# Safety, Codes and Standards (SCS) Research & Development

**Chris LaFleur**
Sandia National Laboratories
January 24, 2017

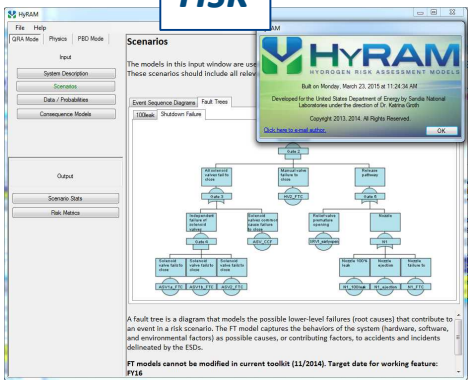
SAND2017-XXXX

# Sandia National Laboratories maintains a diverse portfolio of hydrogen capabilities and facilities

- Hydrogen Infrastructure
  - ***H2FIRST*** (Hydrogen Fueling Infrastructure Research and Station Technology) – joint with NREL
- Hydrogen Storage
  - ***HyMARC***
- Safety, Codes and Standards
  - Hydrogen behavior studies and quantitative risk assessment (QRA)
  - Hydrogen compatibility of materials and components
- Hydrogen Production
  - Solar thermochemical hydrogen production (STCH)
- Systems Engineering
  - Innovative clean energy technologies, including maritime applications
- Fuel cells
  - Advanced alkaline exchange membranes

# Making science accessible through integrated tools

## *risk*




***Develop integrated methods and algorithms***

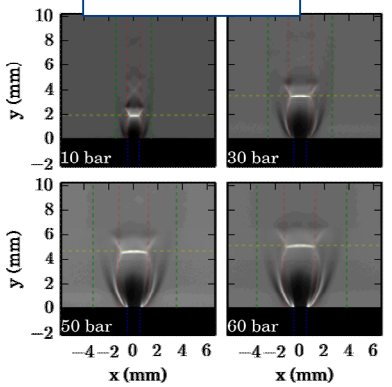
for enabling consistent, logical and defensible QRA

## *application*


***Apply quantitative risk assessment techniques***

in real hydrogen infrastructure and emerging technology

## *behavior*



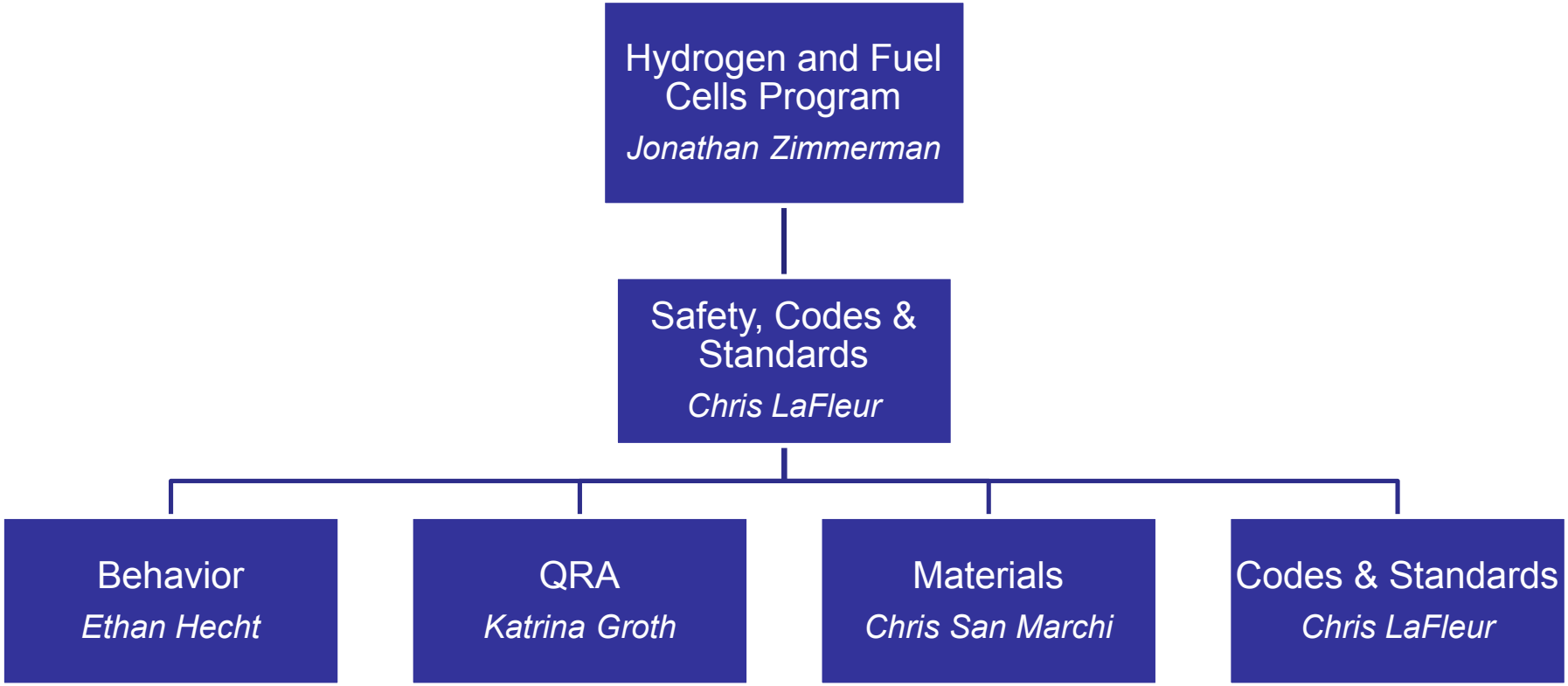

***Develop and validate scientific models***

to accurately predict hazards and harm from liquid releases, flames, etc.

HyRAM
HYDROGEN RISK ASSESSMENT MODELS

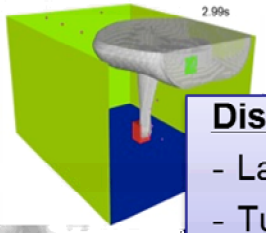
hyram.sandia.gov

# Safety, Codes and Standards Program at Sandia



# R&D for Hydrogen Safety, Codes and Standards

## Hydrogen Behavior



**Physics (deterministic)**

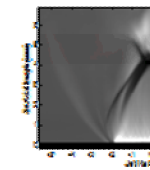
**Dispersion Characteristics**
- Laminar Flow
- Turbulent jet
- Volumetric rupture
- Enclosure Accumulation

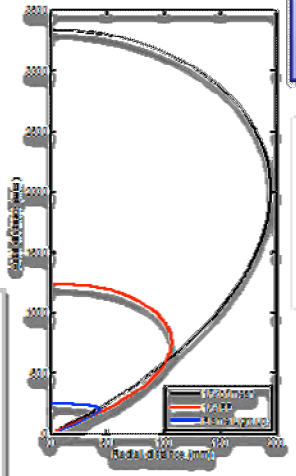
**Probability**

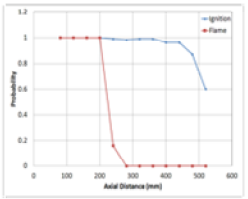
**Ignition Probability**
- Ignition mechanism
- Mixture ignitability
- Ignition delay/location
- Sustained light-up

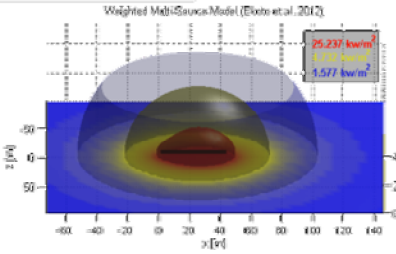
**Consequence (deterministic)**

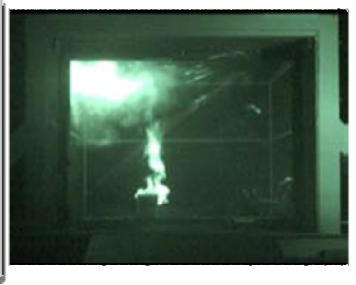
**Hazard Characteristics**
- Flame radiation
- Overpressure (deflagration/detonation)
- $O_2$ dilution/depletion

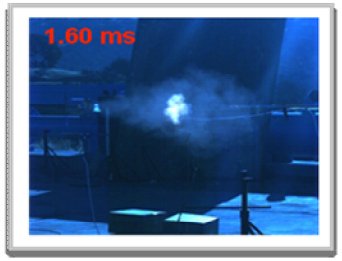






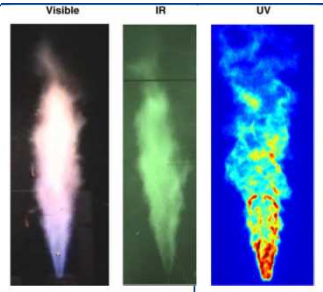






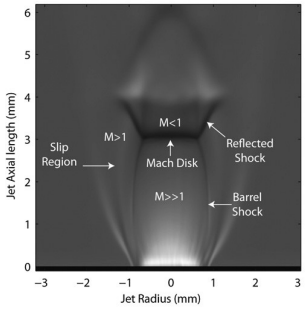
# *Hydrogen Behavior* studies enable predictive capabilities

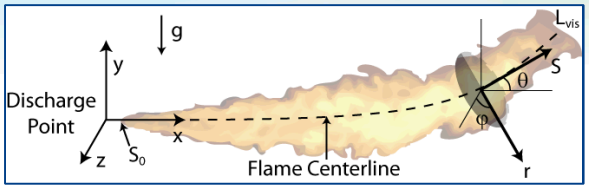
**Radiative properties of H2 flames quantified**




**Barrier walls for risk reduction**

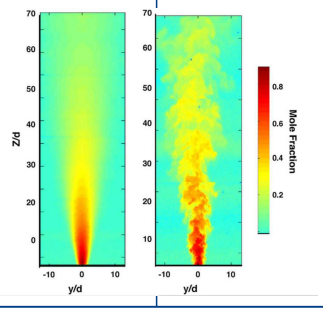
**Ignition of under-expanded H2 jets**



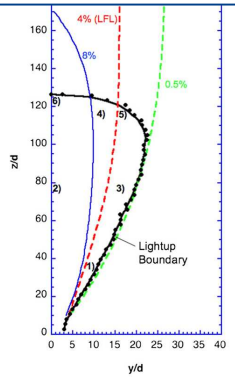

**Buoyant jet flame model with multi-source radiation**

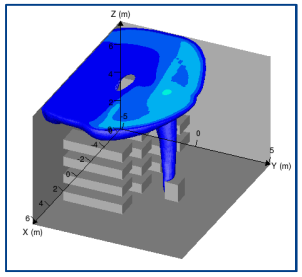
**2005 2007 2009 2011 2013 2015 2017**




**Advanced laser diagnostics applied to turbulent H2 combustion**

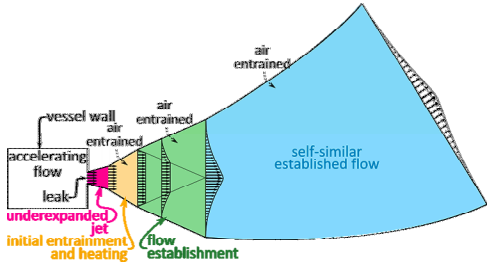
**Ignition limits of turbulent H2 flows**



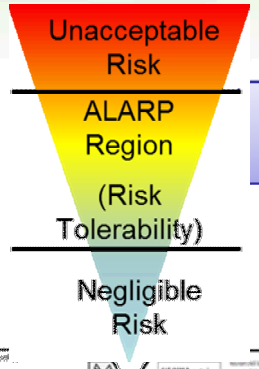

**Experiment and simulation of indoor H2 releases**

**Laboratory-scale characterization of LH2 plumes and jets**



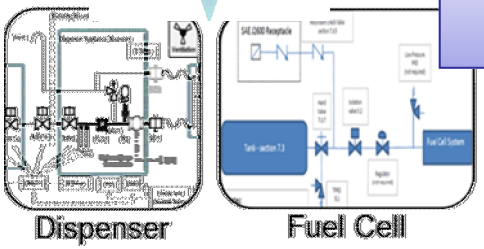
# R&D for Hydrogen Safety, Codes and Standards

## Quantitative Risk Assessment (QRA)

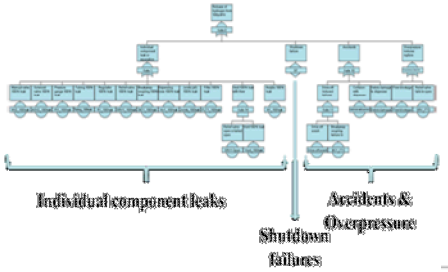



1. Set analysis goals

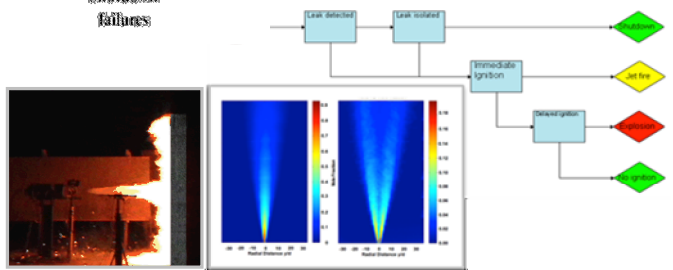
2. System & hazard description

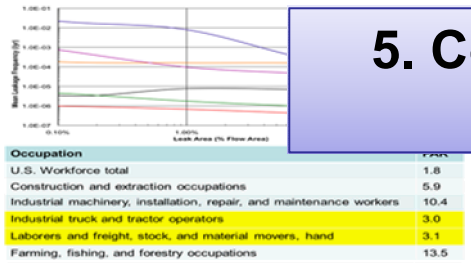



3. Cause analysis




4. Consequence analysis



| Occupation | FAR |
|---|---|
| U.S. Workforce total | 1.8 |
| Construction and extraction occupations | 5.9 |
| Industrial machinery, installation, repair, and maintenance workers | 10.4 |
| Industrial truck and tractor operators | 3.0 |
| Laborers and freight, stock, and material movers, hand | 3.1 |
| Farming, fishing, and forestry occupations | 13.5 |

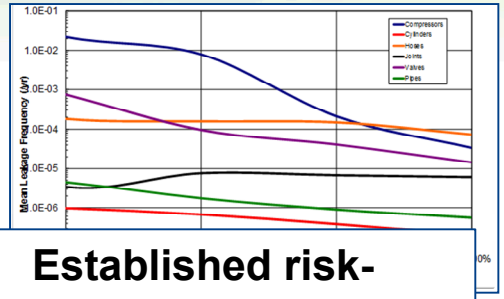
5. Communicate Results

QRA Process

Sandia National Laboratories

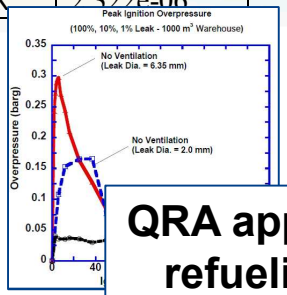
$H_2$FC Hydrogen and Fuel Cells Program

# *Quantitative Risk Assessment* is enabling infrastructure deployment



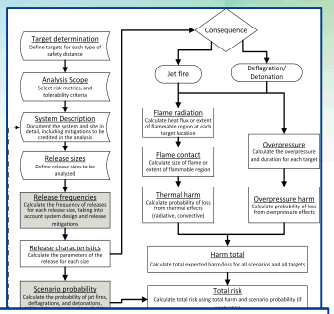

Established risk-informed processes for separation distances

| | |
|---|---|
| PLL | 5.084e-04 |
| FAR | 0.1161 |
| AIR | 2.322e-06 |




QRA applied to indoor refueling to inform code revision

Performance-based system layout demonstrated



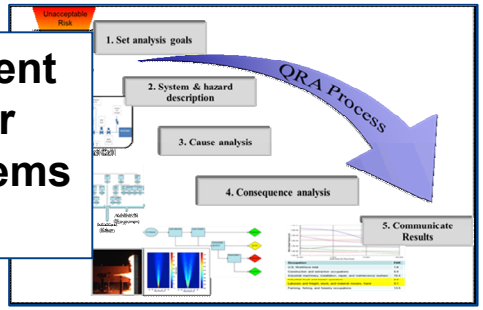

ISO TC197 WG24 incorporating QRA and behavior modeling

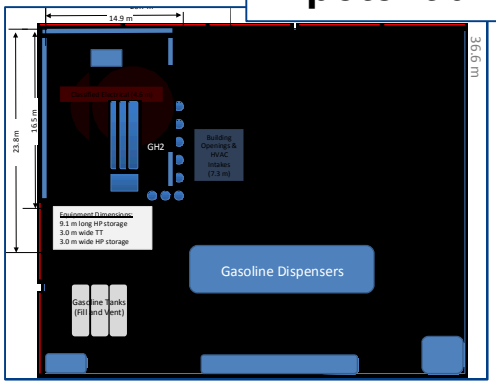
2005 2007 2009 2011 2013 2015 2017

QRA-informed separation distances in NFPA 2

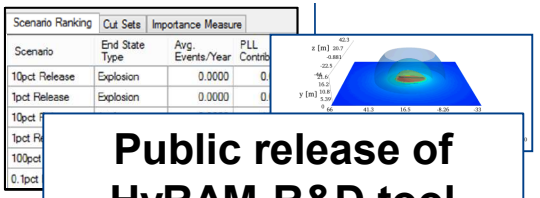
20% station penetration potential due to QRA

Risk assessment proposed for hydrogen systems at ICHS



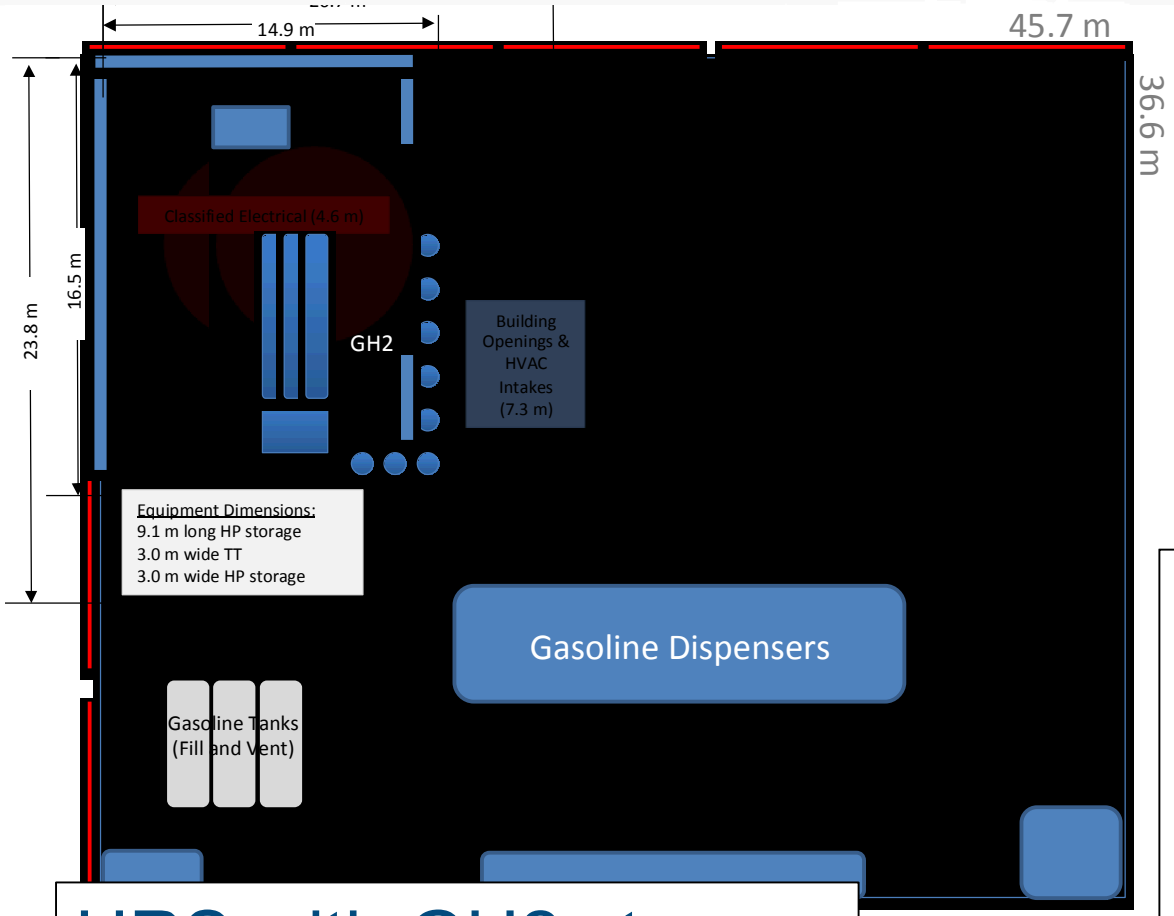




HyRAM
HYDROGEN RISK ASSESSMENT MODELS

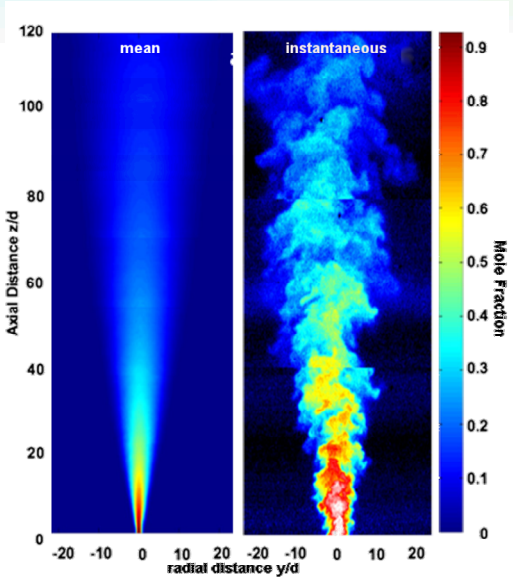



Public release of HyRAM R&D tool

# Science-based codes and standards provide a reasonable and rationale approach to safety




HRS with GH2 storage



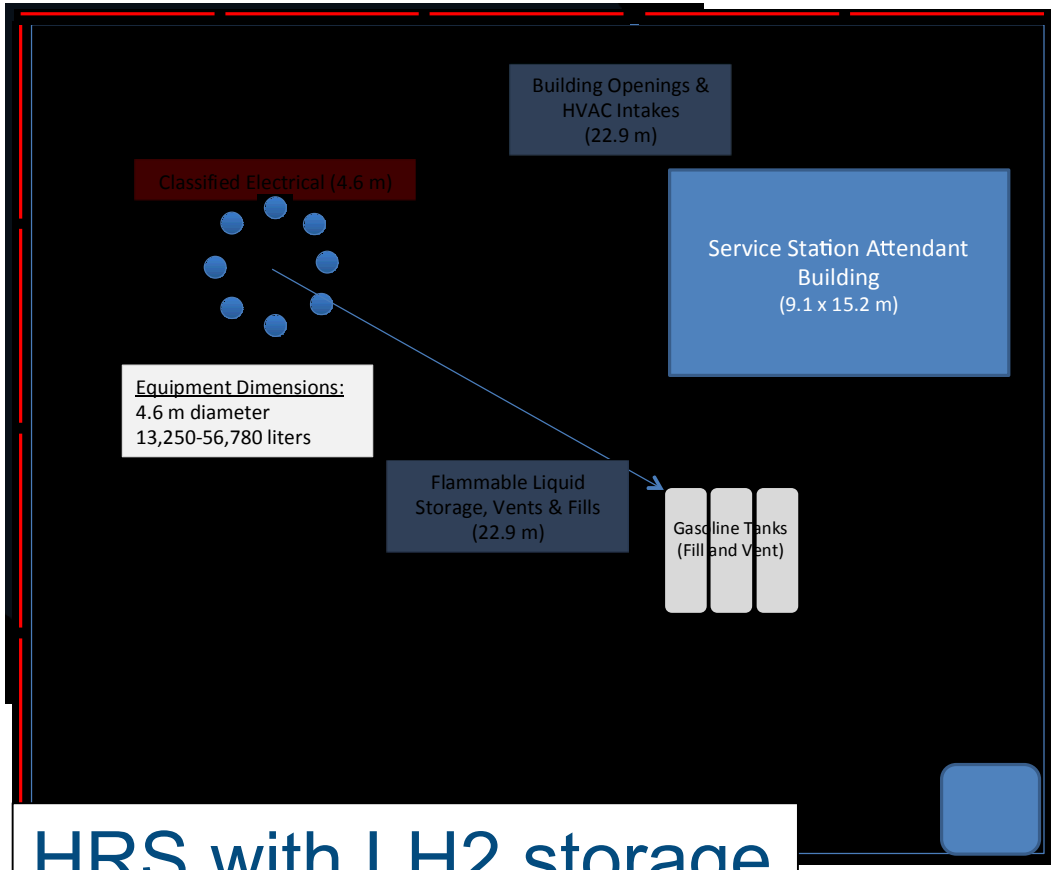

***Impact of science on fire codes and technology deployment*:**

- Potential HRS sites increased from zero to 20% of existing gasoline stations

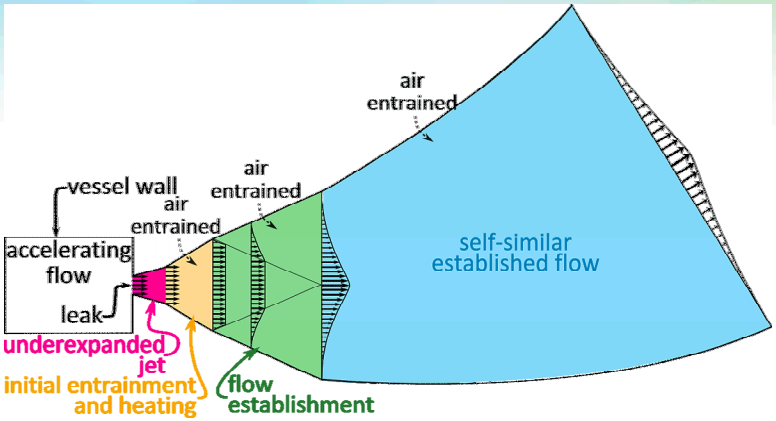
Harris et al. SAND2014-3416

# Liquid is the preferred method of delivering large quantities of hydrogen

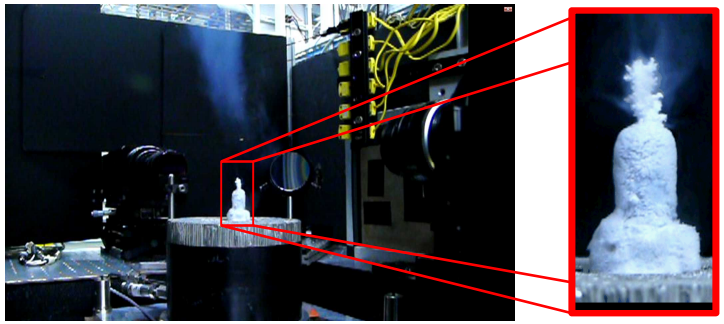
Temperature of LH2 = 20K (-253˚C)




HRS with LH2 storage

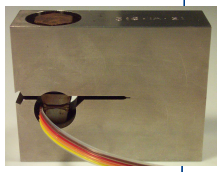



**Laboratory experiments and validated models of cryogenic hydrogen releases inform safety requirements for LH2 storage**



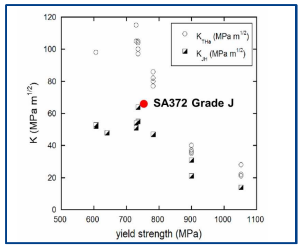
# Evaluation of *Materials Compatibility* enables innovative technologies

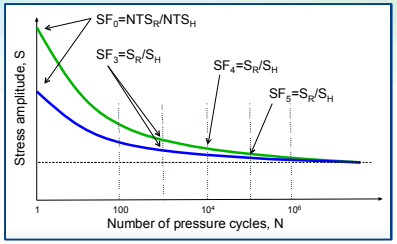
**ASME article KD-10 input on test methodology**



**Platform for matls testing in GH2 at high pressure**

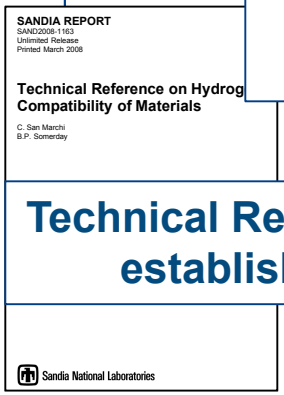
**Critical assessment of statically loaded cracks**




**CSA CHMC1 test methods and matls qualification**

**2005 2007 2009 2011 2013 2015 2017**


SANDIA REPORT
SAND2008-1163
Unlimited Release
Printed March 2008

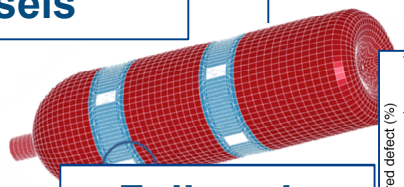
Technical Reference on Hydrog
Compatibility of Materials

C. San Marchi
B.P. Somerday

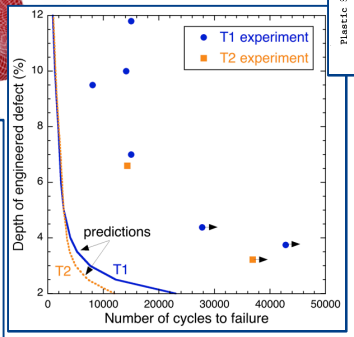
Sandia National Laboratories

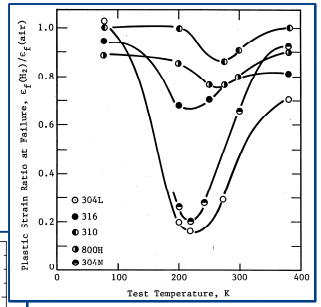
**Technical Reference established**

**First qualification data for high-pressure ASME vessels**



**Full-scale tank testing CSA HPIT1 SAE J2579**




**Platform for high-pressure GH2 over temperature range (-40˚C to +85˚C)**

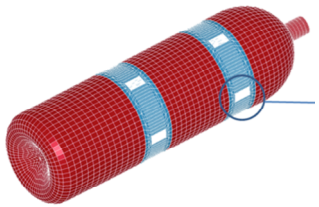
# International leadership in materials and components for hydrogen service

## Goal

Develop and characterize high-performance, hydrogen containment materials to lower capital cost of hydrogen infrastructure for delivery, as well as on-board vehicle systems and components

## Demonstrated Impact

- Full-scale testing of pressure vessels enabled deployment of safe, low-cost fuel cell forklift fuel systems
- Enabling worldwide deployment of hydrogen and fuel cell systems by developing science-based standards
- Identifying high-strength pipeline materials for hydrogen service



CSA SAE ASME

# Summary

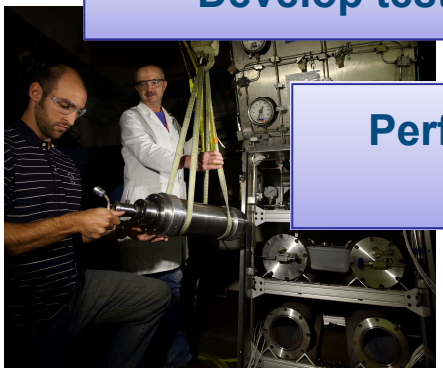
- Hydrogen and fuel cell technology markets are growing
- Legislation and stakeholder commitments are essential to success of hydrogen transportation technologies
- Many innovative solutions for zero emissions transportation solutions
- Sandia manages a diverse portfolio of hydrogen energy activities with the objective of

***providing science and engineering to enable the deployment of clean, sustainable energy technologies***

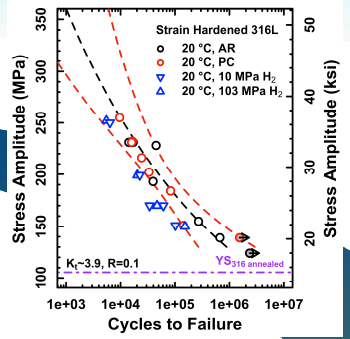
# R&D for Hydrogen Safety, Codes and Standards

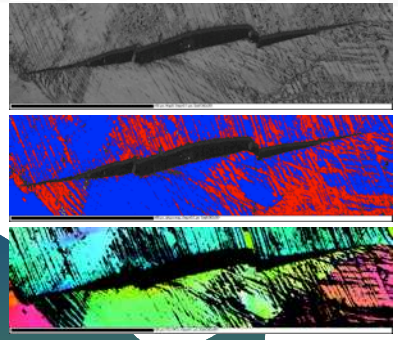
## Materials Compatibility and Suitability

**Develop test methods**

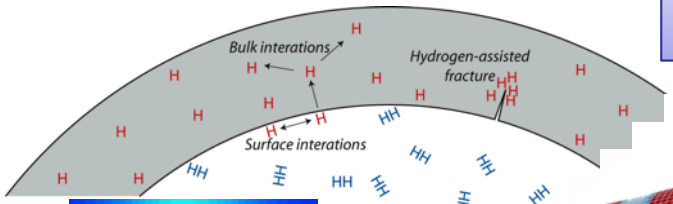


**Performance-based testing (compatibility)**

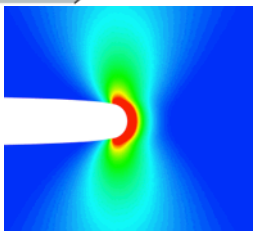


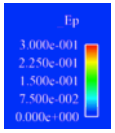
**Understanding physics of hydrogen embrittlement**

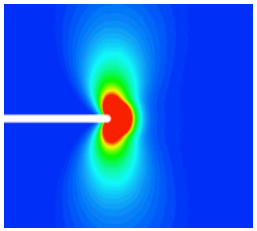



**Predictive models**

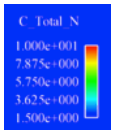


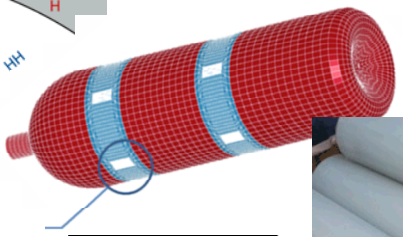
Transport

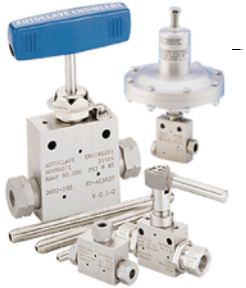


Mechanics





**System validation (suitability)**

# Reference Slides