. Both of these tasks will utilize Sandia National Laboratories' core capabilities to advance the state-of-the-art knowledge about hydrogen behavior and quantitative risk assessment to defensibly revise safety codes and standards.

Methane Pyrolysis for Base-Grown Carbon Nanotubes and CO_2-Free Hydrogen over Transition Metal Catalysts

C4-MCP, LLC
2425 West Olympic Blvd., Ste. 4000
Santa Monica, CA 90404

This project aims to develop a new process for producing CO_2-free hydrogen and solid carbon from natural gas. The objective is to reduce the net production cost of hydrogen to <$2/kg with the sale of valuable byproduct carbon. Recently researchers at West Virginia University reported a promising new catalyst innovation for non-oxidative thermochemical conversion of methane to CO_2-free hydrogen and solid carbon nanotubes. A catalyst was discovered that promotes "base growth" carbon nanotube formation rather than "tip growth", which is the current technology. This enables catalyst regenerability while also generating a highly pure and crystalline carbon product. In partnership with West Virginia University, capability and expertise housed at Pacific Northwest National Laboratory is leveraged to build upon this prior research and improve catalyst design, develop the reactor engineering thus enabling a commercially viable process technology, understand the produced carbon characteristics and market potential, and evaluate the overall techno-economics. The envisioned outcome is the development of a transformational new process for producing CO_2-free hydrogen from inexpensive and domestically abundant natural gas while simultaneously offering the opportunity to reduce its net cost to <$2/kg through sale of highly valuable crystalline solid carbon byproduct.

California Hydrogen Infrastructure Research Consortium

California Governor's Office of Business and Economic Development
1325 J Street, Suite 1800
Sacramento, CA 95814

A team of California agencies (California Air Resources Board, California Energy Commission, South Coast Air Quality Management District, and California Governor's Office of Business and Economic Development) and national laboratories has formed a research consortium focused on near-term hydrogen infrastructure development, deployment, and operation needs in California. Many of these partnerships have been in place for years through individual agreements and work scopes. This consortium intends to continue improving research coordination, impact, stakeholder participation, experiment quality, and information dissemination. Advances in hydrogen infrastructure target multiple nodes of the H2@Scale initiative. As demand increases, improvements in station components and safety are essential to station deployment. Fully realizing the benefits of renewable hydrogen at the dispenser requires novel integration and economic options with renewables and the grid, as identified in H2@Scale. The consortium framework fits the H2@Scale cross-discipline and program collaborations, it has been under development for the last 3 months, and it will be finalized per the H2@Scale CRADA call schedule. The framework is intended to continue beyond this project for a long-lasting strategic partnership with the U.S. Department of Energy, agencies, and national laboratories.

Hydrogen Safety Outreach by the Hydrogen Safety Panel to Expedite Hydrogen Fueling and Energy Project Deployment

Connecticut Center for Advanced Technology, Inc.
222 Pitkin St, Suite 101
East Hartford, CT 06108

The Connecticut Center for Advanced Technology seeks to administer a "Hydrogen Safety Outreach" Program that would provide strategic outreach to building and code officials, project developers, maintenance and storage facility owners, and other interested stakeholders to facilitate the safe deployment and use of hydrogen technologies. Connecticut Center for Advanced Technology will seek to leverage the capabilities of the Hydrogen Safety Panel, administered by Pacific Northwest National Laboratory, as a resource to assist industry and other stakeholders in the Northeast United States.

Specific activities will include identification of hydrogen technology stakeholders, their roles, and challenges; publicizing Hydrogen Safety Panel training sessions to appropriate stakeholders; facilitating the exchange of information between stakeholders and the Hydrogen Safety Panel; and reviewing program reports and best practices. Benefits of the program include assurance that safety is adequately considered in early-market and highly visible projects, improved public confidence and acceptance of hydrogen technology, confirmation that safety features are appropriately designed, and acceleration of early-market deployment.

The outreach will begin in Connecticut, Rhode Island, New York, New Jersey, and Massachusetts, which are the core areas for hydrogen deployment in the Northeast United States, and will expand to other states as needed and appropriate.

Hydrogen Safety Panel Evaluation of Hydrogen Facilities

California Energy Commission
1516 9th Street, MS 6
Sacramento, CA 95814

Demonstrated safety in the production, distribution, dispensing, and use of hydrogen is critical to the successful implementation of a hydrogen refueling infrastructure and the widespread use of fuel cell technologies in transportation. Commercial hydrogen fuel technologies are starting to be deployed, which amplifies the attention paid to such new technologies because of public unfamiliarity. Loss of public confidence at an early stage of development could significantly delay or even preclude further progress in development and deployment of hydrogen and fuel cell technologies as zero-emission transportation solutions.

To ensure safety and minimize the probability of an incident, Pacific Northwest National Laboratory (PNNL) will lead the Hydrogen Safety Panel (HSP) to evaluate hydrogen safety plans in accordance with safety planning for hydrogen and fuel cells projects for proposed renewable hydrogen central production facilities and the light-duty hydrogen refueling infrastructure through the California Energy Commission's future competitive solicitations. Applicants to California Energy Commission solicitations will have the opportunity to use the PNNL HSP resource while developing their renewable central hydrogen production facility or light-duty hydrogen refueling station applications. The PNNL HSP will evaluate the safety portion of the applications and will investigate incidents and safety practices and disseminate the findings and information with authorities having jurisdiction and the public through h2tools.org. The completion of this project will enable the PNNL HSP to continue to promote the safety of hydrogen infrastructure in California and other parts of the United States.

The PNNL HSP is an essential resource to address the concerns about hydrogen as a safe and sustainable energy carrier, using more than 400 years of cumulative hydrogen safety experience, including committee members from National Fire Protection Association, SAE International, American Society of Mechanical Engineers, and the International Standards Organization. A key objective of the PNNL HSP is to integrate safety planning into funded hydrogen projects to ensure that all projects address related safety practices. This objective is crucial when siting, designing, and building renewable hydrogen facilities and light-duty hydrogen refueling stations.

Valuation of Hydrogen Technology on the Electric Grid Using Production Cost Modeling

Electric Power Research Institute
3420 Hillview Ave.
Palo Alto, CA 94304

This research project will estimate the value to the United States electric grid of deploying hydrogen technology (such as electrolyzers and hydrogen-fueled generation) under projected conditions of high renewable penetration. Large-scale grid simulation will be incorporated into a cost-benefit analysis to provide first-ever systems-level assessment of different hydrogen technology scenarios. Four utility companies will participate in scenario development and periodic review. This project will leverage the electric utility industry's working knowledge to develop relevant scenarios and the National Renewable Energy Laboratory's unique concentration of expertise in large-scale grid modeling, techno-economic modeling, and hydrogen technology.

Merchant Hydrogen at Scale: A Technical-Economic Case Study of the Potential for Nuclear Hydrogen Production

Exelon Corporation
10 S. Dearborn Street
Chicago, IL 60680

Existing nuclear plants are uniquely poised to produce hydrogen, providing low-cost power and/or steam for reliable, clean hydrogen generation. This study will determine the technical and economic feasibility of converting an existing nuclear plant (or several) for centralized or distributed hydrogen production. The study contemplates a deep economic analysis sufficient to provide a rationale for nuclear companies to make the investments required to convert their plants, stimulating the hydrogen economy and creating jobs. Exelon will work with a team that spans four national laboratories and additional industrial partners and anticipates that technical benefits to this project will include significant improvements and additions to national hydrogen and nuclear modeling and assessment resources.

Holistic Fuel Cell Electric Vehicle / Hydrogen Station Optimization Model

Frontier Energy, Inc.
1000 Broadway, Suite 410
Oakland, CA 94607

All current hydrogen vehicle fueling models focus on a limited portion of the hydrogen pathway from storage to pressure control, heat exchanger, dispenser, breakaway, hose, nozzle, vehicle receptacle, tubing, manifold(s), valve, and finally the compressed hydrogen storage system. Most hydrogen fueling models limit their scope to the gas temperature behavior in the compressed hydrogen storage system. Some models have added the compressed hydrogen storage system, the breakaway, hose, nozzle, and vehicle components to account for pressure drop and heat transfer therefrom. The holistic fueling model being studied in this project will include all elements in the hydrogen pathway from the high-pressure storage tubes to the vehicle compressed hydrogen storage system.

There is no open-source, high-fidelity hydrogen fueling model available allowing automakers, hydrogen station operators, and other stakeholders to simulate the effects of out-of-bounds fueling conditions, novel tank geometries and materials, new fueling applications (e.g., motorcycles, medium/heavy-duty vehicles), and advanced fueling protocols all together. Proprietary models are available that encompass the entire vehicle-side and station-side fueling components, but they are closed-source and cost prohibitive. Further, these closed models are limited in scope (as described above) and do not provide simulation of the entire station.

Frontier Energy will partner with other industry stakeholders, including Honda R&D Americas, Ford, Hyundai, Linde, Air Liquide, NEL, Shell, Ivys, and others to leverage both the modeling and validation capabilities of the U.S. Department of Energy national labs to develop, validate, and disseminate an open-source fueling model that will, for the first time, address both the vehicle tank and the hydrogen station as a holistic system. The resulting model will help station providers, automakers, safety personnel, first responders, students, and others learn and model the behavior of hydrogen stations and the vehicles they serve.

As other open projects have shown (e.g., GREET, H2A, HDSAM, SERA, H2FAST), making this tool available for all to use and improve will lead to improved hydrogen systems, with a net gain to U.S. competitiveness.

Megawatt-Scale Proton Exchange Membrane-Based Electrolyzers for Renewable Energy Source Applications

Giner ELX, Inc.
89 Rumford Ave.
Newton, MA 02466

Proton-exchange membrane (PEM) electrolyzers have been well industrialized for pure hydrogen production in mobile refueling and energy storage applications when combined with renewable energy sources such as wind and solar. As the demand for these applications increases, electrolyzer stack manufacturers, including Giner ELX, are forced to scale up to stack sizes beyond their testing capabilities. Validation of new megawatt (MW)-scale electrolyzer stacks requires large electrolyzer test beds and electrical requirements that are available at the National Renewable Energy Laboratory's site.

Giner ELX recently developed a 'single stack' platform capable of operating up to 1 MW. In addition to scale-up of the cell active areas, Giner ELX focused on advancing the core key electrolyzer stack technology: increasing operating current density, improving efficiency, reducing cost, and extending lifetime.

The objective of this project is to validate Giner ELX's MW stack platform. The successful operation of the MW stack will be used to validate cell components, membrane, and catalyst under full operating conditions. Furthermore, the data will be used to develop future stack platforms capable of 5 MW and higher.

Scalable Electrolytic Systems for Renewable Hydrogen Production

GTA, Inc.
11403 Morgan Overlook Drive
Knoxville, TN 37931

The goal of GTA's work is development of scalable multi-megawatt water electrolysis systems that exclude platinum group metals, are constructed from readily available commodity materials, and are mass produced using advanced manufacturing and robotics. We fabricated and successfully tested a scalable technology readiness level (TRL) 4 laboratory prototype that demonstrated promising results for achieving the goal. We performed calculations and prepared scale drawings for an envisioned on-site TRL 8 electrolytic hydrogen production system at an offshore 8 MW wind turbine. The work plan of the CRADA project between the National Renewable Energy Laboratory and GTA focuses on validation of the current TRL 4 prototype with potential development and refinement for advancement to a TRL 5 system.

Validating an Electrolysis System with High Output Pressure

Honda R&D Americas, Inc.
1900 Harpers Way
Torrance, CA 90501

Hydrogen station designs are quickly evolving as more stations are installed and more end uses (e.g., light-duty, trucks, and buses) are coming online. Optimal station design depends heavily on the end use, location, and throughput demand of the station. There is no one-size-fits-all design in the hydrogen infrastructure space. Electrochemical compression has the potential to disrupt the hydrogen infrastructure industry, which currently relies on mechanical compression to reach high pressures.

In this project, Honda R&D Americas will partner with the National Renewable Energy Laboratory to perform baseline testing of their polymer electrolyte membrane-based electrochemical electrolysis stack capable of achieving pressures up to 70 MPa. The stack and system have been developed at Honda's R&D facility in Japan. Early studies of the stacks show promise in the technology with an approximate energy consumption reduction of 30% compared to mechanical compression. In theory, an electrochemical compression process should be more reliable than mechanical compression due to the reduction of moving parts.

Understanding new compression technologies and comparing them against the current state of the art will lead to innovations in station design and operation.

Turboexpander: Alternative Fueling Concept for Fuel Cell Electric Vehicle Fast Fill

Honda R&D Americas, Inc.
1900 Harpers Way
Torrance, CA 90501

In this project, Honda and the National Renewable Energy Laboratory are developing an alternative technology for achieving a fast fill at a hydrogen station. Hydrogen stations dispensing at 70 MPa struggle to achieve a 3–5 minute fill. Heating of the hydrogen during fueling occurs from two main effects: Joule Thomson heating across the control valve and compression heating in the tank. Joule Thomson heating is the result of the negative Joule Thomson coefficient that hydrogen exhibits at ambient temperatures when passed through an isenthalpic throttle (e.g., a valve or orifice). Current stations use a chiller and heat exchanger to precool and remove heat from the dispensed hydrogen thereby lowering the enthalpy of the dispensed gas to overcome the heating effects and avoid overheating of the gas in the tank. The alternative fueling concept will instead use a turboexpander to remove shaft power from the flowing hydrogen, lowering the enthalpy and dropping the temperature, through a near isentropic expansion. The turboexpander concept has the advantage of providing a much smaller footprint and lower cost than existing chiller systems as well as reduced parasitic chiller losses by providing on-demand cooling. Turboexpander development will be conducted at the National Renewable Energy Laboratory utilizing the gravimetric test standard to measure parameters of flow, pressure, and temperature for characterizing turbine performance. Data will be used to compare turboexpander performance to the requirements of the existing SAE J2601 fueling protocol.

Membrane Electrode Assembly Manufacturing Automation Technology for the Electrochemical Compression of Hydrogen

HyET Hydrogen USA LLC
7801 Folsom Blvd 2020
Sacramento, CA 95826

Electrochemical compression has the possibility to outcompete mechanical compression for hydrogen end-use applications. While HyET has a compressor that can output 10 kg/day (fully scalable from home to industrial application) at up to 700 bar, the energy demand and reliability requires top-quality electrochemical hydrogen compressor (EHC) membrane electrode assemblies (MEAs) preferably prepared by cost-effective high-capacity manufacturing. High pressure requires a special MEA design, deviating from typical polymer electrolyte membrane fuel cell MEAs, with adapted catalyst layer substrates, asking for a modified coating process.

The National Renewable Energy Laboratory will help HyET by developing an automated catalyst-coating process fit for EHC MEA manufacturing. In addition, inline quality inspection methods will be developed or selected to improve the MEA quality as it is used for EHC stack assembly. In a joint effort, the National Renewable Energy Laboratory and HyET will eventually design an automated manufacturing process for the EHC MEA and approach potential U.S. suppliers of manufacturing equipment.

Membrane Technology for the Electrochemical Compression of Hydrogen

HyET Hydrogen USA LLC
7801 Folsom Blvd 2020
Sacramento, CA 95826

Electrochemical hydrogen compression has the potential to outcompete mechanical compression for hydrogen end-use applications. HyET has a compressor that can output 10 kg/day at up to 700 bar; the energy demand and reliability requires a thin membrane with high proton conductivity, low hydrogen crossover/back diffusion, and proper mechanical stability to withstand the mechanical stress during compression.

HyET has found a proton-conducting polymer with very high proton conductivity that is promising for application in electrochemical compressor cells. However, as a membrane the material lacks the mechanical stability for high-pressure use.

Therefore, Lawrence Berkeley National Laboratory will develop a cost-effective synthesis route ready for scale up, the proper chemistry for mechanical property improvement, and the membrane casting process. HyET will test the resulting membrane materials in electrochemical hydrogen compressor cells on conductivity and pressurization performance. In a joint effort, Lawrence Berkeley National Laboratory and HyET will assess the supply chain for the new polymer and membrane to find U.S. suppliers for polymer and thin films.

Hydrogen Materials Compatibility of Low-Cost, High-Pressure, Polymer Hydrogen Dispensing Hoses

NanoSonic, Inc.
158 Wheatland Drive
Pembroke, VA 24136

This project is focused on the durability of metal-free polymer-based hydrogen dispensing hoses with the hydrogen environment at the molecular level. NanoSonic is partnering with Pacific Northwest National Laboratory in this CRADA to utilize the lab's expertise in hydrogen polymer materials compatibility. The goal is to determine the lifetime of the hydrogen hose polymer and composite constituents via (1) time-temperature superposition studies via dynamic mechanical analysis under hydrogen, (2) friction and wear resistance under in situ hydrogen tribometry, and (3) multi-axis strain testing under cryogenic conditions. Pacific Northwest National Laboratory has the unique test equipment essential to gain this type of insight and lifetime prediction data. Importantly, the work conducted under the CRADA will increase the safety and reliability of NanoSonic's hydrogen hoses while expanding the market for use of our low-hydrogen-permeation polymers and durable cryogenic composites to realize the H2@Scale objectives to reduce the cost of hydrogen.

Develop a Tool to Estimate the Benefits of Tube-Trailer Consolidation Scheme for Station Builders

PDC Machines, Inc.
1875 Stout Drive
Warminster, PA 18974

The capital cost of hydrogen refueling stations is high, with the station currently contributing about half of the dispensed cost of hydrogen. The tube-trailer consolidation operation scheme patented by Argonne National Laboratory is expected to reduce the cost of the hydrogen refueling station by approximately 25%. The tube-trailer consolidation optimizes the operation of the refueling station by efficiently managing the compression and the low-pressure storage that supplies hydrogen to the station. Leveraging the refueling patented algorithm developed at Argonne National Laboratory, this project aims to develop a user-friendly tool that promotes and demonstrates the benefits of the tube-trailer consolidation for station developers. The tool would provide an estimate of various station cost and performance metrics, including the capital cost, tube-trailer payload utilization, the state of charge of vehicles filled for a given demand profile, and the refueling cost per unit of hydrogen dispensed, as a function of various design parameters. Most of the refueling stations in early markets will be supplied by gaseous hydrogen tube trailers, making the consolidation refueling algorithm and this project more relevant with respect to design and operation of refueling stations in these markets. PDC Machines will furnish Argonne National Laboratory, the developer of the consolidation operation algorithm, with performance curves of compressor models to incorporate in the tool. As the developer of the Hydrogen Delivery Scenario Analysis Model (HDSAM) and the Hydrogen Station Cost Optimization and Performance Evaluation (H2SCOPE) tool, Argonne National Laboratory is uniquely positioned to develop the tool, which will demonstrate the potential savings achievable with implementing the tube-trailer consolidation method for hydrogen refueling.

Optimizing an Integrated Renewable-Electrolysis System

PG&E Corporation
77 Beale Street
San Francisco, CA 94105

This study will holistically model the various value streams created by an integrated renewable power–electrolyzer system that produces hydrogen for use in the transportation sector. The model will be used to design an optimized integrated renewable power–electrolyzer system (solar power plant, electrolyzer, and hydrogen storage). Knowledge of hydrogen systems gained during this project will contribute to PG&E's future goal to build and test an integrated renewable power–electrolyzer system at one of PG&E's existing solar facilities to demonstrate the interplay of these value streams in a real-world setting.

Risk Analysis and Modeling to Improve Hydrogen Fuel Cell Vehicle Repair Garages Codes and Standards

Quong & Associates, Inc.
1400 Geary Blvd., Suite 910
San Francisco, CA 94109

Existing codes and standards require repair garages that service hydrogen fuel cell vehicles to add costly equipment such as sensors, alarms, ventilation, and classified electrical equipment. This project will perform an application-specific risk analysis using software like the Hydrogen Risk Assessment Model to identify credible hazard scenarios resulting in unintentional indoor releases of hydrogen during maintenance operations. Results from the risk analysis will be used to identify key hydrogen release scenarios that may occur in the repair garages and require detailed modeling to characterize. Results from the modeling will be used to improve code requirements. Toyota and the team support this project because it can significantly reduce the cost of upgrading repair garages while maintaining the same levels of protection.

Hydrogen Component Performance Diagnostic Testing

RIX Industries
4900 Industrial Way
Benicia, CA 94510

H2@Scale is focused on the wide-scale adoption of hydrogen as a flexible energy storage medium. Due to the low volumetric energy density of gaseous hydrogen, compressors are an essential component of hydrogen storage. Hydrogen compressors that support a flexible grid and on-demand vehicle fueling undergo challenging operating conditions, such as a high number of start and stop cycles and wide input and discharge pressure ranges. Equally robust components are required for these conditions while still meeting the financial requirements of sustainable hydrogen compression.

This project seeks to investigate new seal materials and valves, both of which are responsible for many failures in today's hydrogen compressors, with the goal of demonstrating improved performance and material compatibility.

Innovating High-Throughput Hydrogen Stations

Shell
281 Albany Street
Cambridge, MA 02139

Shell, Air Liquide, Toyota, Honda, and the National Renewable Energy Laboratory are partnering to address technical challenges to advance hydrogen infrastructure and support the expansion of existing and future markets. The collaboration is expected to provide station performance in high-mass-transfer and high-fill-frequency conditions to advance the design and operating strategies of high-throughput stations, supporting light-, medium-, and heavy-duty end-use applications. The information will support system and component solutions, along with optimization for storage, component integration, and renewable hydrogen sourcing. The work supports the broader H2@Scale target of increasing the penetration of variable renewable power and nuclear generation by providing technological advancements for hydrogen end uses in transportation.

Expected outcomes of the project include light-, medium-, and heavy-duty fueling data and specifications, station reliability research aimed at reducing maintenance costs, and advanced light-duty fueling components for control, pressure, and thermal management. In addition, the project will act as a hardware-in-the-loop incubator for new station technologies, integrating industry and researchers across market segments such as station owners, equipment suppliers, hydrogen suppliers, and national labs. New companies entering the market will be able to leverage the expanded infrastructure and capabilities at the National Renewable Energy Laboratory to reduce development costs and risks, resulting in more manufacturers and market competitiveness. The facility will be available to industry and researchers as part of the Energy Systems Integration Facility user facility model. To complete the work, existing National Renewable Energy Laboratory resources will be leveraged, including the Hydrogen Infrastructure Testing and Research Facility for existing and expanded infrastructure, as well as experimentation and analysis tools and personnel in the lab's Hydrogen and Fuel Cell Systems Engineering group.

Region-Specific Merchant Hydrogen Market Assessment and Techno-Economic Assessment of Electrolytic Hydrogen Generation

Southern Company Services, Inc.
600 18th Street North
Birmingham, AL 35203

Electrolyzers potentially bring value to both hydrogen generation and grid services, such as frequency regulation and firm capacity. Low-cost and otherwise curtailed nuclear, renewable, and hybrid steam/electricity generators could be used to generate hydrogen. This project analyzes the existing regional hydrogen markets (especially for low-CO_2 hydrogen), evaluates the value of grid services and firm capacity, explores the ability of electrolyzer technology to provide these services, and provides a techno-economic assessment of electrolytic hydrogen generation from otherwise curtailed resources.

Hybrid Electrical/Thermal Hydrogen Production Process Integrated with a Molten Salt Reactor Nuclear Power Plant

Southern Company Services, Inc.
600 18th Street North
Birmingham, AL 35203

This project buys down risk for the integration of molten salt reactors with hybrid thermal/electrical processes, including the production of hydrogen via a hybrid sulfur process. Molten salts have volumetric heat capacity similar to that of water (more than 200 times greater than that of helium). This makes them an excellent working fluid for high-temperature process heat applications. Previous work on the process, including detailed conceptual plant designs and cost estimates, was based on the use of high-temperature gas-cooled reactors with process heat delivered at 750°–950°C and 1.2–9 MPa for the decomposition step. This work focuses on the conceptual design of the integrated molten salt reactor–hybrid sulfur process (lower pressure and potentially lower temperature than previous work) and improving electrolysis performance.

Tatsuno Coriolis Flow Meter Development Testing in High-Pressure Hydrogen

Tatsuno North America, Inc.
7 Surrey Ln.
Rancho Palos Verdes, CA 90275

Hydrogen flow meter accuracy at 70 MPa dispensers has been identified as a technology challenge for deployment of hydrogen infrastructure. Current NIST Handbook 44 accuracy requirements for hydrogen use as a motor vehicle fuel have been amended to a 5% acceptance tolerance with a 7% maintenance tolerance. This accuracy class is reduced from the 1.5% acceptance and 2.0% maintenance tolerance used for other motor vehicle fuels such as gasoline.

The reduced accuracy class was required by current accuracy limitations when measuring dispensed hydrogen. These limitations are based on additive contributions from flow meter accuracy and high-pressure hydrogen system effects. Flow meter development for improved accuracy will provide a direct benefit to the fuel cell vehicle customer interface and will help to prevent lost revenue by the station operator, thereby adding value to the business case for deploying hydrogen stations.

Flow meter characterization testing of the Tatsuno coriolis flow meter specifically designed for high-pressure hydrogen will utilize the gravimetric standard developed as part of the U.S. Department of Energy/National Renewable Energy Laboratory hydrogen flow meter benchmarking project.

Evaluate High-Temperature Steam Electrolysis Coupled to PWR/MCFR/TWR for Hydrogen Production and Energy Storage

TerraPower, LLC Inc.
330 120th Ave NE, Suite 100
Bellevue, WA 98005

Nuclear plants focused on hydrogen production can potentially generate increased revenues by optimizing between hydrogen generation, electricity production, and energy storage. This increase in revenue translates directly to new opportunities for nuclear power and the potential generation of new jobs. The project will evaluate the use of reversible high-temperature steam electrolysis (HTSE) for hydrogen production from TerraPower's traveling wave reactor (TWR) and molten chloride fast reactor (MCFR) designs, as well as from existing light-water reactors. This CRADA will leverage previous efforts at Idaho National Laboratory and Pacific Northwest National Laboratory related to testing and analysis of HTSE equipment, computational models, and techno-economic analysis. The objectives of this CRADA are:

1. Evaluate the methods and technology advantages of integrating TerraPower nuclear reactor designs and light-water reactor designs with reversible HTSE
2. Assess market opportunities for HTSE and identify industrial applications
3. Address the state of HTSE technology commercial readiness and nuclear reactor integration interface development and demonstration needs. This effort will help identify technology development and commercialization opportunities for Terra Power.