Safety, Codes and Standards – 2022

Activity Overview

Introduction

The Safety, Codes and Standards (SCS) activity area, part of the Technology Acceleration portfolio, supports research, development, and demonstration (RD&D) to improve the fundamental understanding of the relevant physics and provide the critical data and safety information needed to develop and revise technically sound and defensible codes and standards. These codes and standards provide the technical basis to facilitate and enable the safe and consistent deployment and commercialization of hydrogen and fuel cell technologies in multiple applications. SCS activities include identifying and evaluating safety and risk management measures that are used to define requirements and close the knowledge gaps in codes and standards in a timely manner. SCS activities also focus on promoting best safety practices and developing information resources.

In Fiscal Year (FY) 2022, SCS focused on:

- Validating liquid hydrogen release models to inform and update setback distances for bulk liquid hydrogen storage.
- Developing sensor use guidance and wide-area-monitoring technologies and addressing component failure data needs by analyzing component failure modes and quantifying leak size.
- Developing hydrogen-specific quantitative risk assessment tools, data, and methods for supporting, harmonizing, and revising hydrogen codes and standards.
- Providing hydrogen safety expertise and recommendations to funded projects through the Hydrogen Safety Panel, including sharing best practices and lessons learned to the hydrogen community.
- Developing professional training courses and university curriculum content to support workforce development for the hydrogen industry.

These crosscutting efforts support technology development and scale-up of hydrogen activities across the entire hydrogen value chain (production, delivery, storage, and end use) as well as across multiple industry sectors (transportation, grid integration and power generation, industrial and chemical industry, etc.).

Goals

The overarching goal of the SCS activity area is to enable the safe deployment and use of hydrogen and fuel cell technologies and ensure that key stakeholders have confidence in that safety. This goal is pursued by:

- Facilitating the creation, adoption, and harmonization of regulations, codes, and standards (RCS) for hydrogen and fuel cell technologies.
- Conducting research to generate the valid scientific bases needed to define requirements in developing RCS.
- Performing RD&D to inform deployment and enable compliance with RCS.
- Developing and enabling widespread dissemination of safety-related information resources and lessons learned.
- Ensuring that best safety practices are followed in activities sponsored by the Hydrogen Program; to that end, soliciting and reviewing project safety plans and directing project teams to safety-related resources.

Key Milestones

- Identify ways to reduce the siting burdens that prohibit expansion of hydrogen fueling stations by using hydrogen research and development (R&D) to enable a 40% reduction in station footprint, as compared to the 2016 baseline of 18,000 square feet, by 2022.

- Develop a compendium of gaps and priorities requiring harmonization for global codes and standards for hydrogen infrastructure and mobility technologies.
- Initiate at least three new non-automotive-related applied risk assessment and modeling efforts pertaining to large-scale hydrogen deployment applications.
- Ensure monitoring systems and data collection are in place for potential hydrogen and other emissions/releases and validate hydrogen sensor technology capable of parts-per-billion sensitivity, detection speeds of less than one minute, and <$1,000 annual operating cost.

Fiscal Year 2022 Technology Status and Accomplishments

The SCS activity area continues to perform RD&D to provide the scientific basis for codes and standards development with projects in a wide range of areas, including hydrogen behavior, hazard analysis, material and component compatibility, and hydrogen sensor technologies. Using the results from these RD&D activities, the subprogram continues to actively participate in discussions with standards development organizations such as the National Fire Protection Association (NFPA), the International Code Council, SAE International, the CSA Group, and the International Organization for Standardization (ISO) to promote domestic and international collaboration and harmonization of RCS.[1]

A number of codes and standards relevant to the hydrogen industry were published or revised during FY 2022. A database of these codes and standards is maintained on the Hydrogen Safety Panel's H2Tools website.[2]

The H2Tools website provides up-to-date information relevant to the status of SCS activities and enables dissemination of key safety knowledge resources, including several that were updated in FY 2022:

- Hydrogen Incident Examples
- Hydrogen Incident Recovery Guide
- Simplified Safety Planning for Low-Volume Hydrogen and Fuel Cell Projects.

While significant progress has been made in establishing needed RCS and in developing and disseminating safety information, several barriers remain in developing adequate codes and standards and supporting safe deployment of hydrogen technologies. Near-term barriers include:

- Few science-based requirements on hydrogen–natural gas blends
- Incomplete data for liquid hydrogen system component failures and leaks
- Lack of standoff detection technologies for wide-area monitoring of hydrogen leaks
- Insufficient workforce for the emerging hydrogen economy.

Longer-term barriers to both safe deployment and scale-up include:

- Lack of standards for high-throughput fueling for heavy-duty applications, including trucks, marine, and rail
- Incomplete codes and standards for bulk storage of hydrogen
- Unknown regulatory processes for emerging applications, such as those for bulk transport of hydrogen as cargo
- Inconsistent RCS needed to support national and international markets
- Lack of capability of sensors and detection technologies to quantify or monitor hydrogen releases at levels needed for environmental monitoring.

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[1] The full text of relevant RCS can be found at their respective codes and standards development organization websites: NFPA (https://www.nfpa.org/), International Electrochemical Commission (https://www.iec.ch/), SAE International (https://www.sae.org/), American National Standards Institute (https://www.ansi.org/), and ISO (https://www.iso.org/home.html).

[2] Hydrogen Safety Panel, "H2Tools," accessed August 2022, https://h2tools.org/.

In FY 2022, the SCS activity area has continued to make progress in the areas of hydrogen behavior, risk assessment, materials compatibility, hydrogen fuel quality assurance, and codes and standards harmonization. Notably, along with the European Commission, the Hydrogen and Fuel Cell Technologies Office hosted the Clean Hydrogen JU [Joint Undertaking] Expert Workshop on Environmental Impacts of Hydrogen[3] to identify technical needs and next steps for monitoring and mitigating hydrogen releases into the atmosphere.

Of particular significance is NFPA 2, the NFPA's Hydrogen Technologies Code. NFPA 2 is a critical element of the framework for deploying hydrogen technologies in the United States. Enabling the revision of the separation distances laid out in the code document is a major element of the SCS RD&D portfolio. Significant progress was made this year, as SCS met the milestone for 40% reduction in station footprint by enabling updated tables and language for NFPA 2 (2023 edition).

Hydrogen Behavior and Risk R&D

- Utilized bulk cryogenic hydrogen behavior validation data to enable 40% reduction in hydrogen station footprint based on NFPA 2 (Sandia National Laboratories).
- Performed SCS gap assessments for large-scale hydrogen applications, including bulk storage and rail (Sandia National Laboratories).
- Updated HyRAM+ (Hydrogen Plus Other Alternative Fuels Risk Assessment Models) with capability to simulate unconfined overpressure, as well as alternative fuel releases (Sandia National Laboratories).
- Published a literature review of hydrogen–natural gas blend releases (Sandia National Laboratories).

Safety Resources and Support

- Through Hydrogen Education for a Decarbonized Global Economy (H2EDGE), launched five professional workforce development courses, covering basic hydrogen science as well as production, storage, end use, and safety (Electric Power Research Institute [EPRI]).
- Published "Simplified Safety Planning for Low-Volume Hydrogen and Fuel Cell Projects" (Pacific Northwest National Laboratory).

Component R&D

- Developed computational fluid dynamics models of hydrogen dispersion in small enclosures, validated by HyWAM (Hydrogen Wide Area Monitoring) (National Renewable Energy Laboratory).
- Demonstrated the use of ultrasonic leak detection to characterize signatures for leaks with orifices down to approximately 0.02 mm (National Renewable Energy Laboratory).

Materials Compatibility R&D

- Published a U.S. Department of Energy (DOE) Program Record titled "Increased design life for high-pressure stationary hydrogen storage vessels through development of empirically based design curves" (Sandia National Laboratories).

New Project Selections

- Sandia National Laboratories and Wabtec: Risk Assessments of Design and Refueling for Hydrogen Locomotive and Tender (cooperative research and development agreement [CRADA])
- National Renewable Energy Laboratory, National Energy Technology Laboratory, Paulsson, Element One, Renewable Innovations, and others: Assessment of Heavy-Duty Fueling Methods and Components (CRADA)

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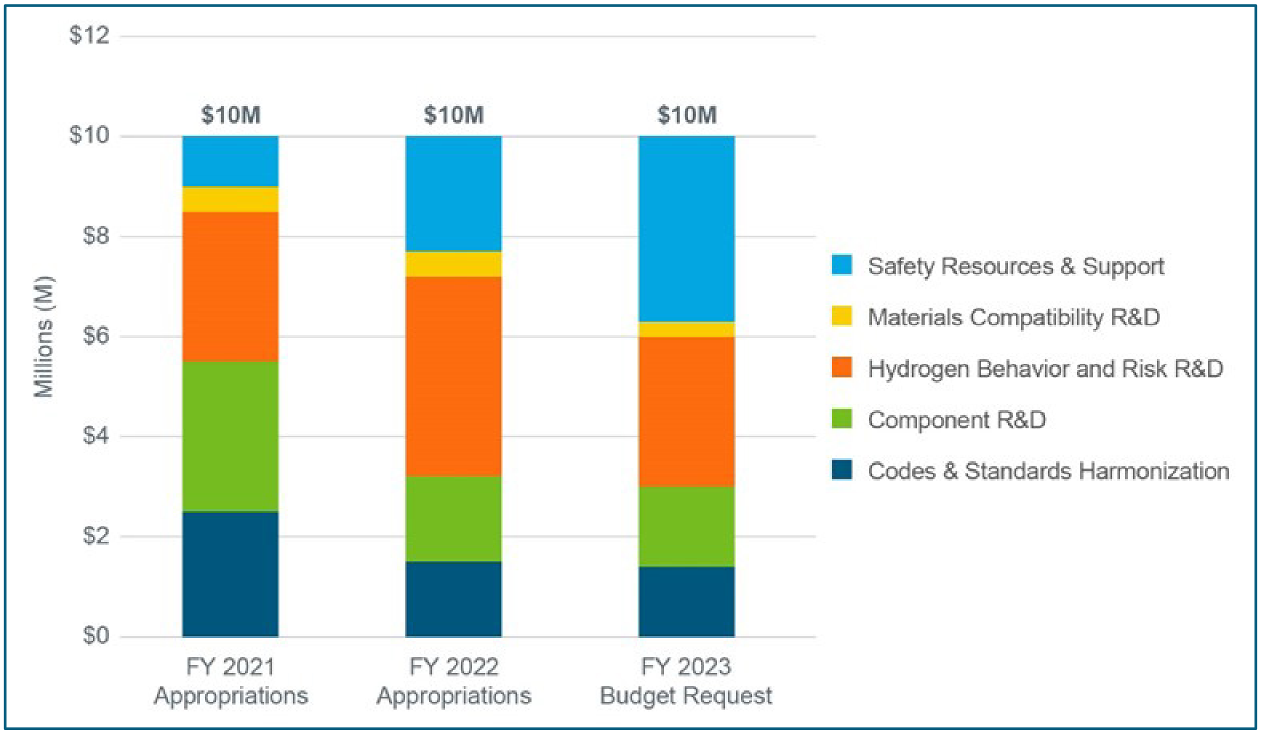
[3] A. Arrigoni and L. Bravo Diaz, Hydrogen emissions from a hydrogen economy and their potential global warming impact, EUR 31188 EN, Publications Office of the European Union, Luxembourg, 2022, ISBN 978-92-76-55848-4, doi:10.2760/065589, JRC130362, https://publications.jrc.ec.europa.eu/repository/handle/JRC130362.

- National Renewable Energy Laboratory and Frontier Energy: MC Formula Protocol for H35HF Fueling[4]

Budget

The FY 2021 appropriation for the SCS activity totaled $10 million, as did the FY 2022 appropriation. Funding in FY 2022 showed an increased focus on applied risk assessment and additional funding support for safety resources and workforce development, balanced funding for codes and standards harmonization and component RD&D, and lower levels of funding for materials compatibility RD&D. Future work in the SCS activity is expected to focus on continued applied risk assessments, expanding sensor and detection work to include quantification and monitoring of hydrogen for environmental impact studies, development of new codes and standards tools, and continued emphasis on safety training and workforce development.



[4] MC refers to total heat capacity. H35HF refers to refueling hydrogen at a high flow (HF) rate to an onboard pressure of 35 MPa (H35).

Project Summaries

Below are brief SCS 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 #SCS-010: Research and Development for Safety, Codes and Standards: Hydrogen Behavior

Ethan Hecht, Sandia National Laboratories

DOE Contract #	WBS 6.2.0.801
Start and End Dates	10/1/2003
Partners/Collaborators	• Air Liquide (via H2@Scale CRADA) • Lawrence Livermore National Laboratory • National Renewable Energy Laboratory • Compressed Gas Association 5.5 testing task force • Fuel Cells and Hydrogen Joint Undertaking • National Fire Protection Association 2 • Massachusetts Institute of Technology • BKi (via previous CRADA, which included the California Fuel Cell Partnership, an auto original equipment manufacturer group, Linde, Shell)

Project Goal and Brief Summary

Sandia National Laboratories is working to address the lack of safety data and technical information relevant to the development of SCS by (1) providing a science and engineering basis for understanding the release, ignition, and combustion behavior of hydrogen across its range of use (i.e., high-pressure and cryogenic applications), (2) generating data to address targeted gaps in the understanding of hydrogen behavior physics (and modeling), and (3) developing and validating scientific models to facilitate quantitative risk assessment of hydrogen systems and enable revision of RCS to accelerate permitting of hydrogen installations. The project began in 2003.

Project #SCS-011: Hydrogen Quantitative Risk Assessment

Brian Ehrhart, Sandia National Laboratories

DOE Contract #	WBS 6.2.0.801
Start and End Dates	10/1/2003
Partners/Collaborators	• FirstElement Fuel • Air Liquide • Quong & Associates • Pacific Northwest National Laboratory • National Renewable Energy Laboratory • Argonne National Laboratory • Network of Excellence for Hydrogen Safety (HySafe) • organizations using the Hydrogen Risk Assessment Model (HyRAM) • National Fire Protection Agency 2/55 • U.S. Department of Transportation Federal Highway Administration • California Fuel Cell Partnership • International Partnership for the Hydrogen Economy • International Electrotechnical Commission

Project Goal and Brief Summary

The primary objective of this project is to provide a science and engineering basis for assessing the safety of hydrogen systems and facilitate the use of that information for revising RCS and permitting stations. Sandia National Laboratories will develop and validate hydrogen behavior physics models to address targeted gaps in knowledge, build tools to enable industry-led codes and standards revision and safety analyses, and develop hydrogen-specific quantitative risk assessment tools and methods to support RCS decisions and to enable a performance-based design code compliance option.

Project #SCS-019: Hydrogen Safety Panel, Safety Knowledge Tools, and First Responder Training Resources

Nick Barilo, Pacific Northwest National Laboratory

DOE Contract #	6.2.0.502
Start and End Dates	3/1/2003
Partners/Collaborators	• California Energy Commission • American Institute of Chemical Engineers • Center for Hydrogen Safety

Project Goal and Brief Summary

This project provides expertise and recommendations through the Hydrogen Safety Panel and through the Hydrogen Tools Portal, H2Tools.org (H2Tools), to identify safety-related technical data gaps, best practices, and lessons learned, as well as help integrate safety planning into funded projects. Data from hydrogen incidents and near misses are captured and added to the growing knowledge base of hydrogen experience to share with the hydrogen community, with the goal of preventing safety events from occurring in the future. The project also aims to implement a national hydrogen emergency response training resource program with adaptable, downloadable materials for first responders and training organizations.

Project #SCS-021: Hydrogen Sensor Testing Laboratory

William Buttner, National Renewable Energy Laboratory

DOE Contract #	WBS 6.2.0.502
Start and End Dates	10/1/2010
Partners/Collaborators	• Shell North America • Amphenol Thermometrics • AVT and Associates • Element One • KWJ Engineering Inc. • First Element, Emerson • Health and Safety Executive's Health and Safety Laboratory • Transport Canada • Environment and Climate Change Canada

Project Goal and Brief Summary

Sensors are a critical hydrogen safety element and will facilitate the safe implementation of the hydrogen infrastructure. The National Renewable Energy Laboratory's Sensor Testing Laboratory tests and verifies sensor performance for manufacturers, developers, end users, and standards developing organizations. The project also helps develop guidelines and protocols for the deployment of hydrogen safety sensors under a variety of conditions and applications.

Project #SCS-028: Hydrogen Education for a Decarbonized Economy

Tom Reddoch, Electric Power Research Institute

DOE Contract #	DE-EE0009253
Start and End Dates	10/01/2020–03/31/2025
Partners/Collaborators	• Gas Technology Institute • Oregon State University • University of Delaware • Embedded Assessments • Hydrogen Industry Partners

Project Goal and Brief Summary

As an emerging field, the hydrogen industry faces the challenge of mobilizing an experienced workforce—a critical need where safety must be emphasized. This project establishes the H2EDGE initiative to enhance workforce readiness by collaborating with industry and university partners to develop and deliver training and education materials, including professional training courses, university curriculum content, certifications, credentials, qualifications, and standards for training. H2EDGE will establish regional university hubs and an affiliate university network to train the workforce for the hydrogen economy. Professional short courses and university curricula will focus on the four pillars of the hydrogen industry: production, delivery, storage, and use.

Annual Merit Review of the Safety, Codes and Standards Activity

Summary of Safety, Codes and Standards Activity 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.

Inconsistent standards are beginning to be established across the globe, which will cause confusion in the market if not addressed, especially as companies and governments work toward implementing low-carbon energy solutions. More support for codes and standards development is suggested, particularly regarding new and emerging applications for hydrogen. Widespread commercialization will require regulatory changes at the national, state, and regional levels, and with so many emerging applications, it may be time to establish a specific mission, strategy, and goals for the SCS subprogram. To facilitate the regulatory frameworks for deployment of technologies across a range of new applications (e.g., grid resilience, heavy-duty trucks, maritime, aviation, and railway), related R&D needs should be identified.

The Hydrogen Safety Panel is a great resource that can help drive consistency and learnings. The Hydrogen Program should clearly communicate and push to resolve obstacles in existing codes and standards that are hindering implementation. There is a need to achieve alignment and standardization of clean hydrogen production and distribution evaluation methods, metrics, targets, and implementation. There should also be a focus on codes and standards for local/lower-pressure hydrogen distribution networks, and it would be helpful to accelerate both SCS work and materials testing work to support easier and less costly deployment of hydrogen pipelines. Technology validation efforts related to light-duty vehicle and forklift fueling are providing a large enough body of data to inform practical, statistics-based standards going forward. Moreover, the larger industrial uses of hydrogen will need to be addressed, as existing codes and standards generally do not cover such processes and are handled independently through risk analysis by producers and users.

International collaboration is an area where there should be many opportunities for projects that support global harmonization of hydrogen standards. The Hydrogen Program could develop a strategy to ensure that international partnerships and related agreements are reflected in the myriad of regulatory frameworks in the United States. It is very encouraging to see international collaborations; perhaps these collaborations could be further enhanced in terms of SCS development. Design and parts standardization would also be a good focus for international collaboration. Such collaboration could be used to encourage original equipment manufacturers to communicate and standardize certain parts and designs, which would be very beneficial to supply chain development.