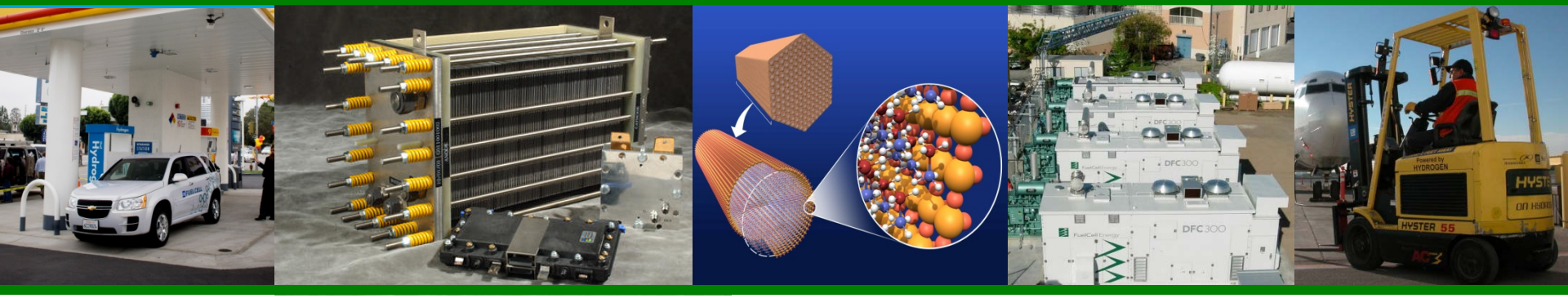
U.S. DEPARTMENT OF ENERGY




# Safety, Codes & Standards Program Area

# -Plenary Presentation-

*Will James*

*Fuel Cell Technologies Office*

***2017 Annual Merit Review and Peer Evaluation Meeting***

***June 5 - 9, 2015***

# Goals & Objectives



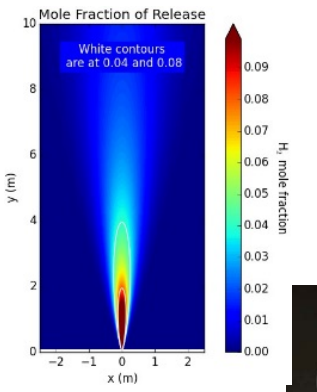
## Codes & Standards

- Conduct **R&D to provide critical data** and information needed to define requirements in developing codes and standards.
- Support and facilitate development of **essential codes and standards** to **enable widespread deployment** of hydrogen and fuel cell technologies and completion of essential regulations, codes and standards (RCS).

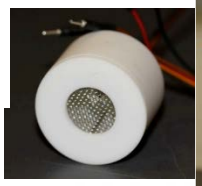
## Safety

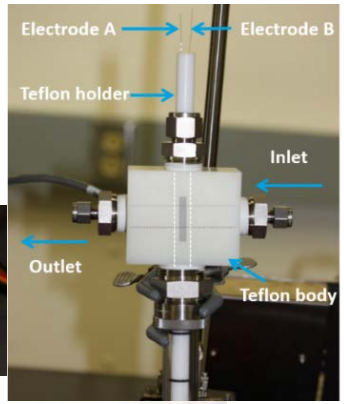
- Ensure that **best safety practices** underlie activities supported through DOE-funded projects.
- Enable **widespread sharing** of **safety-related information resources** and lessons learned with key stakeholders.

HyRAM
HYDROGEN RISK ASSESSMENT MODELS







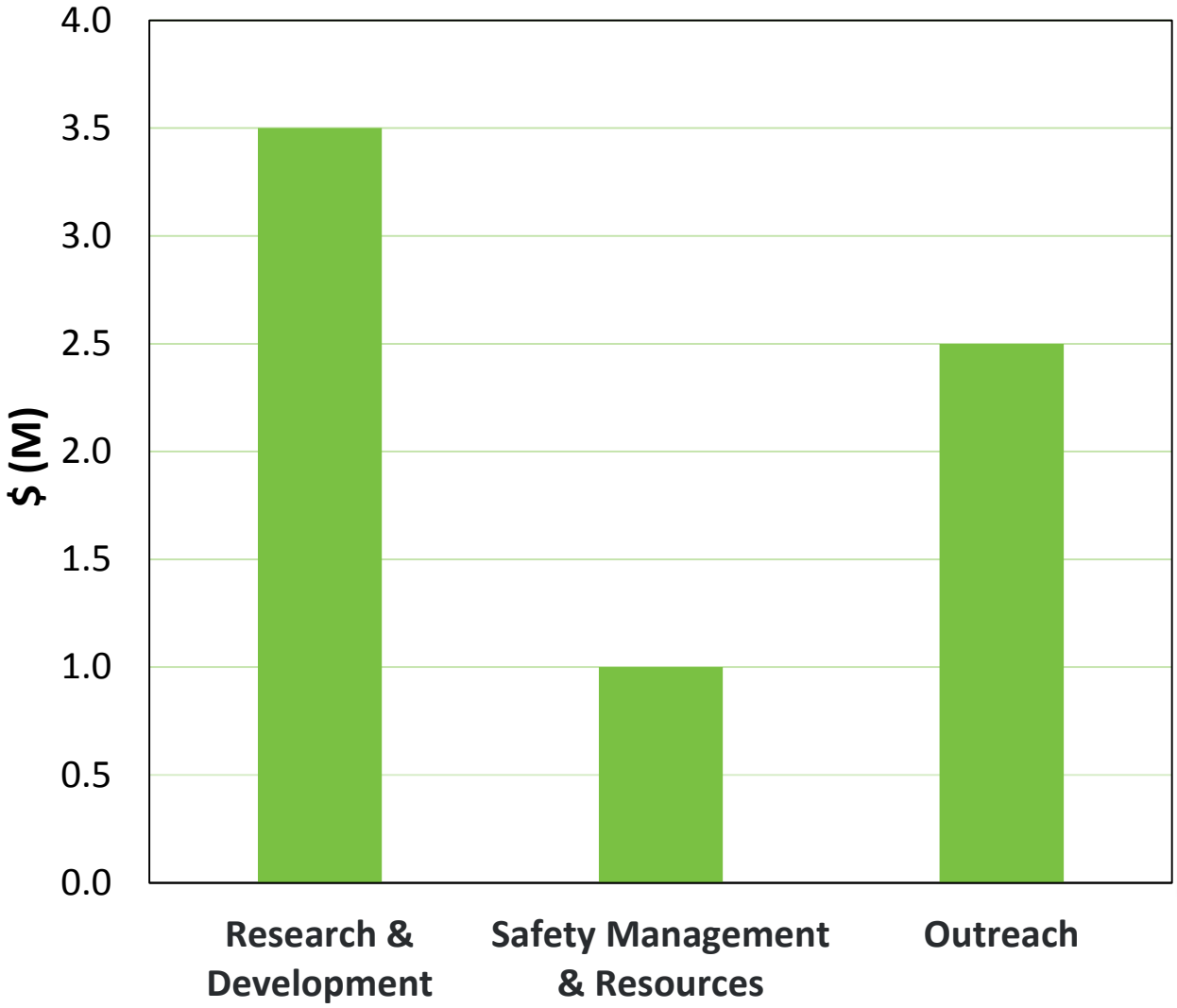




***Funding R&D needed to develop science-based codes and standards, thereby enabling the safe deployment of $H_2$ and fuel cell technologies***

# Budget

## FY 2017 Appropriation = $ 7M




## Emphasis

- Liquid $H_2$ behavior
- Quantitative risk assessment
- $H_2$ compatibility of metallic and non-metallic materials
- $H_2$ contaminant detector for fuel quality
- Support critical stakeholders in $H_2$ safety best practices

# Current Status – Codes & Standards




## Vehicle Standards

GTR-13
SAE J2579
HGV 2-2014
HGV 3.1-2015
CSA HPRD 1-2013
ANSI/CSA FC 3-2004

## Fueling and Communication

SAE J2601
SAE J2799
SAE J2600

## Separation Distances

NFPA 2/55

## Fuel Quality

SAE J2719

***U.S. DOE R&D efforts resulted in significant time saved in the development of station-related codes and standards.***

# Strategy and Barriers

| Focus areas | Barriers* | Objectives |
|---|---|---|
| Hydrogen Behavior | Insufficient data for code revision (e.g.- large station footprints) | R&D model development and verification to establish scientific basis for codes and standards revisions |
| Risk Assessment | Usage and access restrictions; Limited reliability data | Develop tools on a scientific foundation which can be used for various hydrogen applications |
| Materials Compatibility | Lack of information on new materials compatibility with hydrogen | Establish a foundational materials understanding, which will enable and support the C&S development |
| Detection & Sensors | High cost and limited commercial availability of products | Develop $H_2$ contaminant detectors for fuel quality at $H_2$ station. |
| Outreach & Support | Limited access and understanding of safety data and information | Support critical stakeholders in understanding hydrogen safety best practices. |

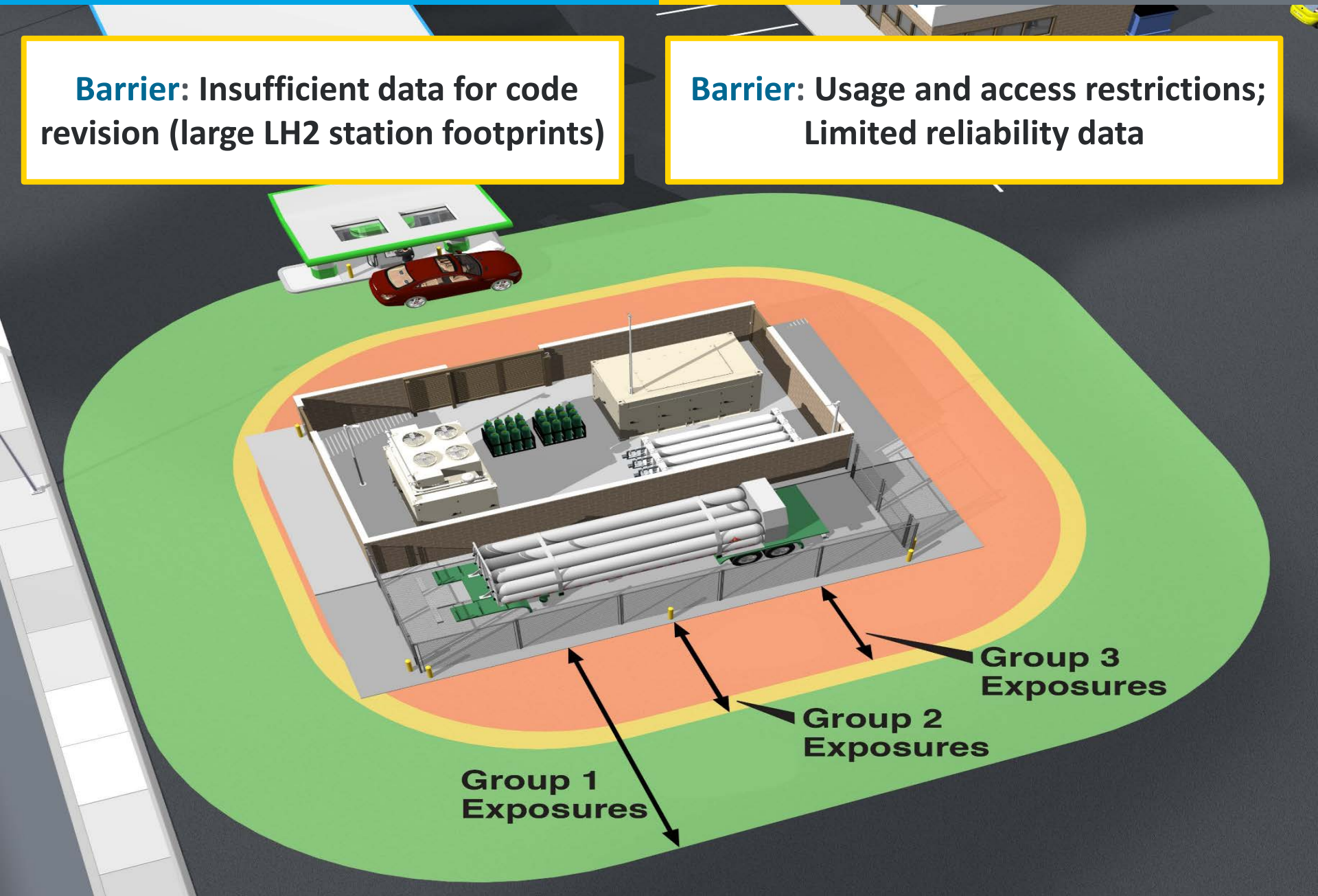
* From Safety, Codes and Standards MYRD&D (June 2015)

# Barrier: LH2 Separation Distances



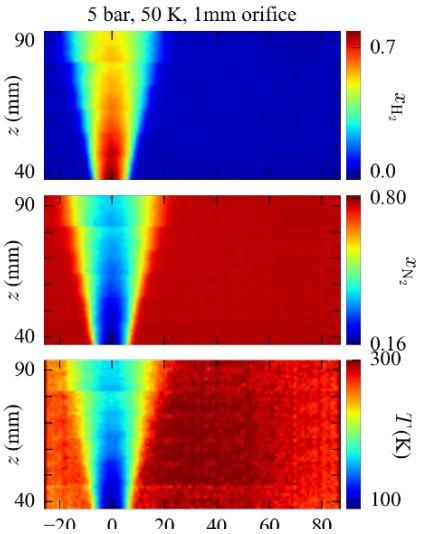
**Barrier:** Insufficient data for code revision (large LH2 station footprints)

**Barrier:** Usage and access restrictions; Limited reliability data



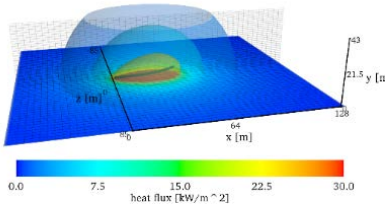
# R&D Accomplishment: Separation Distances

- **Hydrogen Behavior (SCS010)**
  - **Developed and implemented Raman imaging technique to measure cryogenic plumes at 50K**

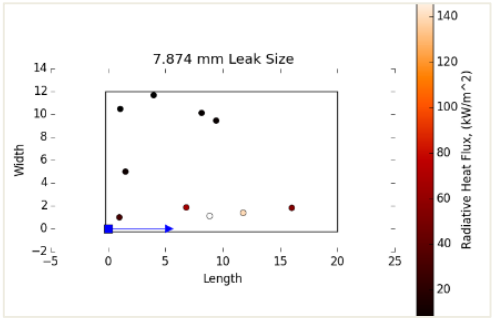



- **Quantitative Risk Assessment (SCS011): HyRAM 1.1 released with new features**
  - Incorporated the curved flame module now in QRA mode – **improved physical accuracy**
  - Achieved **67% reduction in curved flame computing time**

HyRAM
HYDROGEN RISK ASSESSMENT MODELS

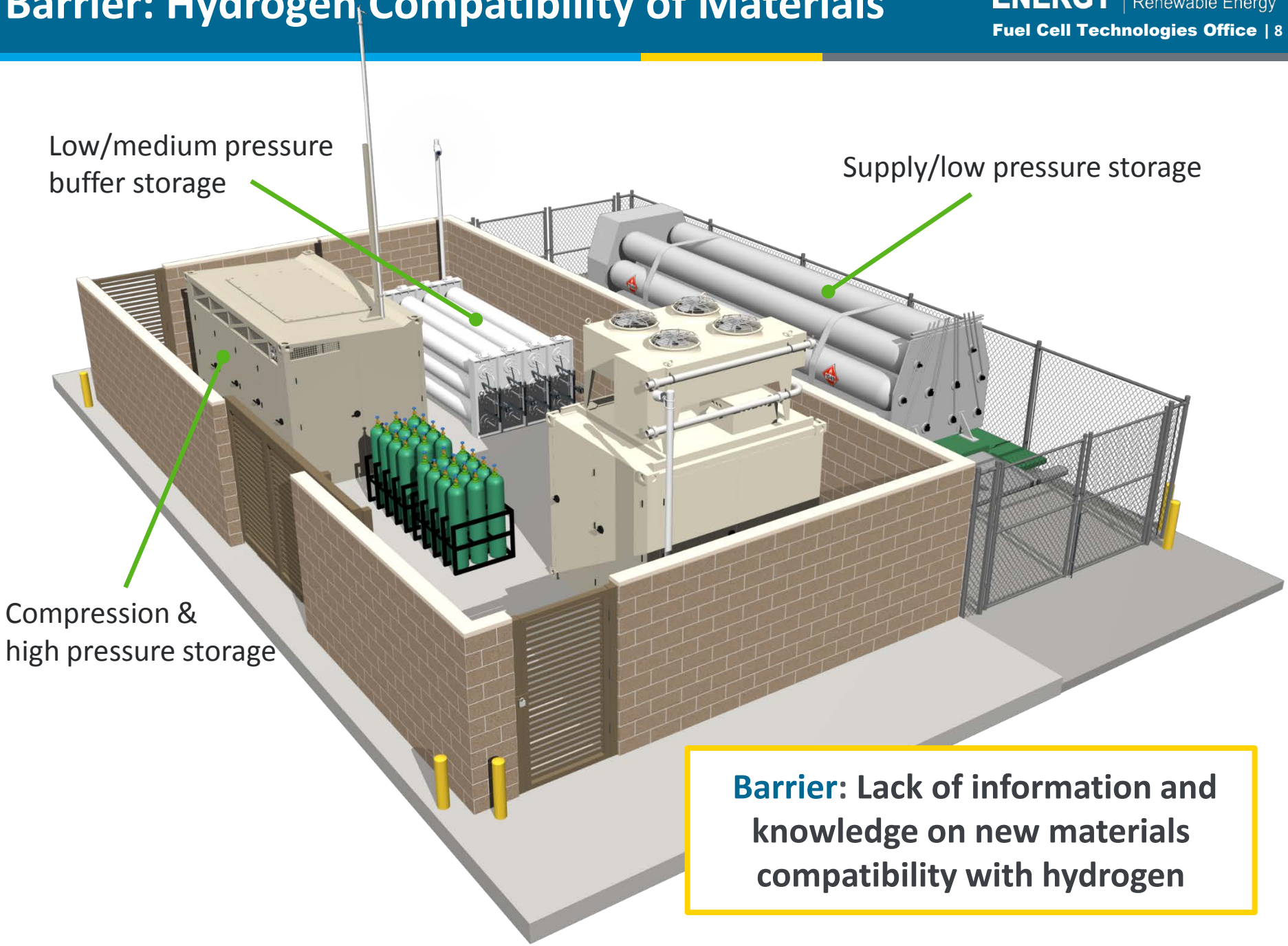



- **Enable Hydrogen Infrastructure through Science-based Codes and Standards (SCS025)**
  - **Achieved additional 50% reduction for GH2 in 2020 edition of NFPA 2**
  - **Initiated the evaluation multiple leak scenarios to demonstrate that the alternate design ensures equivalent system safety, which could help to provide variances.**



# Barrier: Hydrogen Compatibility of Materials



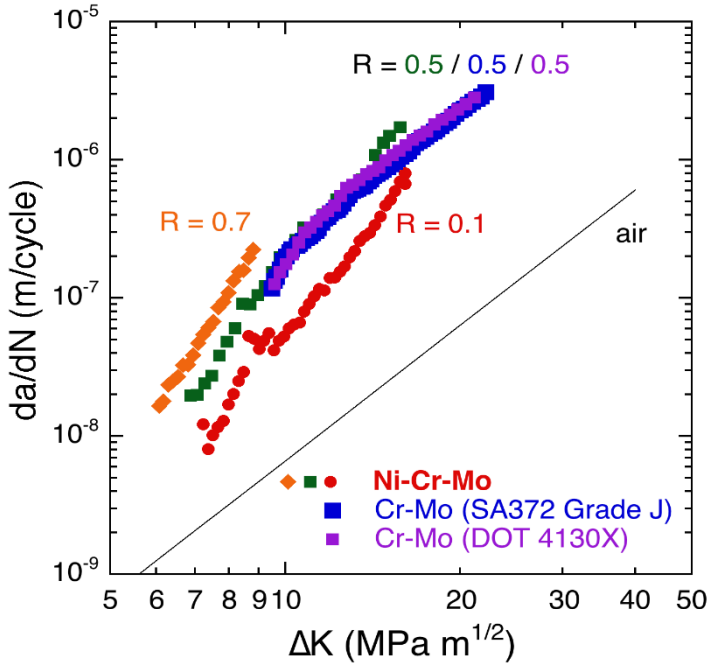



**Barrier**: Lack of information and knowledge on new materials compatibility with hydrogen

# R&D Accomplishment: $H_2$ Materials Compatibility

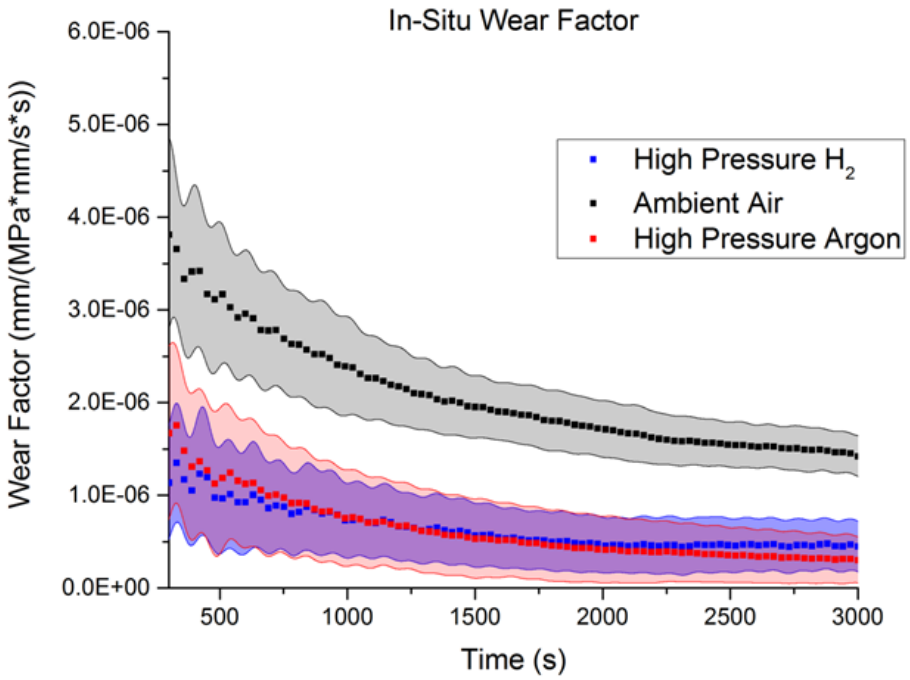
## Metallic Materials Compatibility (SCS005)

- FY2017: High-hardenability steels (Ni-Cr-Mo) show similar fatigue crack growth rates as common PV steels (Cr-Mo) in gaseous hydrogen




## Non-Metallic (Polymer) Compatibility (SCS026)

- FY2017: Initiated testing program of critical materials to understand behavior (e.g.- Tribology in 500 bar $H_2$

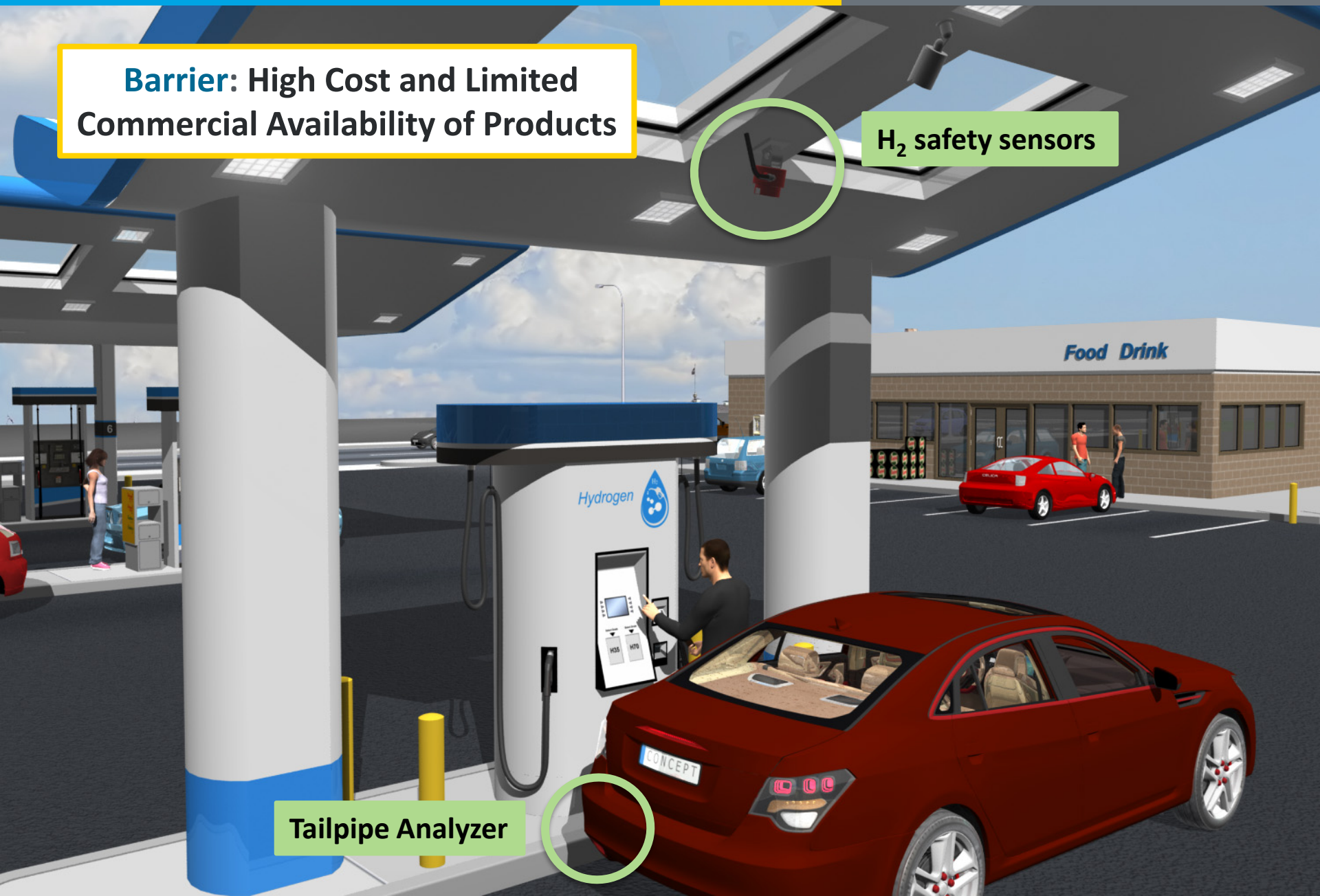



***Performing critical materials R&D to understand material behavior in high pressure hydrogen, which will enable RCS in support of infrastructure deployment***

# Barrier: Safety Sensors



**Barrier: High Cost and Limited Commercial Availability of Products**



# R&D Accomplishment: Safety Sensors

**Objective**: **Develop low cost, low power, durable, and reliable $H_2$ safety sensor for vehicle and infrastructure applications.**

1. **Vehicle Repair Facility**: NREL-KPA/Toyota (sensors mandated by IFC). Deployed in CA and NE on-going
   - NREL successfully qualified sensor for application, facilitating AHJ acceptance.
   - On-going support to assure continued success.
2. **Vehicle Tailpipe $H_2$ Emissions**: NREL, in support of Global Technical Regulation (GTR)
   - Developed FCEV Exhaust Analyzer for verification of GTR-13 requirements.
   - Performance verified in the laboratory; Field tested on FCEV; detected hydrogen successfully

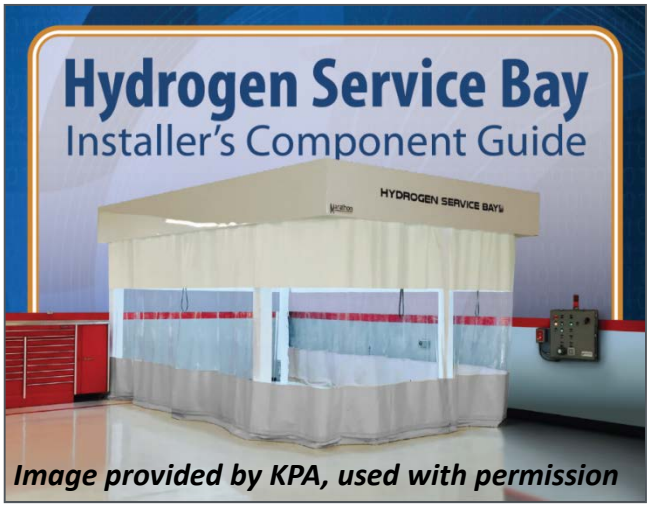
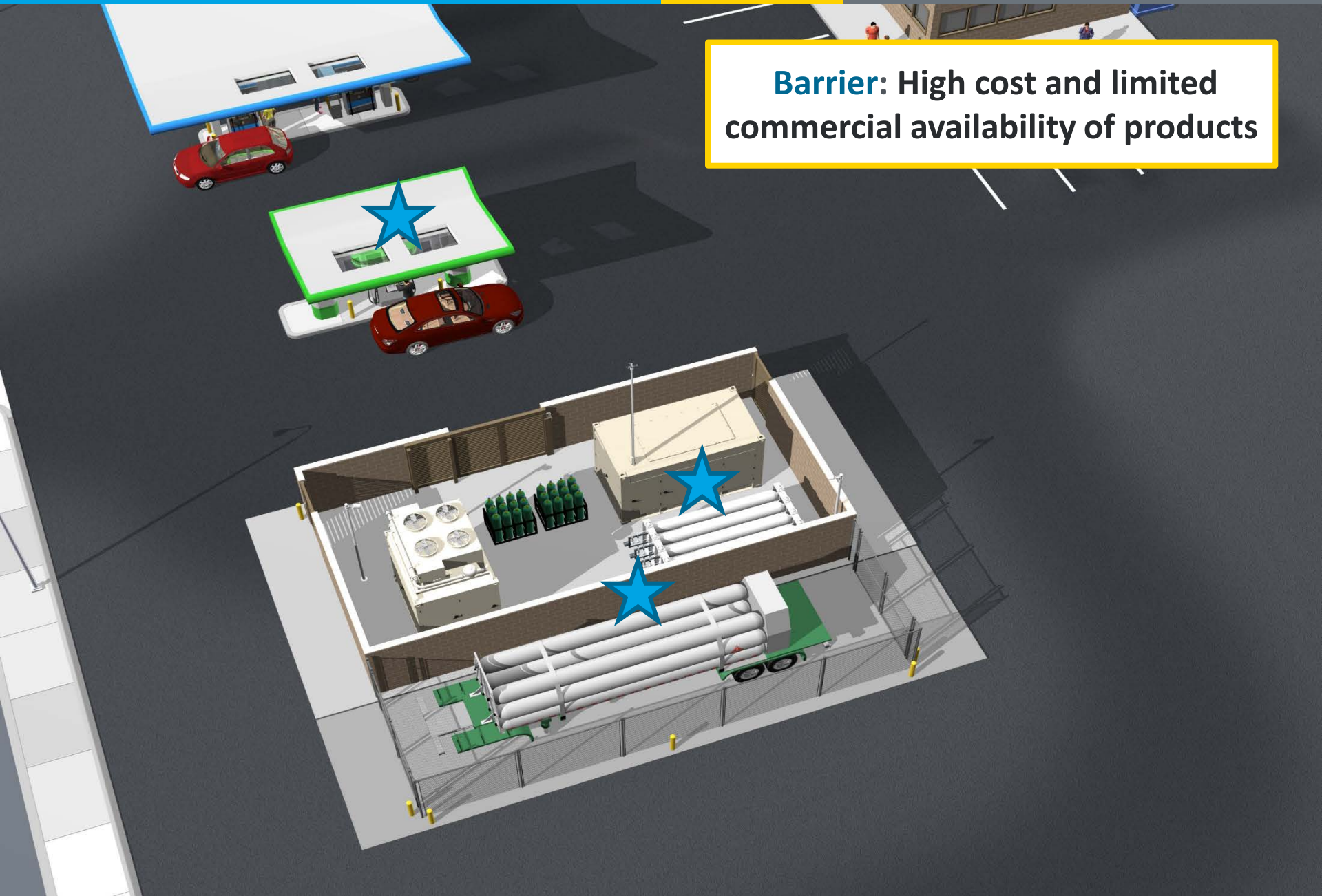


*Image provided by KPA, used with permission*

***Comprehensive knowledge on safety sensor behavior is improving safety for FCEVs, infrastructure, and repair garages; all critical components of broad commercialization of hydrogen technology.***

# Barrier: Fuel Quality Assurance





**Barrier: High cost and limited commercial availability of products**

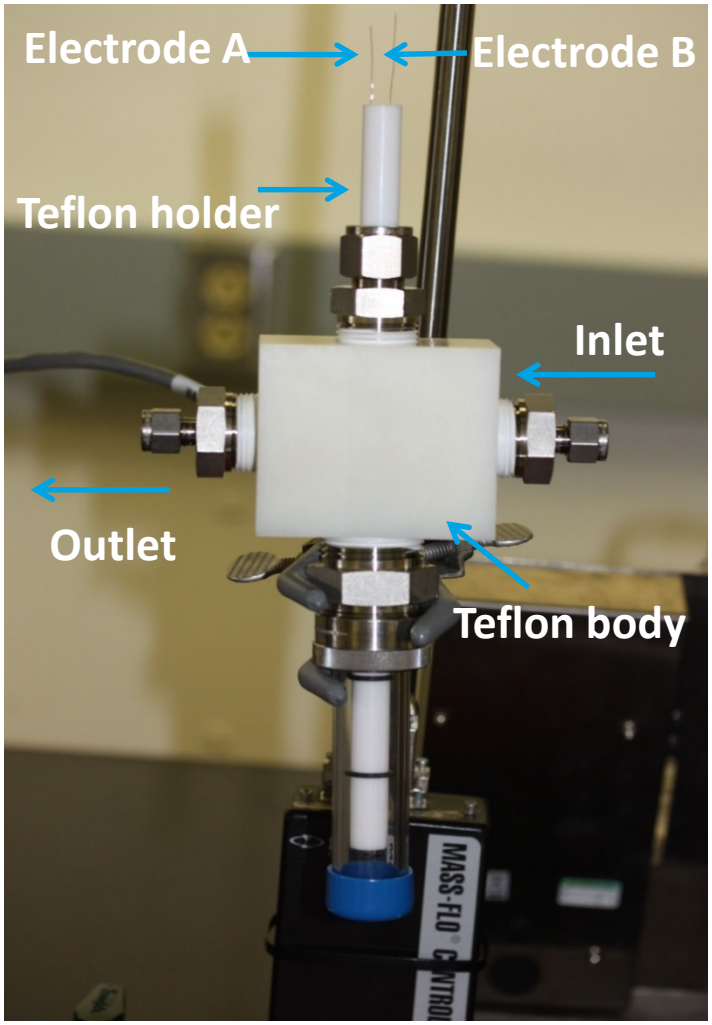
# R&D Accomplishment: Fuel Quality and Fuel Quality Assurance

## Hydrogen Fuel Quality (SCS007)

- Determined that low loaded MEAs are not tolerant to SAE J2719 level of impurities.
- Parametric study of impurities underway to quantify CO and H2S tolerance levels of low loaded MEAs.
- Testing under dynamic conditions including impurity mitigation strategies will ultimately determine the future of fuel quality standards.

## Hydrogen In-Line Analyzer (SCS007)

- **Patent application filed for analyzer prototype.**
- One order of magnitude improvement in baseline
- Dramatic improvement in CO sensitivity (sensitive to < 50 ppb)
- Operation under dry H2 for > 1 month




***A means of detecting contaminants in the hydrogen fuel stream is vital to ensure quality according to SAE J2719 and prevent damage to the fuel cell.***

# R&D Accomplishment: Fuel Quality Assurance

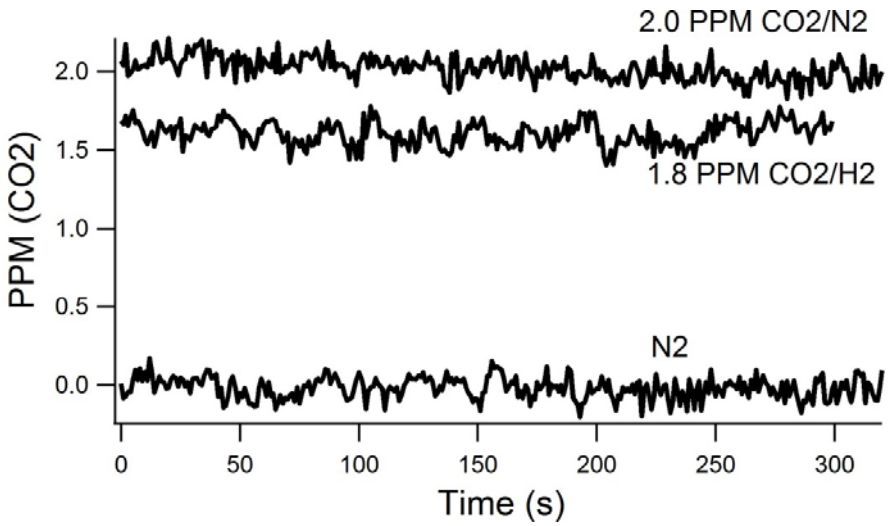
## Leveraging SBIR Program to make impact:

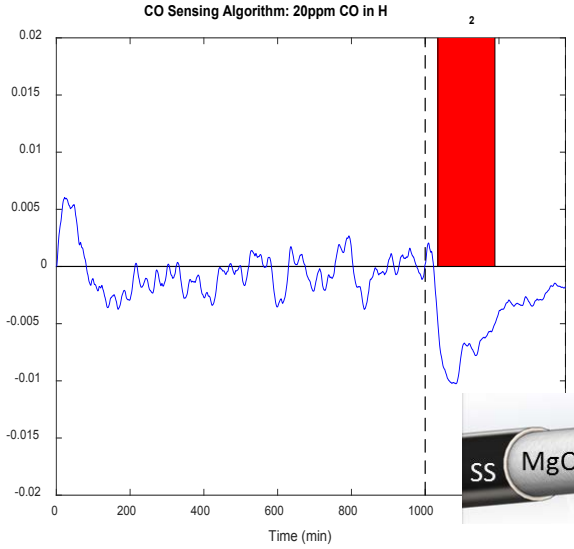
1. **Southwest Science (SCS028): Developing diode laser hydrogen contaminant detector for real-time measurements in fuel station**

- Detection at SAE J2719 levels CO, CO2,CH4, and high levels of S. Expect H2O and NH3 will be demonstrated at better than SAE J2719.

2. **Sustainable Innovations & UCONN (SCS029): Developing electrochemical hydrogen contaminant detector**

- Preliminary design complete, commercially available components, up to 12 sensors in single housing
- Working to achieve improved durability and lifespan through electrolyte modification





***Detecting contaminants in the hydrogen fuel stream is vital to ensure fuel quality according to SAE J2719 and prevent damage to the fuel cell.***

# R&D Accomplishment: Inter-Laboratory Research Integration Group (IRIG)

## IRIG Objectives (SCS001):

- **Enable R&D to positively impact public safety by writing code proposals based on research**
- **Identify areas of research that are needed to support code development based on deployment priorities**
- **Achieve the above objectives through a structured process that utilizes DOE laboratory work**
- **Implement the Codes & Standards Continuous Improvement (CCSI) process**

## IRIG Team/FY17 Objectives

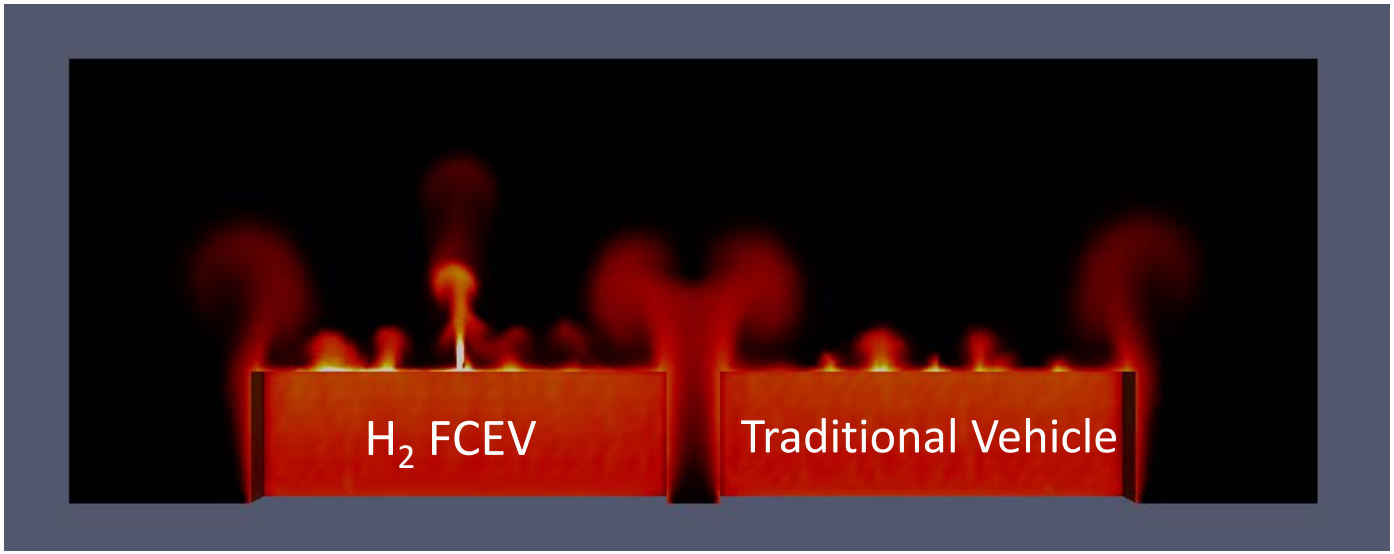
- **Members**: NREL, PNNL, SNL, and LANL
- Submit at least three high impact proposals, potential topics include:
  - NFPA 502: proposal on FCEVs in tunnels
  - NFPA 2: Safe venting for hydrogen stack discharges
  - Component safety (likely hose safety requirements)
  - Multi-fuel stations
  - H2@Scale

***Leveraging DOE research, particularly unused R&D assets, can support major code proposals and enable advances in public safety.***

# Cross-cutting Effort: Tunnel Safety Evaluation

## Tunnel Safety Evaluation Accomplishments (SCS025):

- Developed risk analysis framework and identified scenarios of concern
- Coupled **Computational Fluid Dynamic** (CFD) and **Heat Transfer models** to evaluate hydrogen fire impact on steel structure. Model will evaluate steel strength & potential for explosive spalling of concrete. (one example)
- Work done by SNL with support from NREL and PNNL



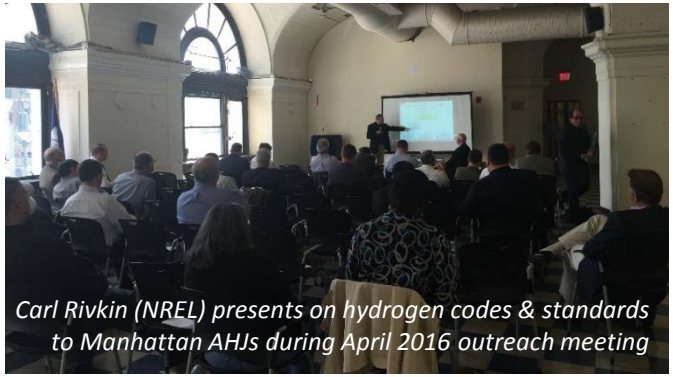

***Risk analysis and modeling results will be communicated to code officials to assist in their decision-making on allowing FCEVs in tunnels.***

# Enabling Safe Deployment: California & the Northeast

## *Safety outreach in both California and Northeast in FY17: Supporting the safe rollout of hydrogen infrastructure (SCS019)*

### Accomplishments:

- **October 2016 – Held meetings in NY (x2), NJ, and MA:**
  - Attendees: Fire marshals, local and state officials, automotive industry and hydrogen developers.
  - Discussed hydrogen station deployment and responded to questions and concerns.



*Carl Rivkin (NREL) presents on hydrogen codes & standards to Manhattan AHJs during April 2016 outreach meeting*

- **March 2017 — Held meetings at 7 California locations:**
  - Attendees: Hydrogen fueling station builders, code officials, and other state officials and stakeholders
  - Discussed safety issues and lessons learned from recent station deployments.
  - Pertinent learnings from the meetings may be added to the Best Safety Practices online resource.


***Safety meetings result in feedback to R&D and code community, helping to ID gaps and improve best practices***

# Enabling Safe Deployment: H2Tools.org

**Objective**: Ensure that best safety practices underlie and inform R&D activities supported through DOE-funded projects (SCS019).

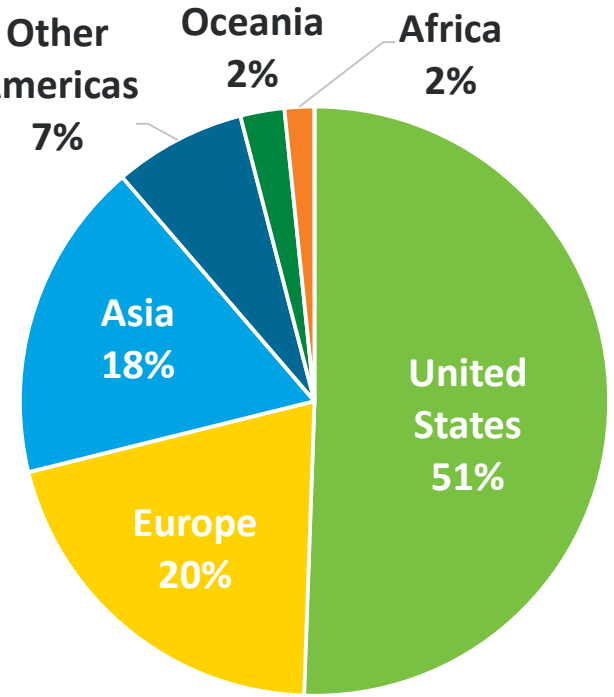
## *Site Content*

- **3,581** Total Pages
- **2,414** Bibliographic References
- **217** Lessons Learned Pages
- **142** Best Safety Practices Pages

## *Usage Stats**

- **135,160** Total Pageviews since 2015
- **23,805** Sessions
- **5.68** Pages Visited per Session
- **7:26** Minutes per Session

## H2Tools.org - A Global Resource!




*Nonbounce statistics through March 31, 2017

***The U.S. is a leader in hydrogen safety; H2Tools.org is a key resource to disseminate safety information***

# Enabling Safe Deployment: FEMP Partnership

**FCTO, PNNL, and NREL + Federal Energy Management Program (FEMP) (SCS019): Provide agencies and organizations with information, tools, and assistance needed to deploy clean energy technologies.**

- PNNL and NREL will collaborate to develop training material and train agencies over a 5 year effort
- Trainings will transition as FCEVs become more widely available in federal fleets.
- **FY17**: Incorporate introductory hydrogen information into FEMP training and outreach material.
  - Will present at the August 2017 Energy Exchange

FEMP Federal Energy Management Program

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

NREL NATIONAL RENEWABLE ENERGY LABORATORY

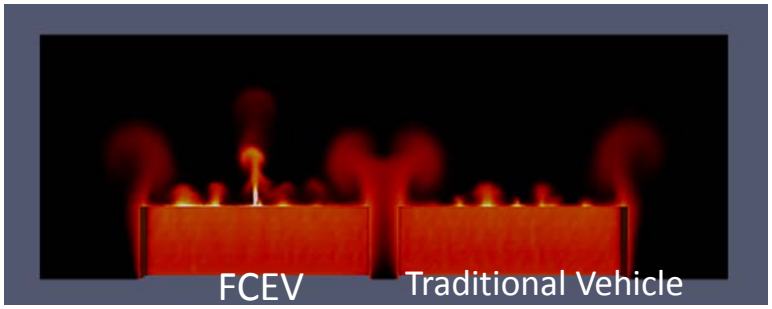
Energy Exchange
Collaborate • Connect • Conserve
An educated approach to resiliency
U.S. Department of Energy Federal Energy Management Program

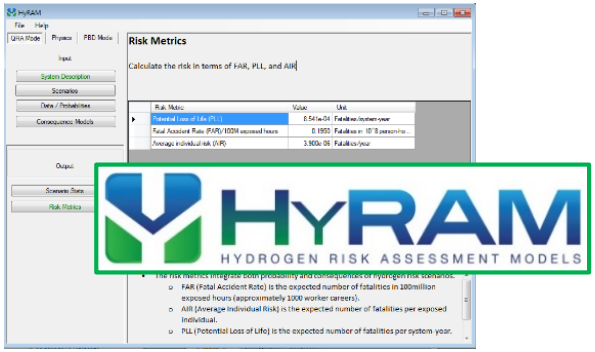
**Note: Any proposed future work is subject to change based on funding levels.**

***As the number of FCEVs on the road continue to increase, it is important to get federal agencies familiar with hydrogen and fuel cell technologies***

# R&D Progress Since AMR 2016

- New techniques measured cryogenic plumes in liquid $H_2$ release laboratory **(SCS 010)**
- Engaged stakeholders for feedback on polymeric materials; identified four of interest and initiated testing and characterization program **(SCS 026)**
- Developed risk analysis framework and identified scenarios of concern for tunnel safety **(SCS 025)**
- Patent application filed for in-line fuel quality analyzer **(SCS 007)**
- HyRAM 1.1 released with new features **(SCS 011)**
- Successfully qualified repair facility sensor for application, facilitating AHJ acceptance **(SCS 021)**




***Continuing to perform critical R&D to enable science-based codes and standards***

# Collaborations

## International

- IPHE - International Partnership for Hydrogen & Fuel Cells in the Economy
  - 18 countries & EC, 30 projects
- International Energy Agency Hydrogen Implementing Agreement (IEA HIA) Task 37
- IA HySAFE
- Independent Projects (EU, Japan, Korea, etc)

## DOE-EERE Safety, Codes and Standards

## Industry Partnerships & Stakeholder Assocations.

- Tech Teams (USCAR, energy companies- U.S. DRIVE) – GM, Ford, DOT, CaFCP, Exxon
- Fuel Cell and Hydrogen Energy Association (FCHEA)
- H2USA
- Various CDOs & SDOs (SAE, NFPA, ISO, CSA, ICC, etc )

**National Collaborations (inter- and intra-agency efforts):**

## State & Regional Partnerships

- **California Fuel Cell Partnership**
- **CT Center for Advanced Technology**
- **Massachusetts Hydrogen Coalition**

## National Laboratories

**Los Alamos**
**NREL**
**Oak Ridge**
**Pacific Northwest**
**Sandia**

## Federal Agencies

**DOT NASA DOE-FEMP**

– Interagency coordination: staff-level Interagency Working Group Assistant Secretary-level Interagency Task Force mandated by EPACT 2005.

# Summary of activities

- Continue to examine cryogenic releases to increase the ability to cite liquid hydrogen stations
- Evaluate metallic materials that could potentially be used in hydrogen service to reduce cost by without sacrificing safety
- Develop better understanding of hydrogen effects in non-metallic materials for hydrogen refueling infrastructure including the development of a publicly available technical reference
- Continue support for the development of a domestic supply chain of safety, codes & standards-related hydrogen and fuel cell components, including a testing and standard committees providing input for critical components
- Outreach to first responders and code officials to support the public acceptance of hydrogen and fuel cell technologies through collaborative partnerships, state, and local initiatives.

**Foundational understanding in science will help enable the safe deployment of hydrogen and fuel cell technologies safely**

# Thank you

**Will James**
**Project Manager**
**202-287-6223**
**charles.james@ee.doe.gov**

Laura Hill
*Project Manager*
202-586-8384
laura.hill@ee.doe.gov

Jay Keller
*Consultant*
925-519-2043
Jay.keller@zces-inc.com

Leah Fisher, *Contractor*
202-586-1646
leah.fisher@ee.doe.gov

**hydrogenandfuelcells.energy.gov**