SAND2015-9932C

Enabling Fuel Cell Technologies with Hydrogen Science and Engineering

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Sandia National Laboratories

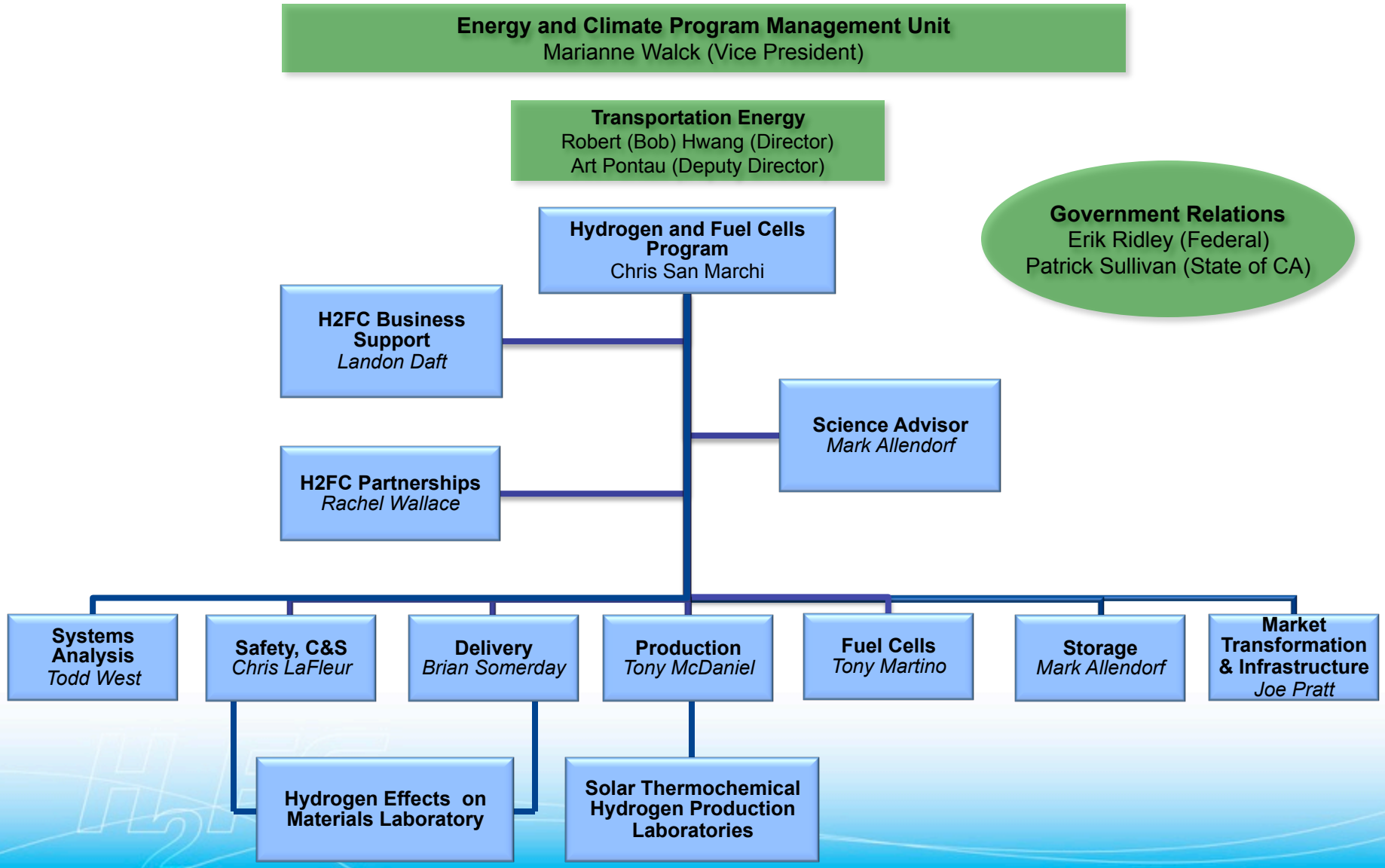
Hydrogen capabilities at Sandia National Laboratories

- Hydrogen behavior studies
- Quantitative risk assessment (QRA)
- Hydrogen compatibility of materials and components
- Solar thermochemical hydrogen production (STCH)
- Solid-state storage materials
- Hydrogen infrastructure and systems engineering
- Membrane synthesis and development
- Scenario and technoeconomic analysis
- Advanced computing for materials and components

Hydrogen facilities and projects at Sandia National Laboratories

- Turbulent Combustion Laboratory (TCL)
- ***HyRAM*** (Hydrogen Risk Assessment Models)
- Hydrogen Effects on Materials Laboratory (HEML)
- Solar Fuel Laboratory (SFL) and National Solar Thermal Test Facility (NSTTF)
- ***HyMARC*** (Hydrogen Materials – Advanced Materials Consortium) – joint with LLNL and LBNL
- ***H2FIRST*** (Hydrogen Fueling Infrastructure Research and Station Technology) – joint with NREL
- Alkaline exchange membrane synthesis and development
- Macro System Model (MSM) and Parachoice model

Hydrogen and Fuel Cells Program at Sandia



Hydrogen Safety, Codes and Standards program element

Providing the science and engineering to accelerate the deployment of clean and efficient hydrogen technologies

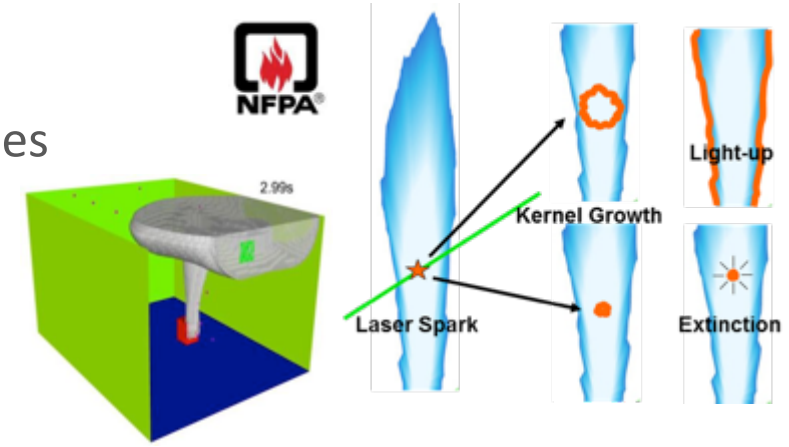
Hydrogen and fuel cell systems enable dramatic reductions in both GHG emissions and foreign oil dependence

Science-based regulations, codes and standards ensure technology requirements are consistent, logical and defensible

Accelerating deployments with fundamental understanding of *hydrogen behavior* and *quantitative risk assessment (QRA)*

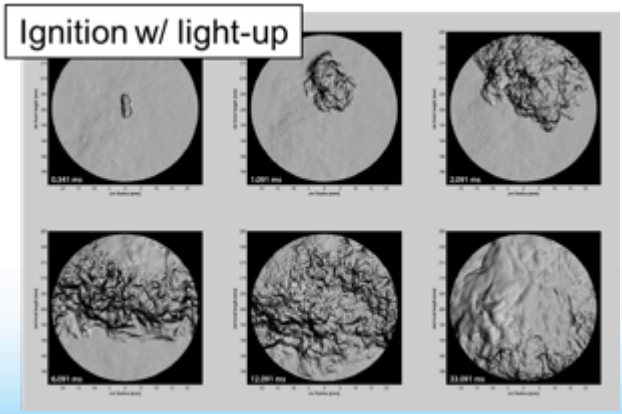
Goal

Facilitate the safe use of hydrogen technologies by understanding and mitigating risk



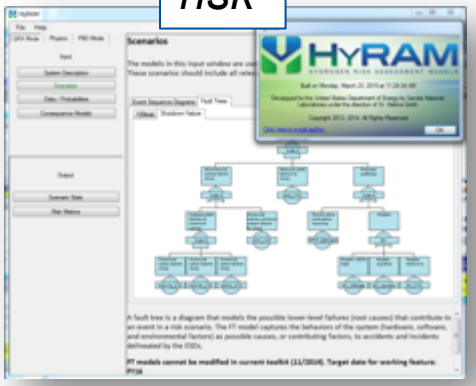
Demonstrated Impact

- Enabling the deployment of refueling stations by developing science-based, risk-informed decision making processes for specification of safety distances in existing code
- Sandia's analysis has enabled the indoor use of fuel cell powered vehicles



Behavior and *risk* models can be integrated to enable consistent (and accepted) risk assessment process

risk



Develop integrated methods and algorithms

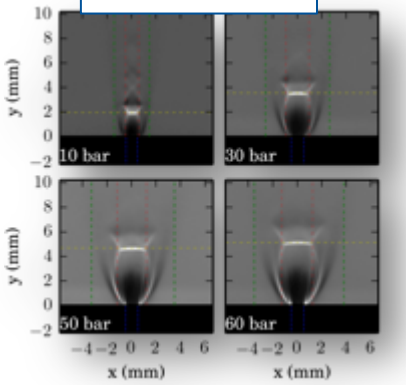
for enabling consistent, logical and defensible QRA

application

Apply quantitative risk assessment techniques

in real hydrogen infrastructure and emerging technology

behavior



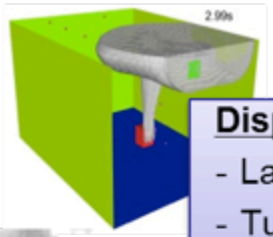
Develop and validate scientific models

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

HyRAM
HYDROGEN RISK ASSESSMENT MODELS

R&D for Hydrogen Safety, Codes and Standards

Hydrogen Behavior



Physics (deterministic)

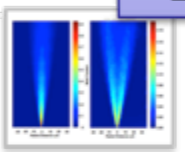
Dispersion Characteristics
- Laminar Flow
- Turbulent jet
- Volumetric rupture
- Enclosure Accumulation

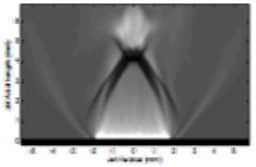
Probability

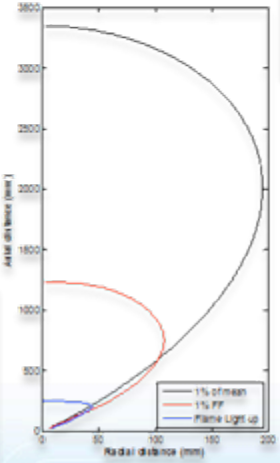
Ignition Probability
- Ignition mechanism
- Mixture ignitability
- Ignition delay/location
- Sustained light-up

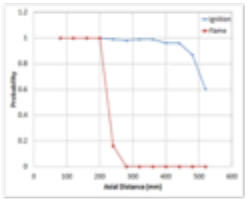
Consequence (deterministic)

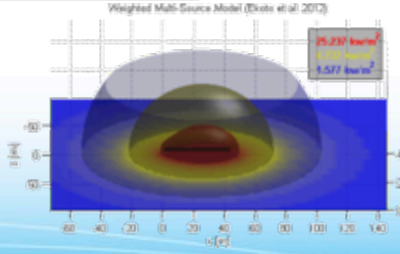
Hazard Characteristics
- Flame radiation
- Overpressure (deflagration/detonation)
- O_2 dilution/depletion

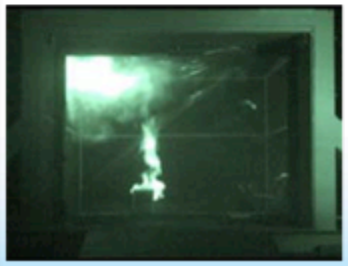






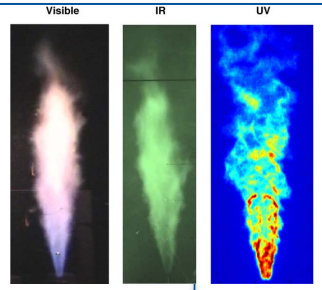






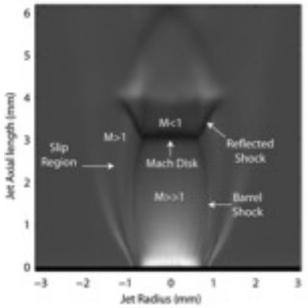
Hydrogen Behavior studies enable predictive capabilities

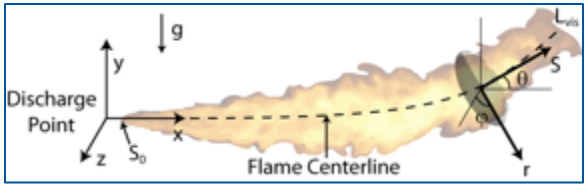
Radiative properties of H2 flames quantified



Barrier walls for risk reduction

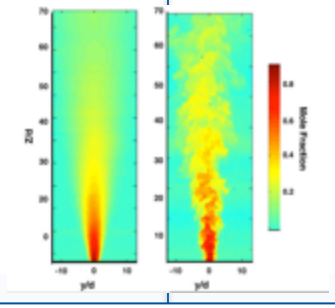
Ignition of under-expanded H2 jets





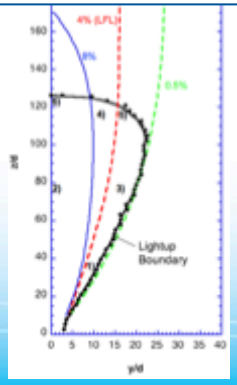
Buoyant jet flame model with multi-source radiation

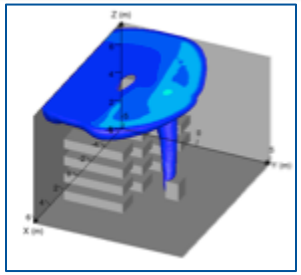
2005 2007 2009 2011 2013 2015 2017



Advanced laser diagnostics applied to turbulent H2 combustion

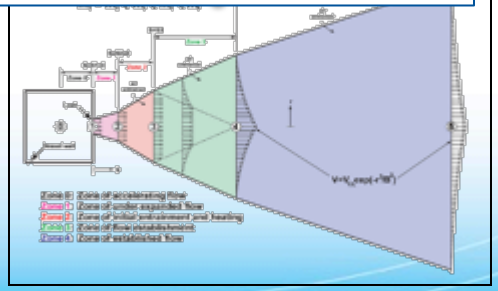
Ignition limits of turbulent H2 flows





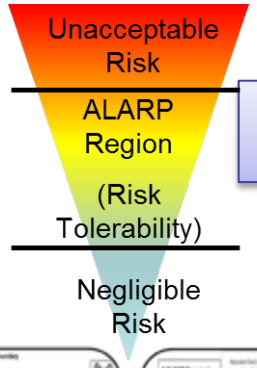
Experiment and simulation of indoor H2 releases

Laboratory-scale characterization of LH2 plumes and jets



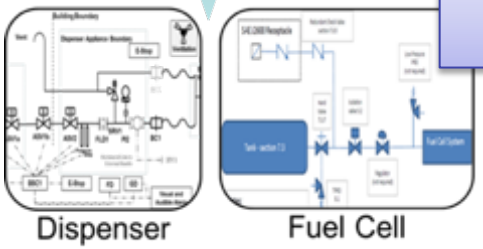
R&D for Hydrogen Safety, Codes and Standards

Quantitative Risk Assessment (QRA)



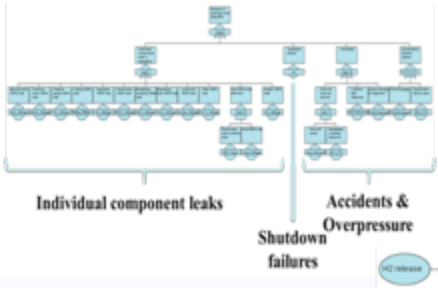
1. Set analysis goals

2. System & hazard description

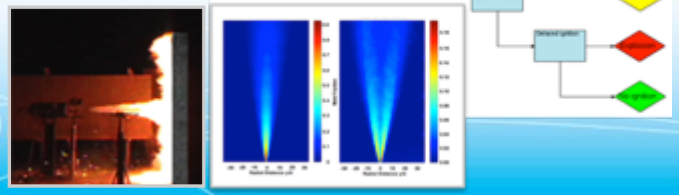


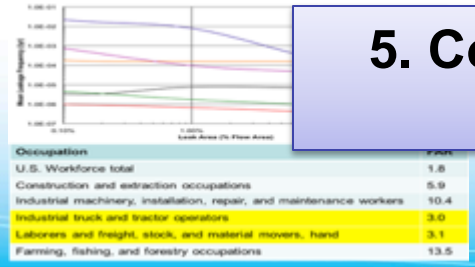
QRA Process

3. Cause analysis



4. Consequence analysis

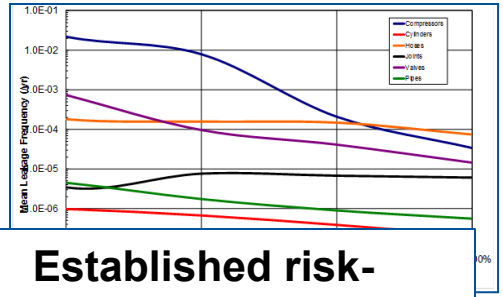




Occupation	
U.S. Workforce total	1.8
Construction and extraction occupations	5.9
Industrial machinery, installation, repair, and maintenance workers	10.4
Industrial truck and tractor operators	3.0
Laborers and freight, stock, and material movers, hand	3.1
Farming, fishing, and forestry occupations	13.5

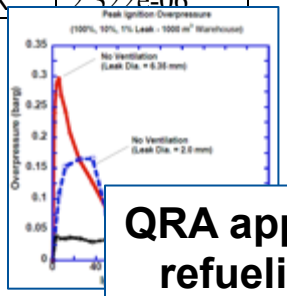
5. Communicate Results

Quantitative Risk Assessment is enabling infrastructure deployment



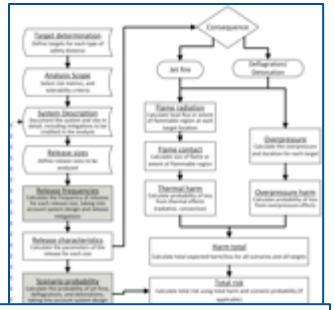
Established risk-informed processes for separation distances

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



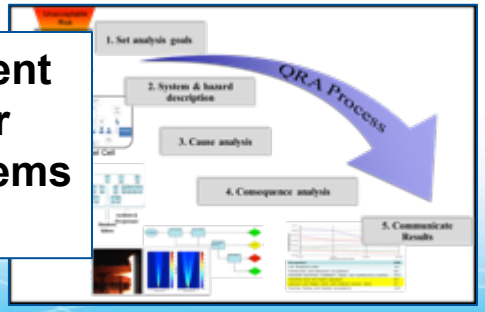
ISO TC197 WG24 incorporating QRA and behavior modeling

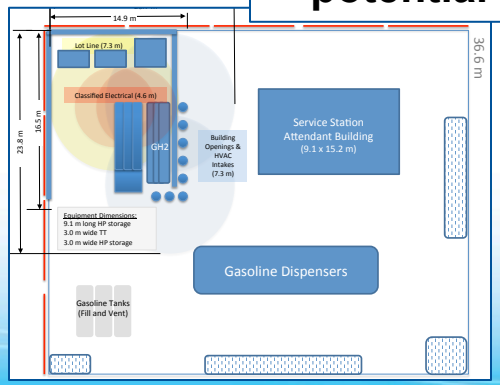
2005 2007 2009 2011 2013 2015 2017

QRA-informed separation distances in NFPA 2

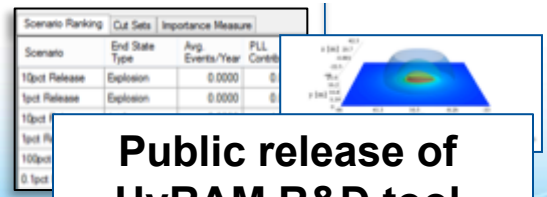
20% station penetration potential due to QRA

Risk assessment proposed for hydrogen systems at ICHS



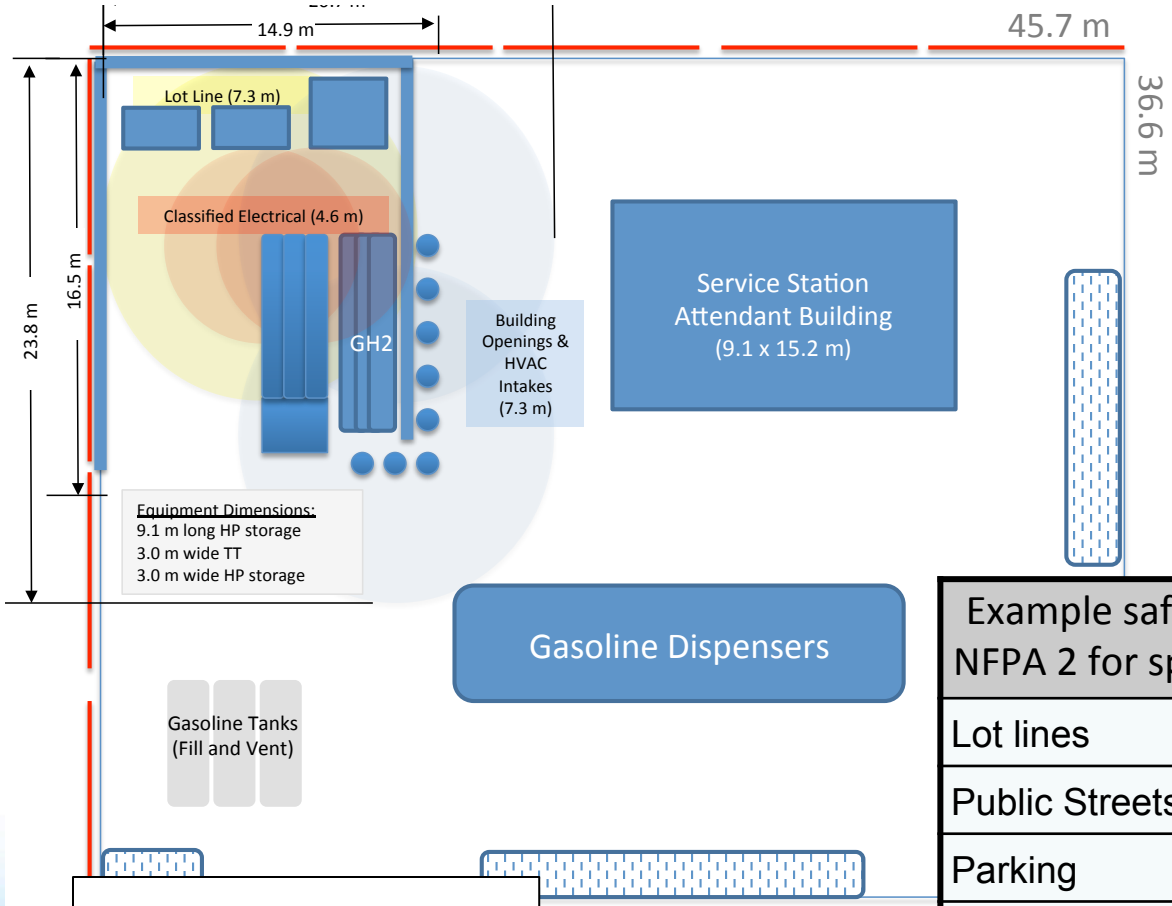


HyRAM HYDROGEN RISK ASSESSMENT MODELS



Public release of HyRAM R&D tool

Fire protection code reduced safety distances based on risk-informed, science-based methodology



GH2 storage

Outcome: **initial safety distances precluded GH2 at existing fueling stations, science-based distances enable the acceptance of GHS at up to 20% of sites**

Harris et al. SAND2014-3416

Example safety distances (m) NFPA 2 for specific boundaries	GH2	LH2
Lot lines	7.3	10.1
Public Streets, Alleys	7.3	10.1
Parking	4.0	22.9
Buildings (sprinkled, fire rated)	3.0	1.5
Building Openings or air intakes	7.3	22.9

Future challenge:

Safety distances for liquid H2 storage are too large for commercial fueling stations in the US

Example safety distances (m) NFPA 2 for specific boundaries	GH2	LH2
Lot lines	7.3	10.1
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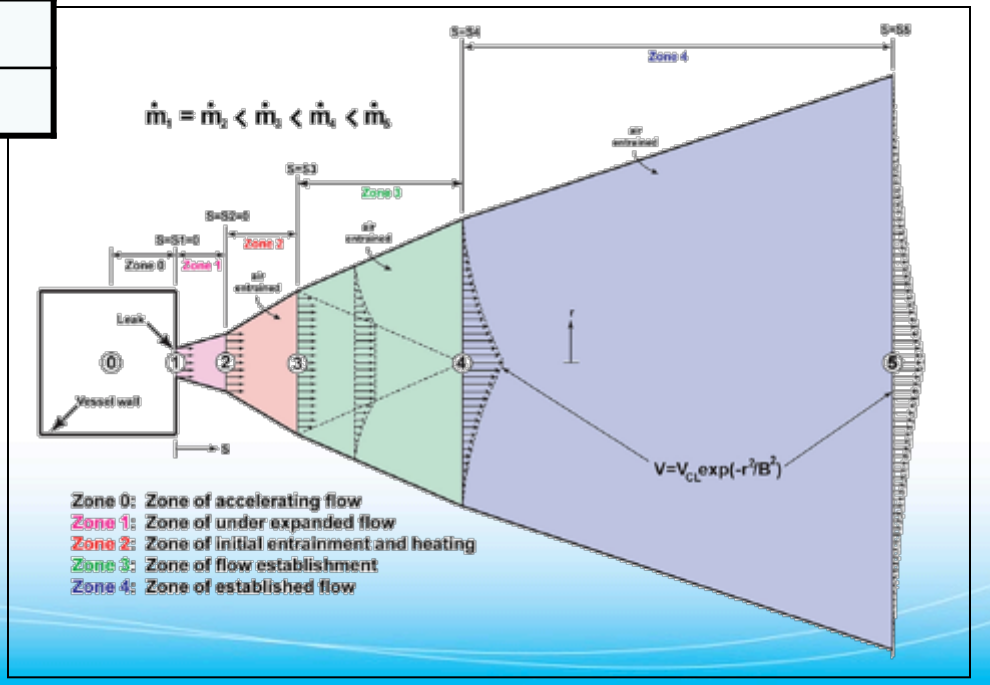
Buildings (sprinkled, fire rated)	3.0	1.5
Building Openings or air intakes	7.3	22.9

Harris et al. SAND2014-3416

Goal: **use science-based approach to inform safety distances for LH2**

- **NFPA activity**

Validated models of LH2 releases integrated into the QRA framework will inform quantification of risk and aid the definition of safety distances



Leadership in materials and components for hydrogen service

Goal

Develop and characterize high-performance, hydrogen containment materials to lower capital cost of hydrogen infrastructure, systems and components

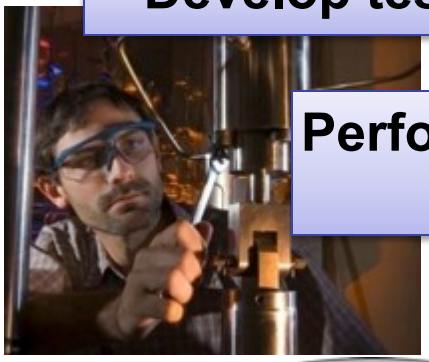
Demonstrated Impact

- Enabled worldwide deployment of hydrogen and fuel cell systems by developing science-based standards
  - Technology roadmaps
  - Databases
  - Leveraged research

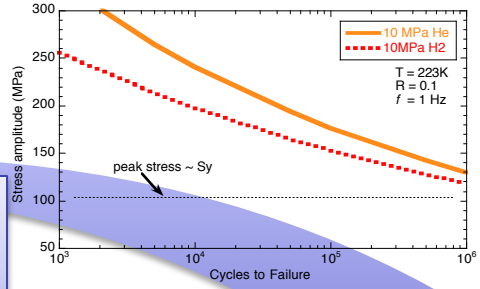
R&D for Hydrogen Safety, Codes and Standards

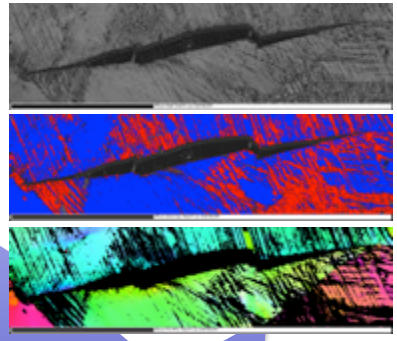
Materials Compatibility and Suitability

Develop test methods

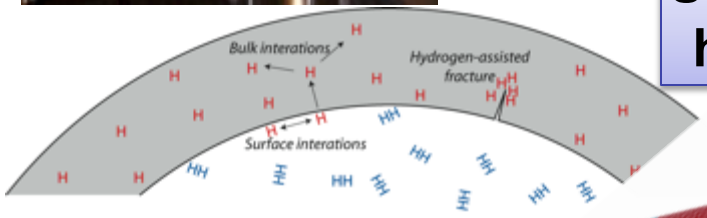


Performance-based testing (compatibility)

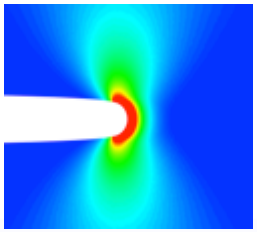




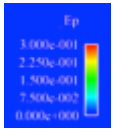
Understanding physics of hydrogen embrittlement

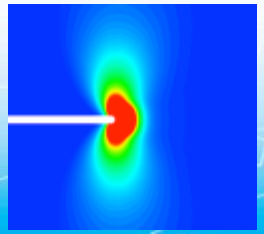


Predictive models

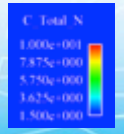


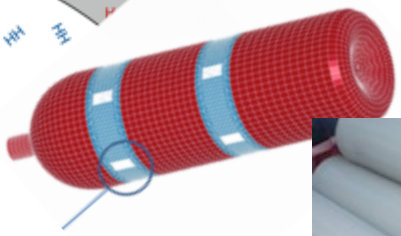
Transport

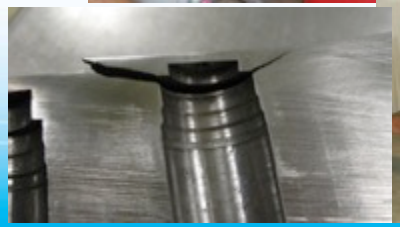




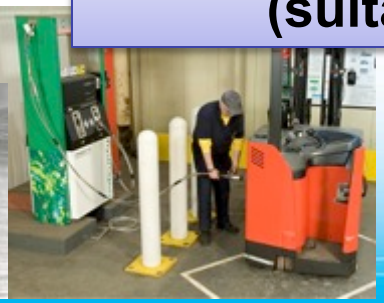
Mechanics







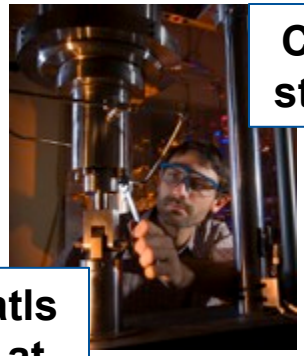
System validation (suitability)



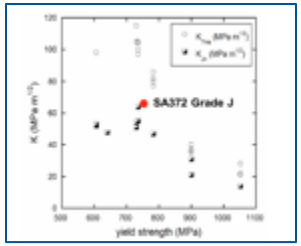
Evaluation of *Materials Compatibility* enables innovative technologies

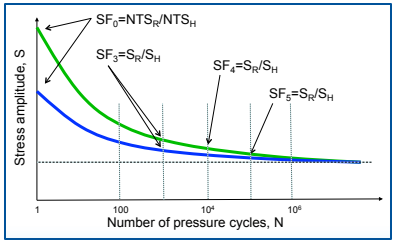
ASME article KD-10 input on test methodology

Platform for matls testing in GH2 at high pressure



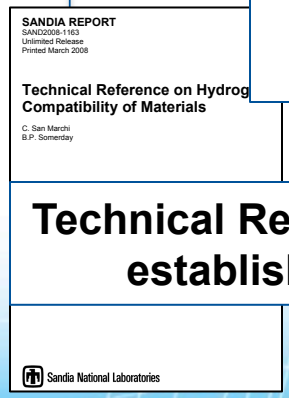
Critical assessment of statically loaded cracks





CSA CHMC1 test methods and matls qualification

2005 2007 2009 2011 2013 2015 2017


SANDIA REPORT
SAND2008-1163
Unlimited Release
Printed March 2008

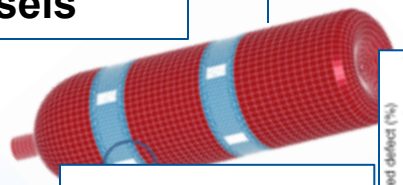
Technical Reference on Hydrog
Compatibility of Materials

C. San Marchi
B.P. Somerday

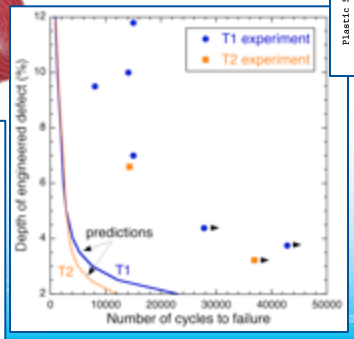
Sandia National Laboratories

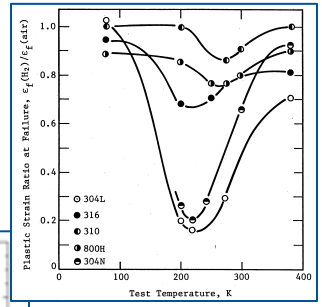
Technical Reference established

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)

Full-scale testing of pressure vessels enabled deployment of safe, low-cost fuel cell forklift fuel systems

plug power

NUVERA FUEL CELLS

NORRIS CYLINDER

We quantified uncertainties in the cycle life of hydrogen storage tanks for the lift-truck application.

- Enhanced safety and market growth enabled through standards development

CSA SAE ASME NFPA

example of embrittlement failure from the 1970's

- Today, there are >15,000 clean and efficient fuel cell forklifts in service (and growing!)

Summary

Diverse portfolio of hydrogen activities at Sandia, including R&D for Safety, Codes and Standards:

- Hydrogen behavior models enable safety analysis
  - Validated, defensible, referenceable models
- QRA framework enables scientific basis for revision of code requirements
  - Consistent, logical framework for quantifying risk and applying to decision making processes
- Understanding of materials performance enables deployment of innovative technologies
  - Accommodate hydrogen effects by quantification of materials behavior in relevant hydrogen environments