NREL
NATIONAL RENEWABLE ENERGY LABORATORY

hySafe
INTERNATIONAL ASSOCIATION FOR HYDROGEN SAFETY

HySafe Research Priorities Workshop
Materials Compatibility/Components

Rob Burgess, Arlen Kostival, Matt Post, Bill Buttner, Carl Rivkin

November 11th, 2014

Materials Compatibility/Components Scope

Objective: To highlight hydrogen component R&D gaps and outline activities needed to support component safety/reliability system deployment

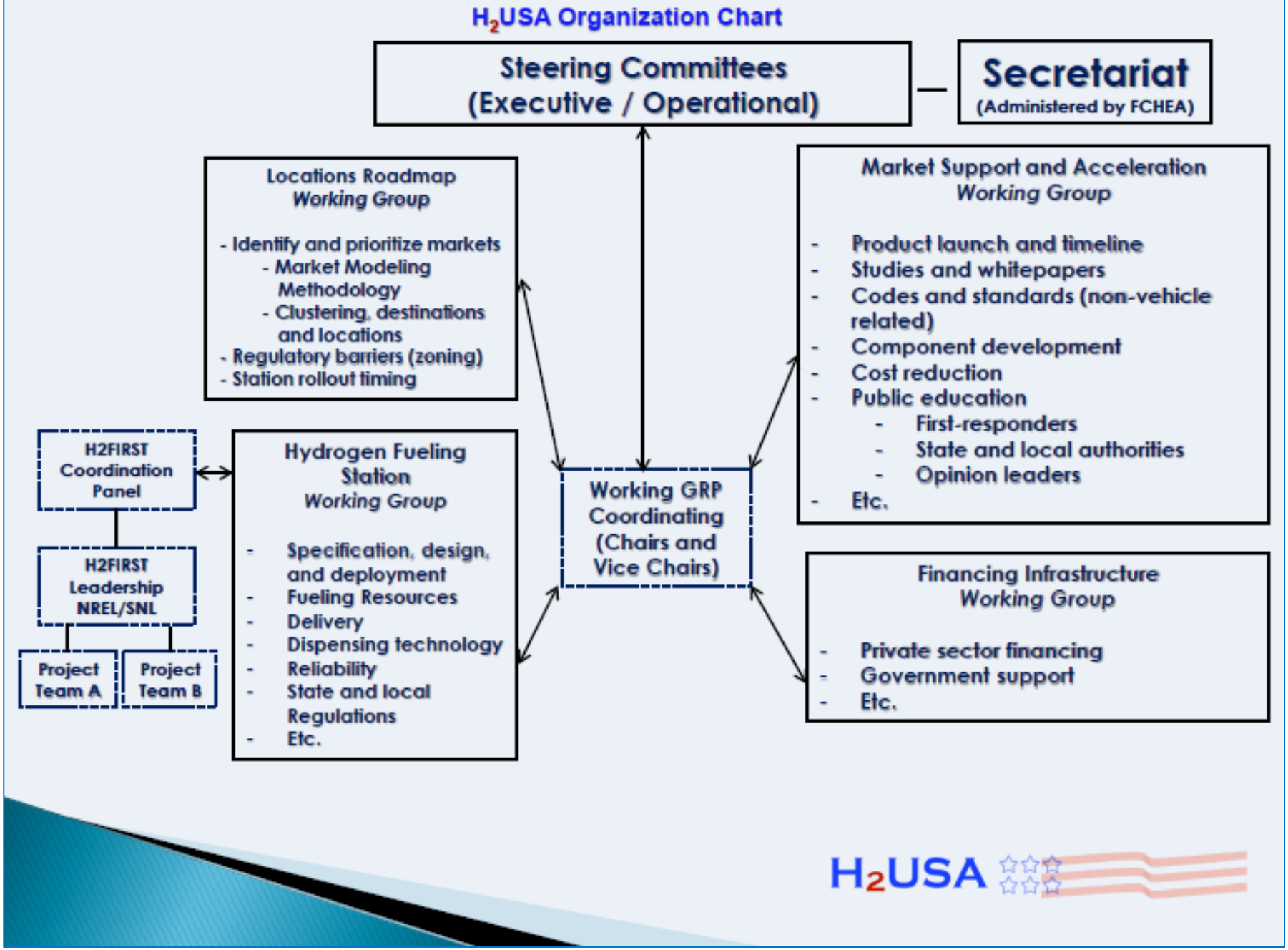
- H2USA/H2FIRST Organizations
- National Lab Activities
- Component Supplier Perspective
- R&D Gaps/Future direction

Component/Deployment Activities
H2USA
H2FIRST

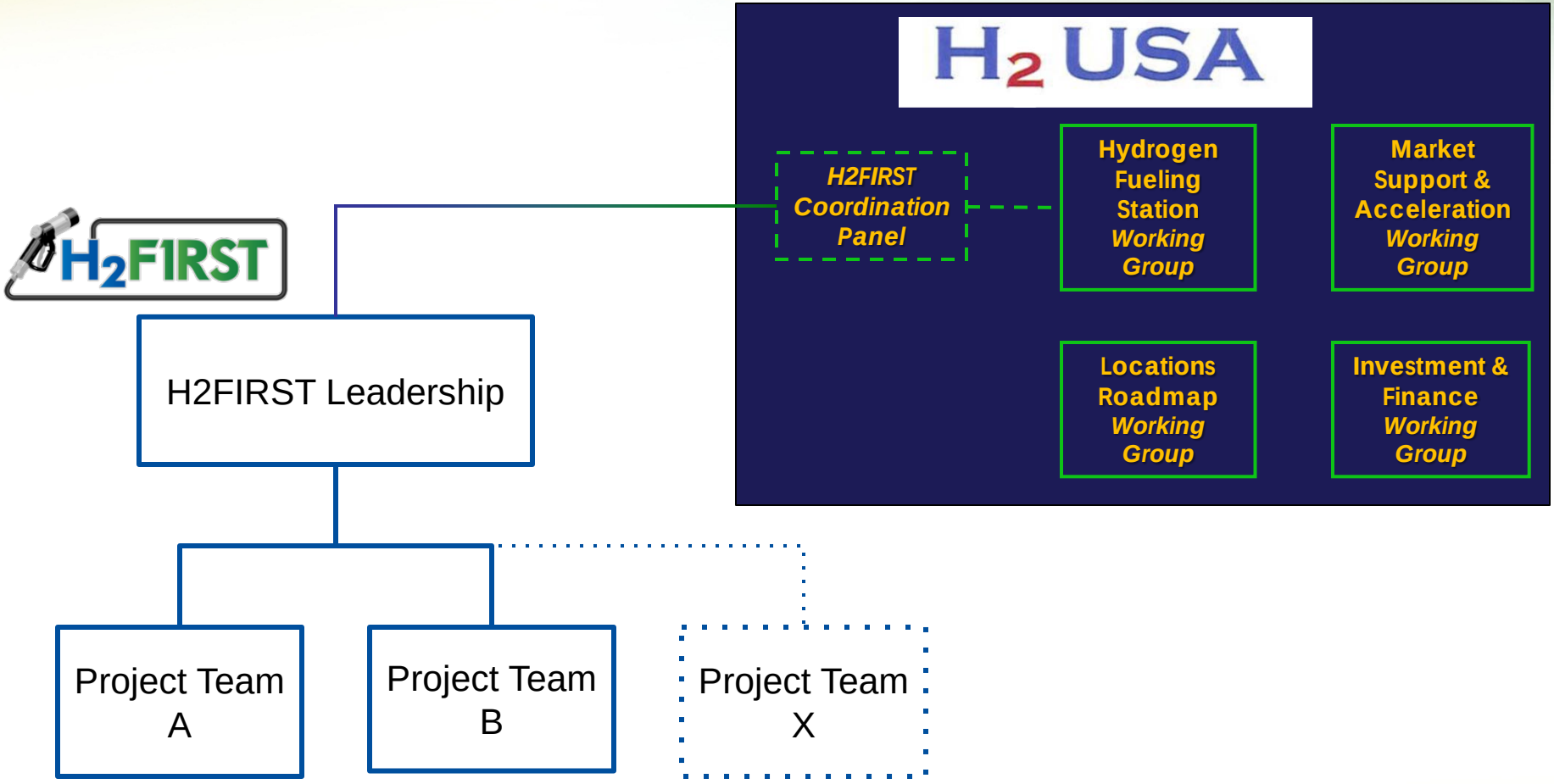
H_2USA
Mission Statement

The mission of H_2 USA is to promote the commercial introduction and widespread adoption of FCEVs across America through creation of a public-private collaboration to overcome the hurdle of establishing hydrogen infrastructure.

H_2USA Organization Chart



H2FIRST supports H2USA and is integrated with the Stations Working Group



H2FIRST Mission

- **Mission: Ensure fuel cell vehicle customers have a positive fueling experience relative to conventional gasoline/diesel stations as vehicles are rolled out in the near term and transition to advanced fueling technology beyond 2017.**
- The success of FCEVs relies largely upon a positive user experience (their first experience), which depends on fueling infrastructure performance, availability, and reliability issues.

Commercial FCEVs Launch ~2014-2015

CA.GOV The California ENERGY COMMISSION — News Release

For Immediate Release: May 1, 2014
Media Contact: Teresa Schilling - 916-654-4989

California Investing Nearly $50 Million in Hydrogen Refueling Stations

Accelerates construction of 28 new stations and one mobile refueler to boost statewide public network

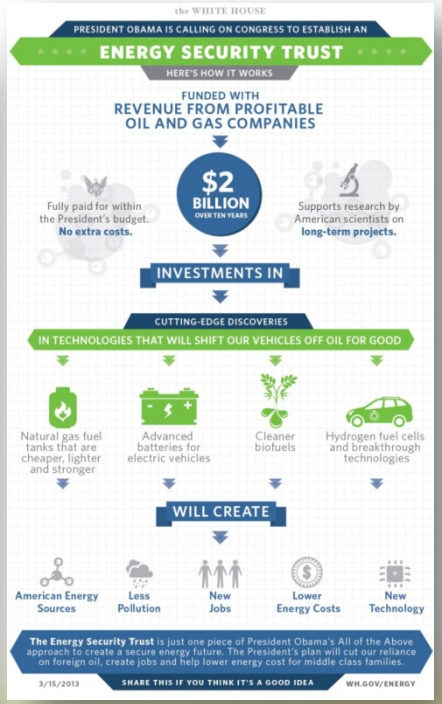
SACRAMENTO - The California Energy Commission today announced it will invest $46.6 million to accelerate the development of publicly accessible hydrogen refueling stations in California in order to promote a consumer market for zero-emission fuel cell vehicles.

The recommended funding awards to eight different applicants were made through the Energy Commission's Alternative and Renewable Fuel and Vehicle Technology Program (ARFVTP). The recommended awards include six 100 percent renewable hydrogen refueling stations and will add 13 new locations in Northern California and 15 in Southern California, strategically located to create a refueling network along major corridors and in regional centers. The mobile refueler will provide added reliability to the early hydrogen refueling network to provide refueling capability when stations are off-line.

"Transitioning to low- and zero-emission vehicles is critical to meeting air quality goals and to reducing the emissions that lead to climate change," said Energy Commissioner Janea A. Scott. "With this funding, California will accelerate the construction of a reliable and affordable refueling infrastructure to support the commercial market launch of hydrogen fuel cell vehicles."

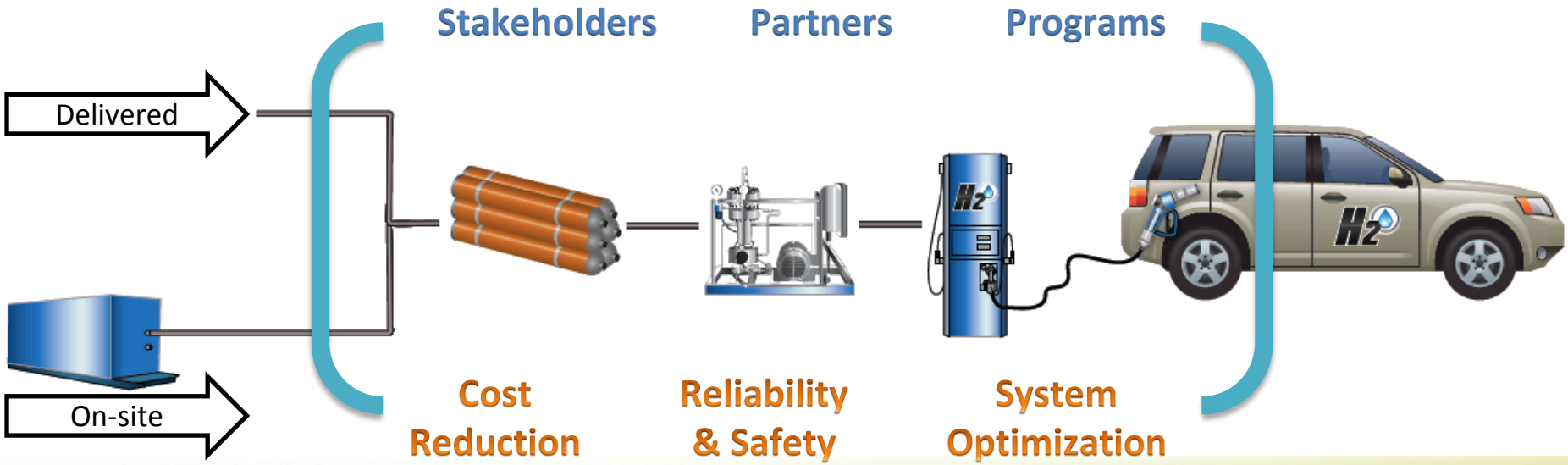
The recommended awards will advance Gov. Brown's executive order directing state government to support and facilitate the rapid commercialization of zero-emission vehicles (ZEVs) in California, with a benchmark that by 2020 "the State's zero-emission vehicle infrastructure will be able to support up to one million vehicles."

Today's recommended awards will add 28 new stations to 9 existing and the 17 stations currently under development. These 54 hydrogen refueling stations represent significant progress towards meeting California's goal of establishing a 100-station network to support the full commercialization of fuel cell vehicles in California.



Approach

- Identify "high probability for success opportunities" for timely advancement of near-term fueling stations.
- Identify and develop common laboratory capabilities that can serve many purposes for advancing hydrogen fueling technologies.
- Ensure relevance of activities through appropriate industry engagement.



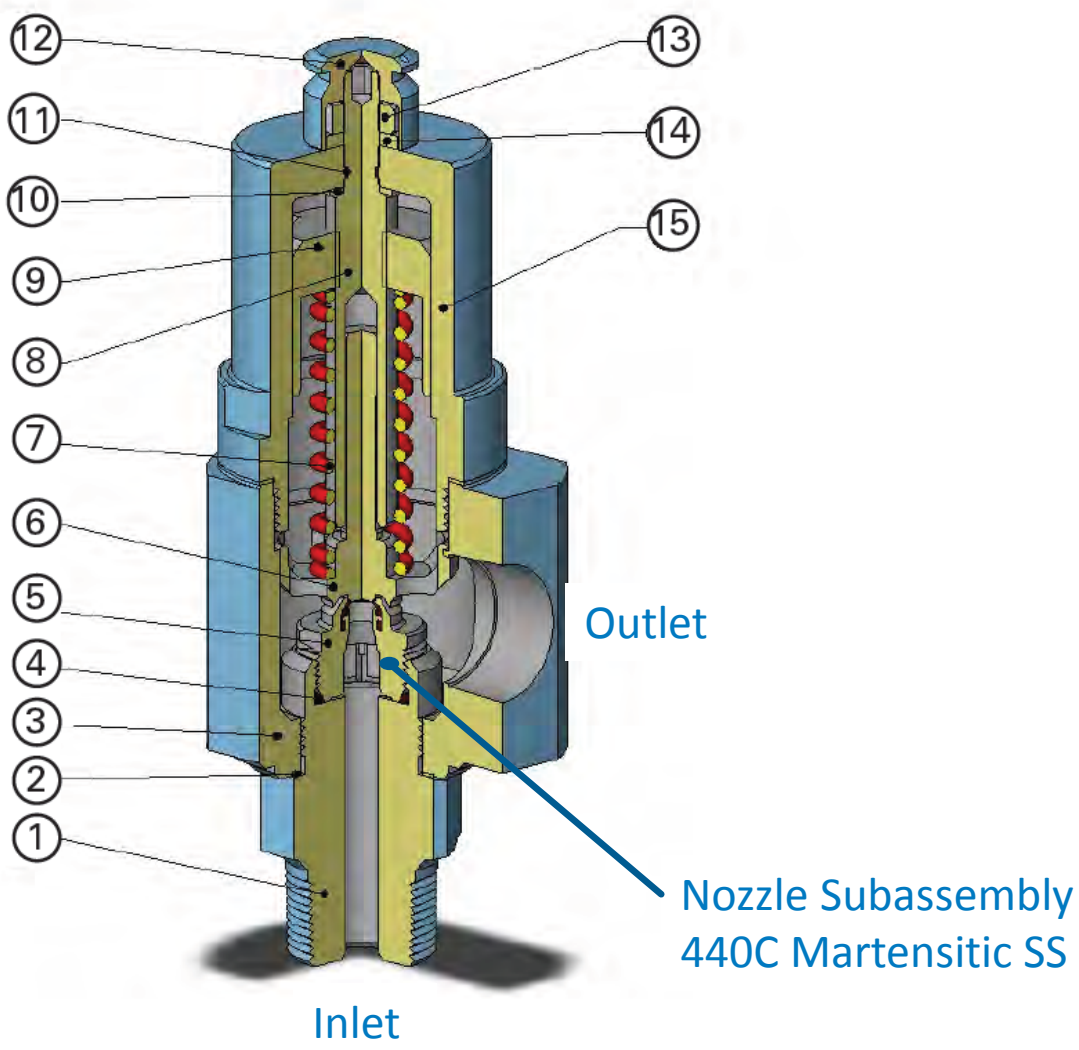
DOE National Laboratory Role in Hydrogen Component Development

National Laboratory role in Hydrogen Component Safety

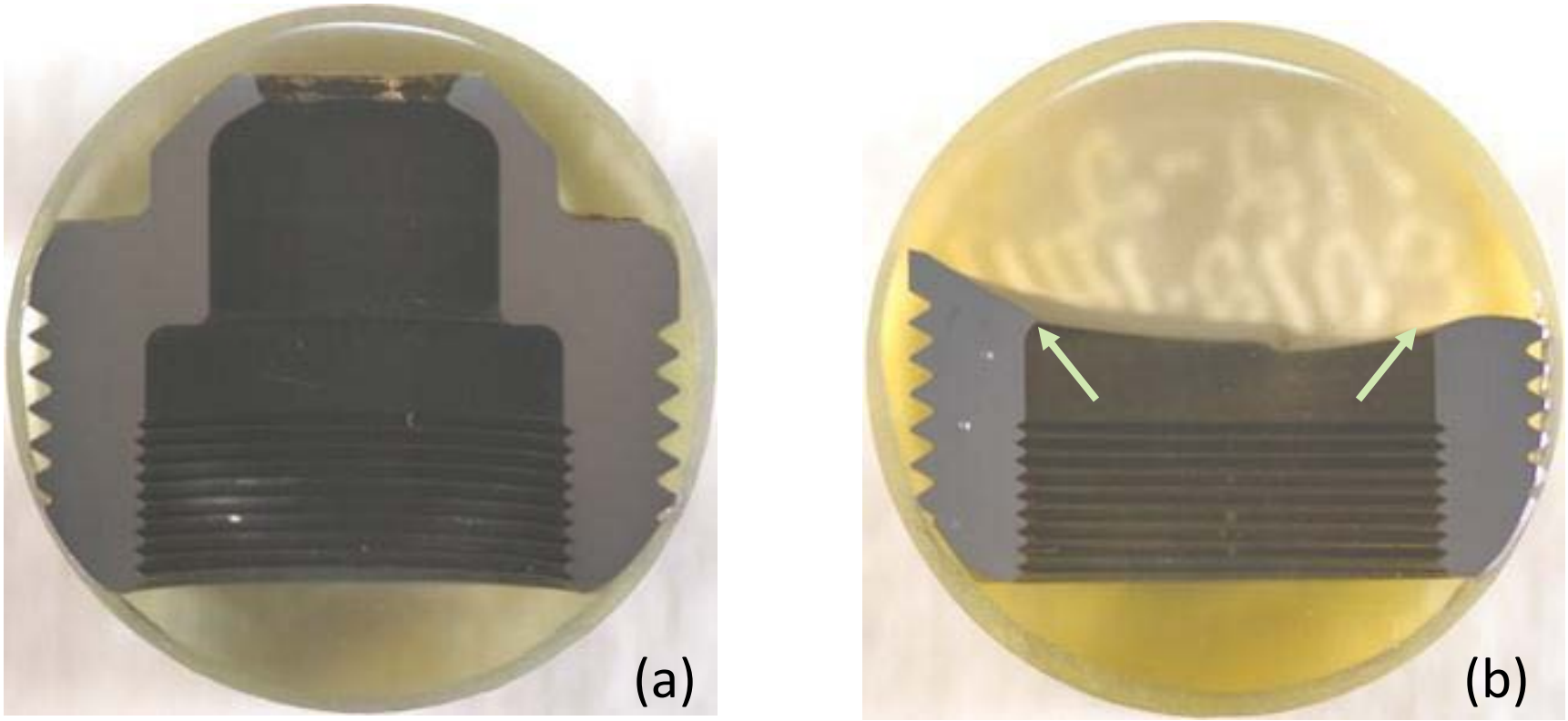
- **Provide R&D support to industry**
  - Testing and analysis of components and systems
- **Collaborations such as HSUSA and H2FIRST provide framework for component safety efforts**
- **Gain understanding of known failure modes**
- **Work with codes and standards organizations to provide technical basis for requirements**
- **Outreach activities include workshops, presentations and publications**

Hydrogen Relief Valve Safety/Reliability Test

- **Pressure relief valve**
- **High strength nozzle inlet sub assembly**



Known Failure (relief valve)



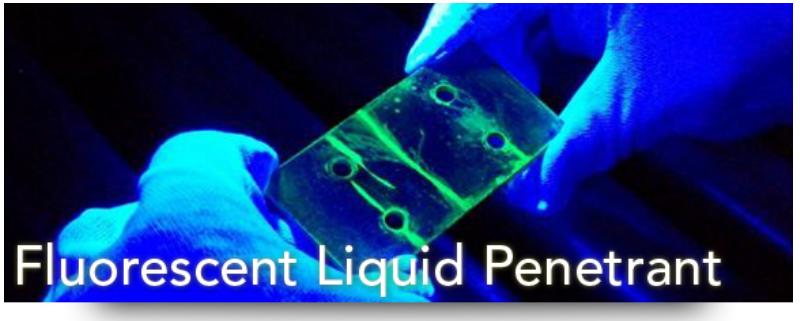
Polished cross sections of (a) functioning nozzle and (b) failed nozzle 440C martensitic material. The arrows indicate the internal corner associated with failure of the nozzle.

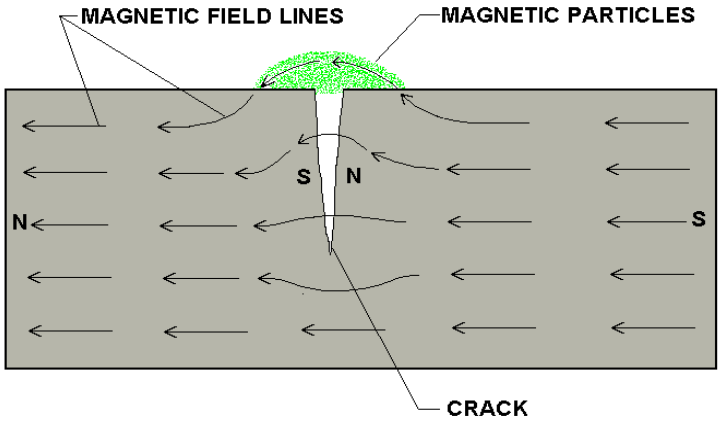
Source: *Sandia report SAND2012-5170*

PRD Inspection/Evaluation

Collaboration with Colorado School of Mines Metallurgy Lab

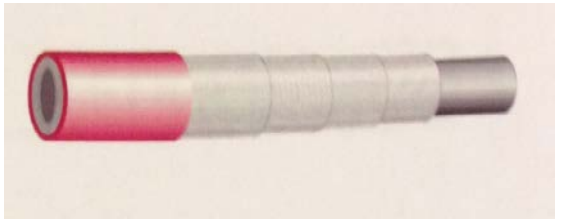
- Regular inspection of samples for crack growth and propagation using:
  - Dye Penetrant Inspection
    - Use penetrating UV reactive liquid to inspect part for cracks
  - Ultrasonic (Pulse-Echo) Inspection
    - Use high frequency sound waves to map internal structure of component
  - Magnetic Particle Inspections
    - Similar to dye penetrant, but magnetic field is applied to part and fluorescent iron filings are used to indicate surface/subsurface cracks



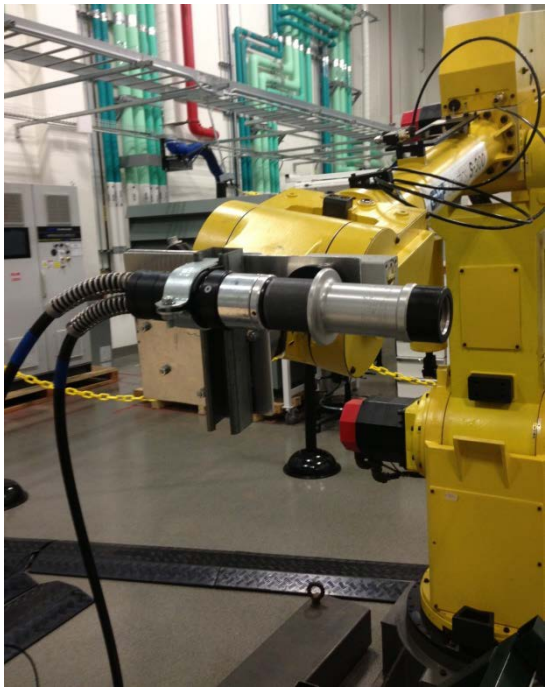


Dispensing Hose Testing

- Working closely with the original equipment manufacturer, Spir Star, NREL's hose reliability R&D project aims to improve the reliability and reduce the cost of 700 bar hydrogen refueling hose assemblies.

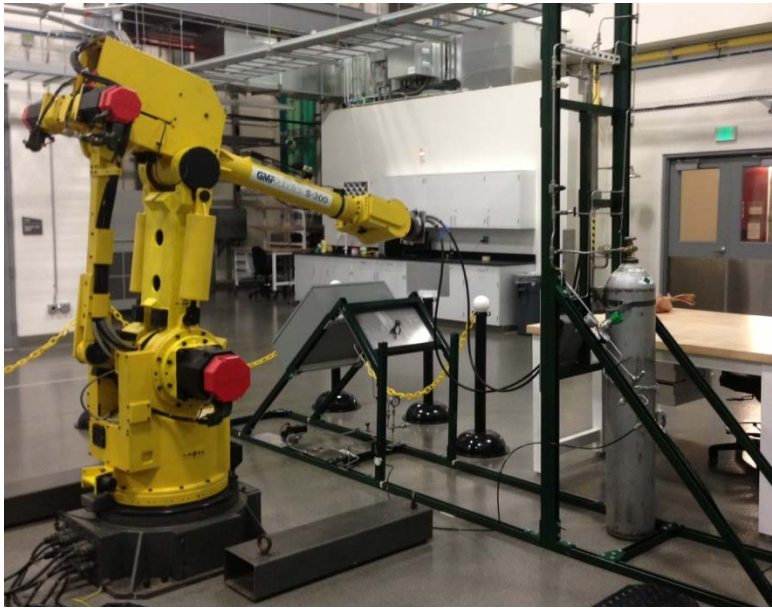


- Unifying the four stresses (Pressure, Temperature, Mechanical and Time) in one high-cycling autonomous test apparatus is expected to reveal the compounding impacts of high volume 700 bar fuel cell electric vehicle refueling that has yet to be experienced in today's low-volume market.



Approach

- The approach includes performing chemical and physical analysis on hose material before and after testing to understand the relative changes in its bulk properties and material degradation mechanism.



- Long-duration accelerated life testing in hydrogen is accomplished autonomously to simultaneously stress the hose assembly with realistic fueling protocols (pressure, time, temperature) and the mechanical stress applied to hose during the process of connecting and disconnecting the hose to the vehicle during the fueling event.

Component Supplier Perspective

Component Design for Hydrogen Service

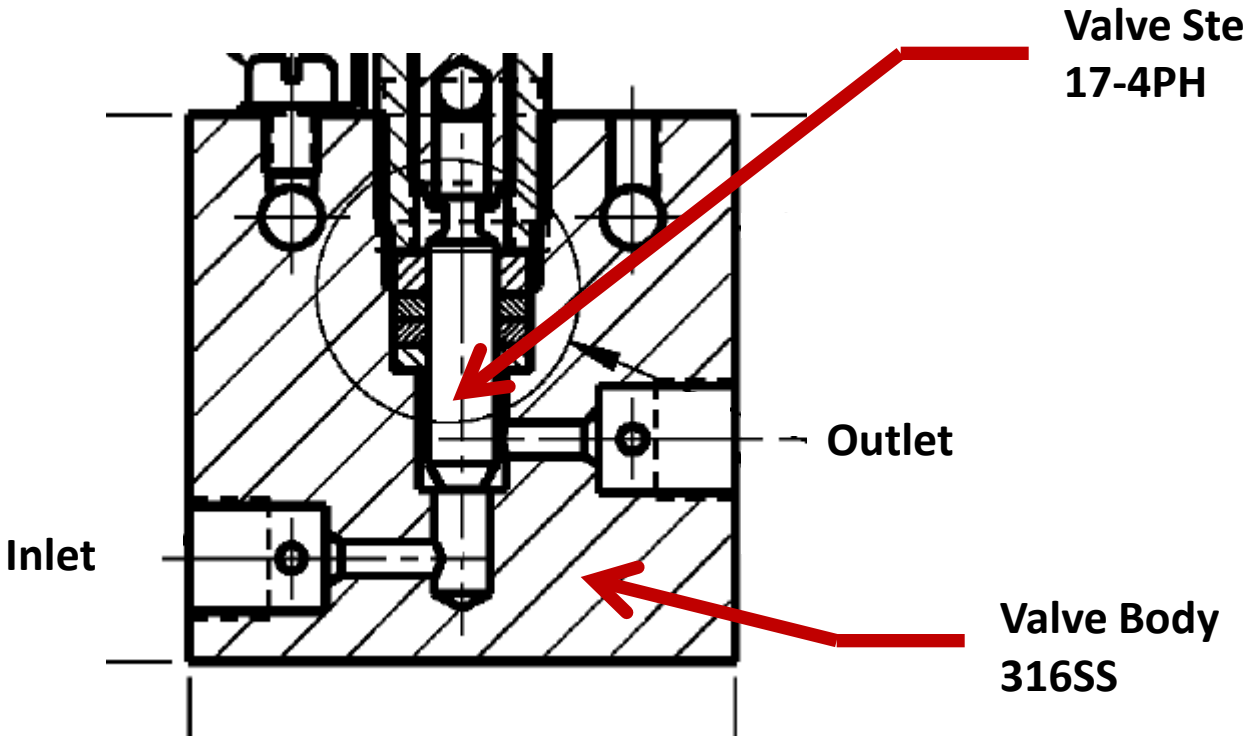
- Material selection for compatibility
  - 316L
  - 6061
  - Others (RRA acceptance criteria)
- Added NDE inspection criteria
  - Flaw size criteria
- De-rate specified pressure
  - Reduced stress
- Reduced lifetime rating
  - Fatigue life criteria

Brittle material design considerations

- **Brittle materials are used for properties such as strength, conductivity, optics, hardness etc.**
- **Understanding hydrogen effects on materials**
  - Sandia National Lab: Technical Reference for Hydrogen Compatibility of Materials, source: http://www.sandia.gov/matlsTechRef/
- **Design factors for brittle materials**
  - Compressive loading will suppress crack growth
    - No tensile loading or residual tensile load
  - Non pressure bearing structure
  - Manufacturing quality control
  - Understanding failure modes and effects

NREL facility pneumatically operated valve

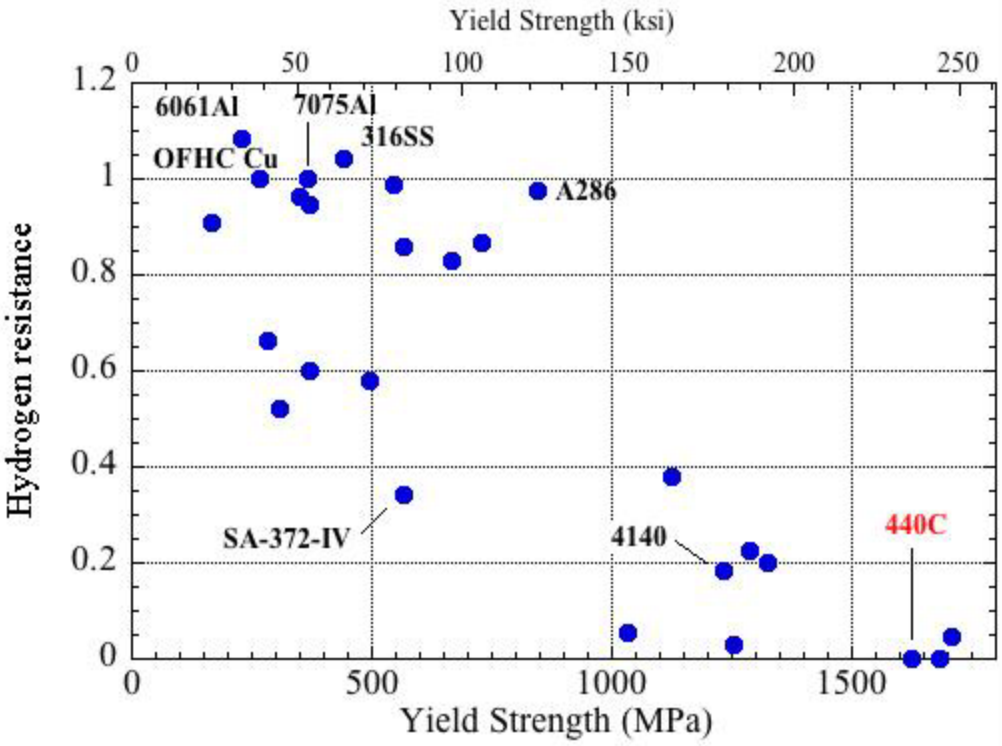
Needle valve design is used in NREL's Energy Systems Integration Facility (ESIF) for vent system remote operation



High strength 17-4PH stem material is seating against dissimilar 316SS for reliable sealing surface

R&D Gaps/Future Plans

Hydrogen Effect on Ductility (reduction in area)



Hydrogen susceptibility as a function of yield strength for a range of structural alloys. The susceptibility is the ratio of reduction of area in a tensile test measured in gaseous hydrogen at pressure of 69 MPa relative to measurement in helium at the same pressure.

Source: All data from Rocketdyne compiled by Sandia National Laboratories

Codes and Standards Progress

- **Codes/Standards**
  - ASME KD-10
    - Special requirements for fracture resistance of all-steel vessels in Section VIII, Division 3
  - CSA CHMC1
    - Test Method for Evaluating Material Compatibility in Compressed Hydrogen Applications
  - SAE J2579 Appendix guidance
    - Approved materials – 316L, 6061 etc.
    - Certify material per CHMC1 testing
    - Complete component level cycle test
- **Component test results will be used as basis for improved codes and standards**

Component R&D Gaps

- Design challenges
  - 70MPa
  - -40˚C Precooled
  - Fuel quality
- Material selection
  - Codes and Standards
  - Sandia Data
  - Fracture mechanics approach
- Quality control – quality assurance
  - NDE inspection criteria - acceptable flaw size
- Stress analysis
  - Residual stress
  - Crack initiation
- Reduced lifetime rating
  - Fatigue life criteria
- International collaboration on component R&D
  - JRC-IET, BAM, HyTREC, Others

Future Plans

- **Work with component suppliers to provide technical support for new high pressure hydrogen components**
- **Component test projects (PRD's, Hoses, Sensors, Nozzles, Receptacles, Meters)**
- **DOE/NREL - Utilize new ESIF (Energy Systems Integration Facility) user facility to support infrastructure R&D needs**
  - Energy Systems Integration Lab
  - High Pressure Test Cells
  - Sensor Test Lab
  - 70 MPa fueling
- **Coordinate with H2FIRST and H2USA**
- **International collaboration**


NREL
NATIONAL RENEWABLE ENERGY LABORATORY
Thank You