Sandia National Laboratories

H2FC Hydrogen and Fuel Cells Program

SAND2017-5842 PE

Hydrogen Safety, Risk Assessment, and Material Compatibility R&D

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Sandia National Laboratories

H2@Scale Review Meeting

Washington, DC

June 9, 2017

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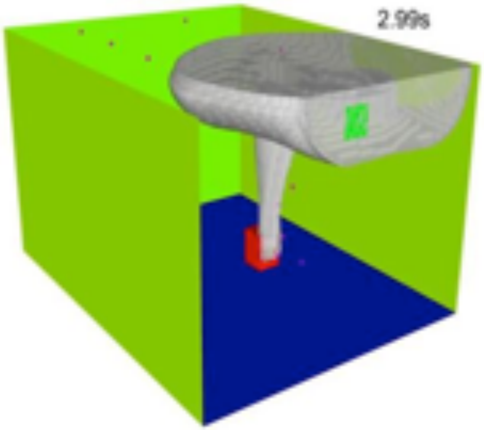
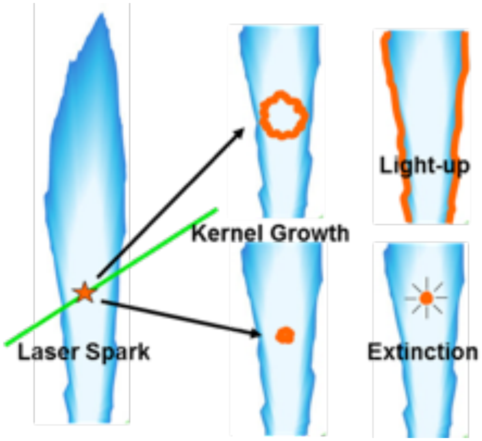
Defensible safety standards for the built environment

Goal

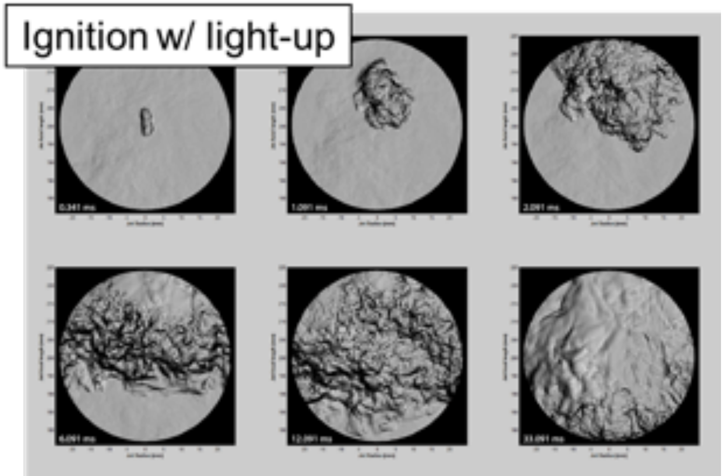
Facilitate the safe use of hydrogen technologies by understanding and mitigating risk





Demonstrated Impact

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



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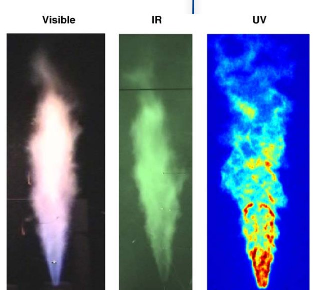
H_2FC Hydrogen and Fuel Cells Program

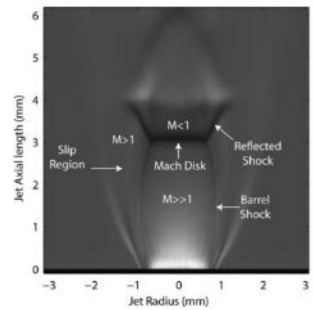
Experimental observations and mathematical models

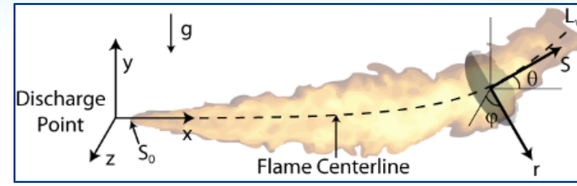
Radiative properties of H_2 flames quantified



Barrier walls for risk reduction

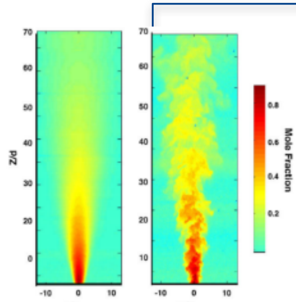
Ignition of under-expanded H_2 jets





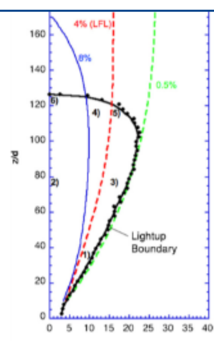
Buoyant jet flame model with multi-source radiation

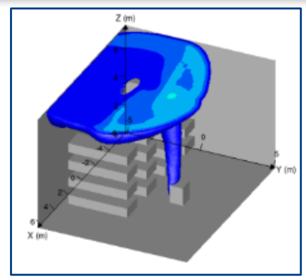
2005 2007 2009 2011 2013 2015 2017



Advanced laser diagnostics applied to turbulent H_2 combustion

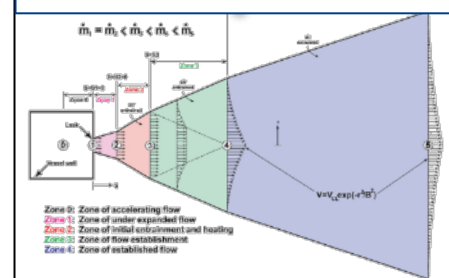
Ignition limits of turbulent H_2 flows





Experiment and simulation of indoor H_2 releases

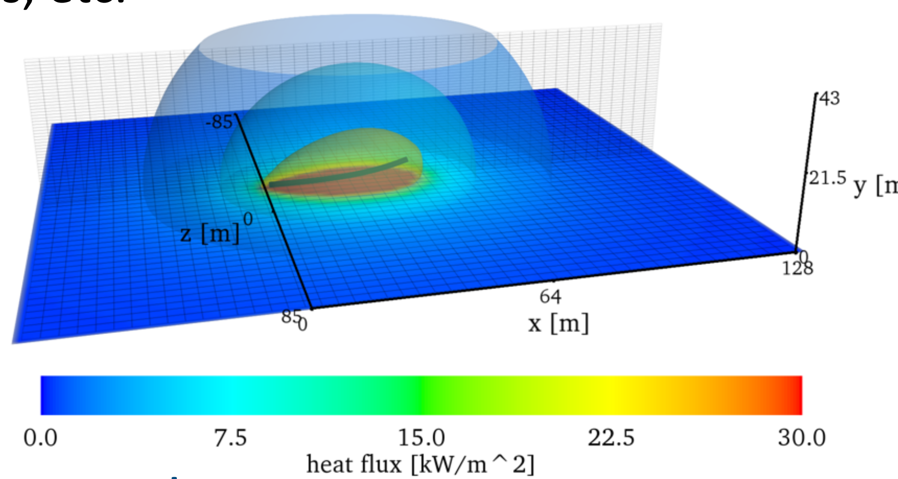
Laboratory-scale characterization of LH_2 plumes and jets



Risk framework incorporates science basis for safety

Hydrogen Behavior Models

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



Quantitative Risk Assessment

Develop integrated methods and algorithms enabling consistent, traceable, and rigorous QRA (Quantitative Risk Assessment) for hydrogen facilities and vehicles

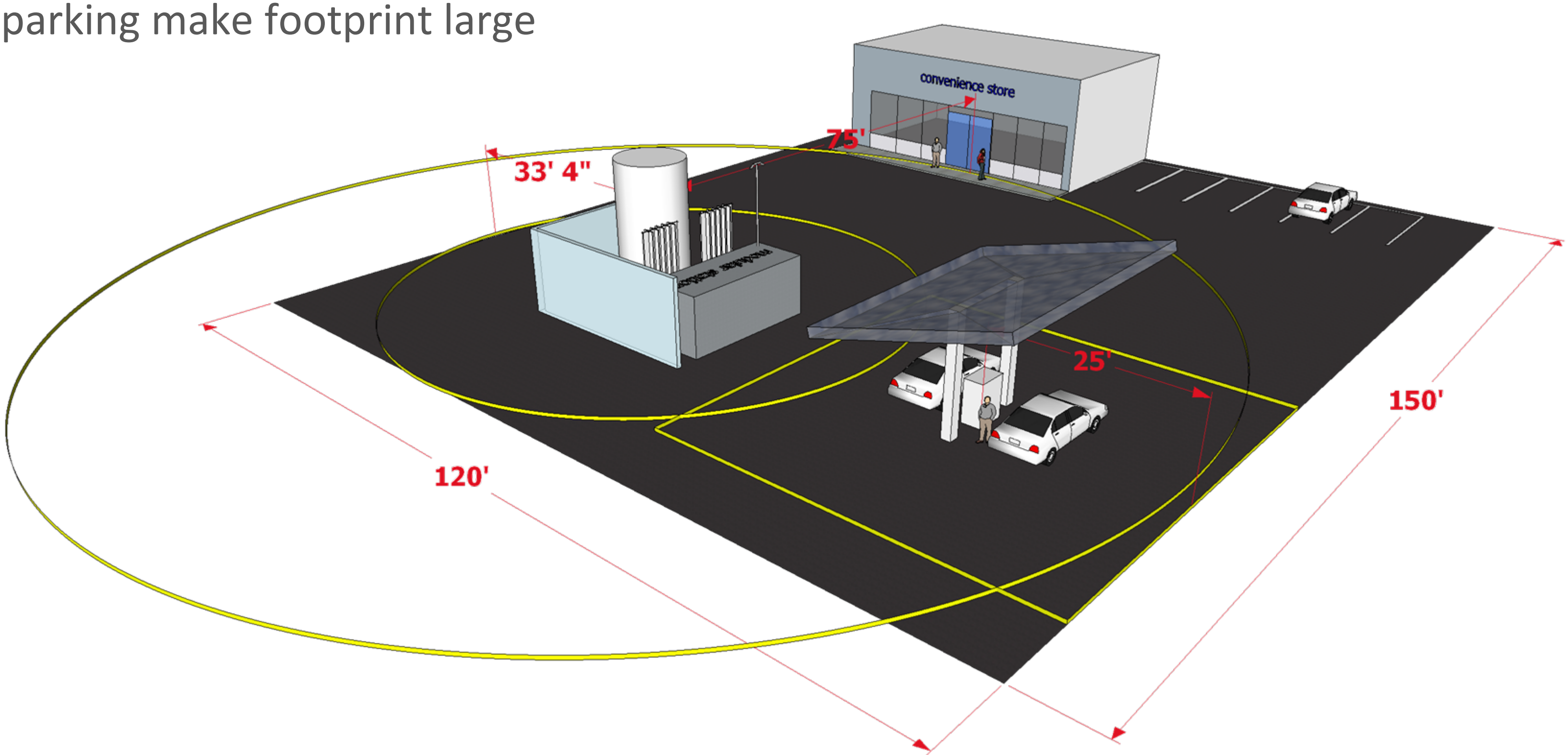
Decision Support for Standards Development

Provide physics models and risk calculations to address real problems in hydrogen infrastructure and emerging technology

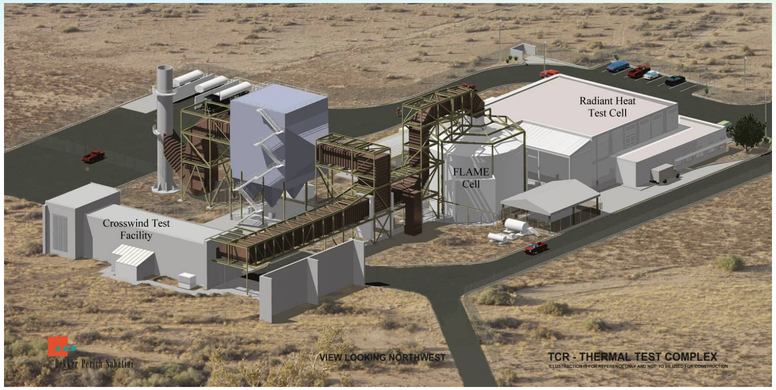
HYRAM
HYDROGEN RISK ASSESSMENT MODELS

Current separation distances for bulk liquefied hydrogen are based on consensus, not science

- Previous work by this group led to science-based, reduced, gaseous H_2 separation distances
- Higher energy density of liquid hydrogen over compressed H_2 makes it more economically favorable for larger fueling stations
- Even with credits for fire-rated barrier wall, 75 ft. offset to building intakes and parking make footprint large



Phenomena from large-scale liquid releases are not well understood



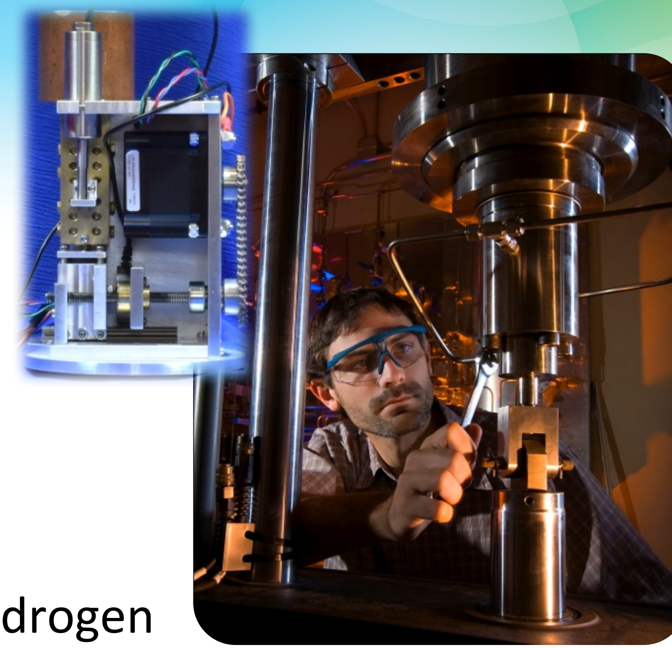
Need experiments to characterize:

- Pooling
- Evaporation from LH2 pools

Planning underway for experiments at Sandia (Albuquerque) facilities:

- Thermal test complex
  - Flame cell
    - Up to 3m diameter pool
    - 18.3 m dia. x 12.2 m high
    - Well characterized conditions for model validation
  - Crosswind test facility
    - Dispersion in controlled crosswind
    - Single-direction flow
    - Well-characterized ambient conditions
- Severe Accident Phenomena/Analysis (Surtsey)
  - 100 m^3 pressure vessel with 6 levels of instrumentation ports

Leadership in materials and components for hydrogen service



Goals

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

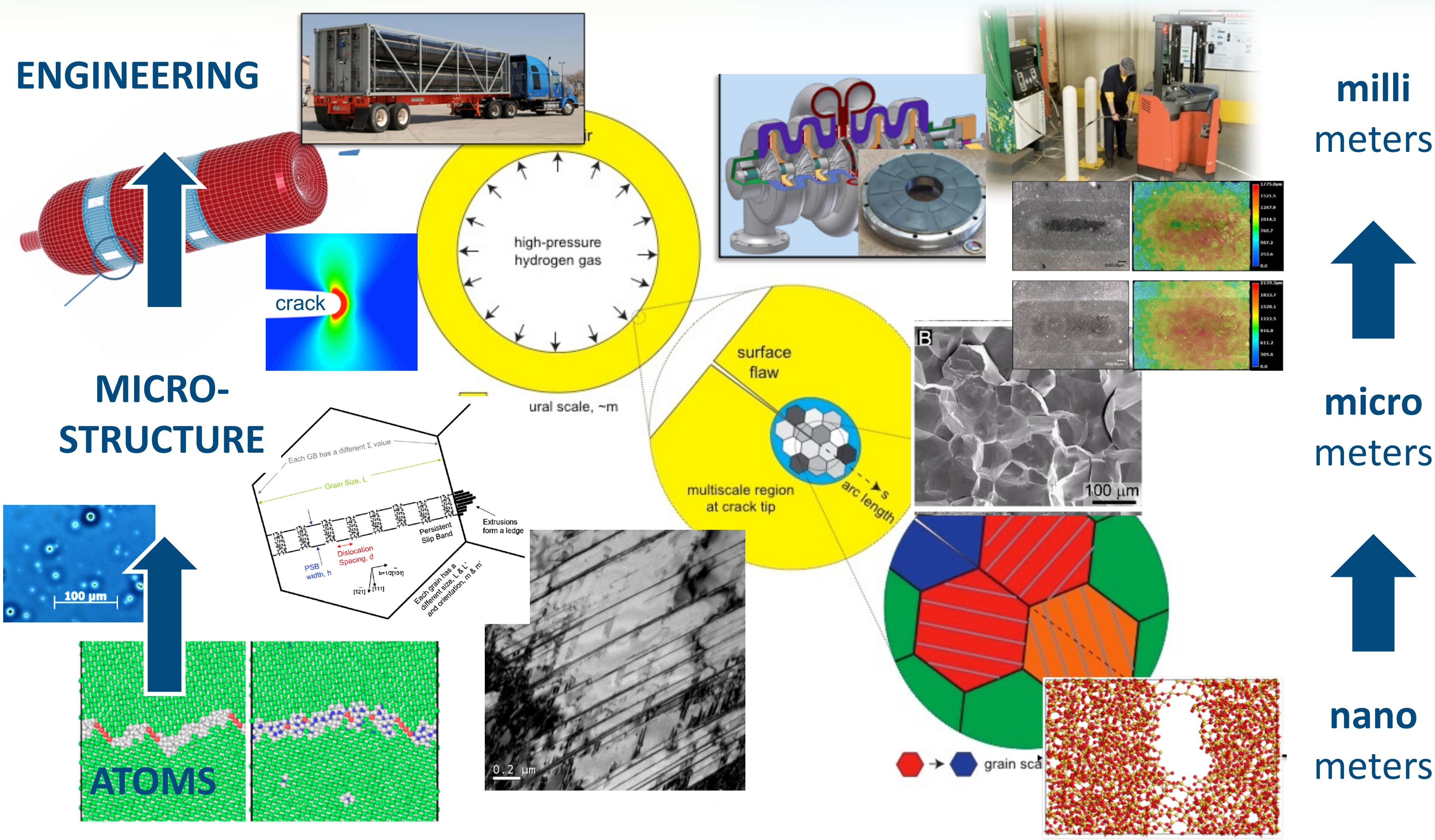
- Understand fundamentals of hydrogen interactions with metals and polymers to enable materials selection and mitigation strategies for hydrogen-enhanced degradation

Demonstrated Impact

- Enabled worldwide deployment of hydrogen and fuel cell systems by developing test methodologies for science-based standards

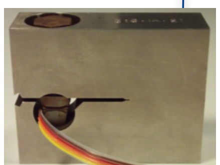
GRANTA MI

Foundational materials science for hydrogen systems engineering: *Atoms to Engineering concept*

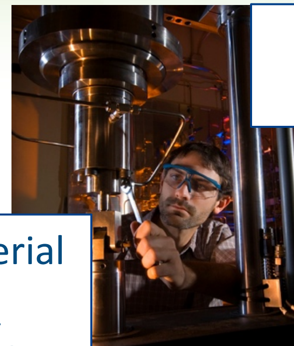


Evaluation of *Materials Compatibility* enables hydrogen technology innovation

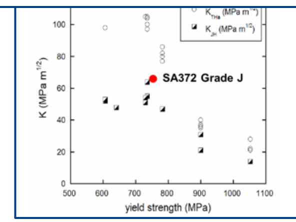
ASME article KD-10 input on test methodology

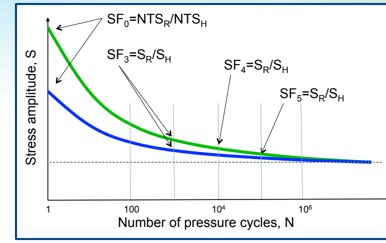


Platform for material testing in GH_2 at high pressure



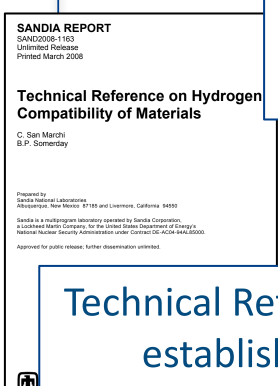
Critical assessment of statically loaded cracks





CSA CHMC1 test methods and material qualification

2005 2007 2009 2011 2013 2015 2017



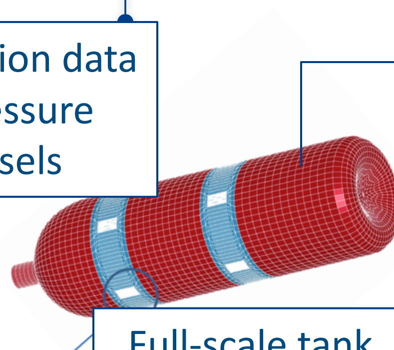
SANDIA REPORT
SAND2008-1163
Unlimited Release
Printed March 2008

Technical Reference on Hydrogen Compatibility of Materials

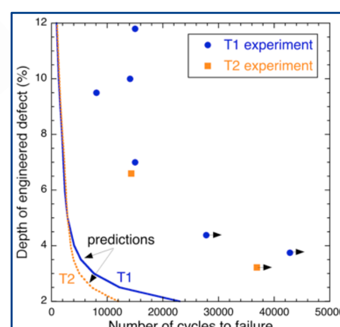
C. San Marchi
B.P. Somerday

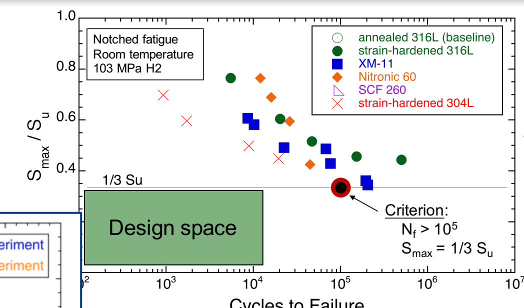
Technical Reference established

First qualification data for high-pressure ASME vessels



Full-scale tank testing
CSA HPIT1
SAE J2579

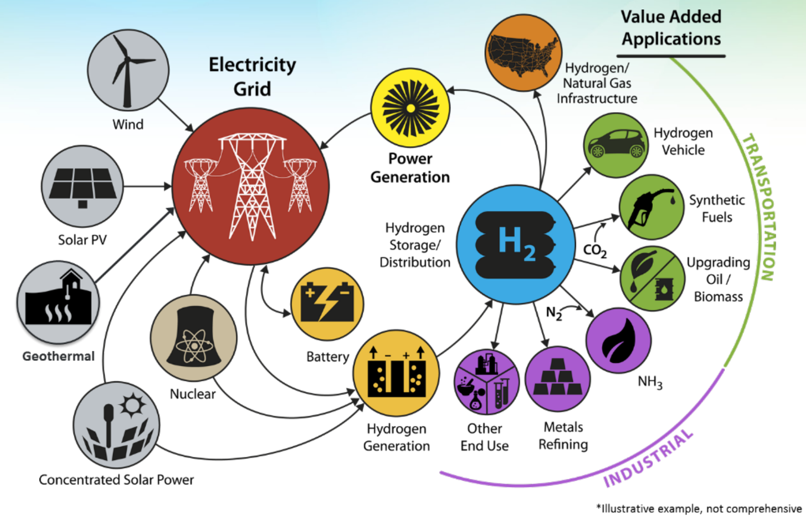




Platform for high-pressure GH_2 over temperature range (-40˚C to +85˚C)

Safety, Codes and Standards needs for H2@Scale

- Protocols for distributed production and power systems integration
- Oxygen management in distributed systems
- Metrology at scale (metering for geologic storage and pipelines)
- Purity requirements and purification
- Gas segregation in mixed gas systems
- Leakage in geologic storage and pipeline systems
- Materials compatibility in existing infrastructure (PVC, cast iron, *etc.*)
- Combustion requirements (*e.g.*, burners)
- Safety requirements for underground storage at point of use
- Maritime standards for international shipping and transport over waterways
- Safety standards for conveyance of LH_2



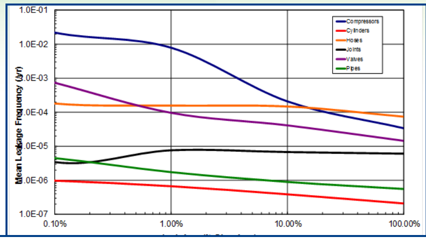
*Illustrative example, not comprehensive
Source: NREL

BACKUP SLIDES

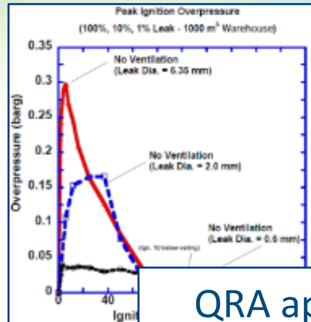
Sandia National Laboratories

H_2FC Hydrogen and Fuel Cells Program

Evolution of quantitative risk assessment in standards

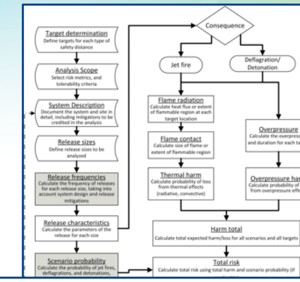


Established risk-informed processes for separation distances



QRA applied to indoor refueling to inform code revision

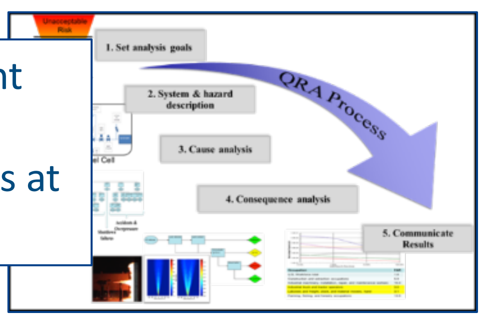
Performance-based system layout demonstrated



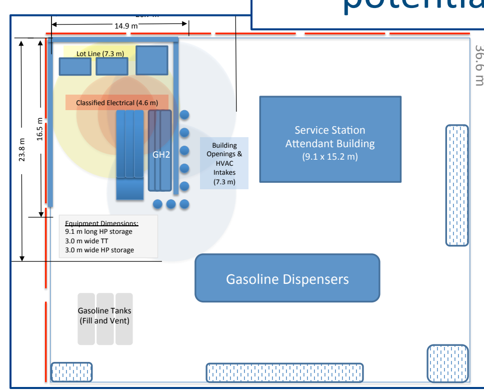
ISO TC197 WG24 incorporating QRA and behavior modeling

2005 | 2007 | 2009 | 2011 | 2013 | 2015 | 2017

Risk assessment proposed for hydrogen systems at ICHS

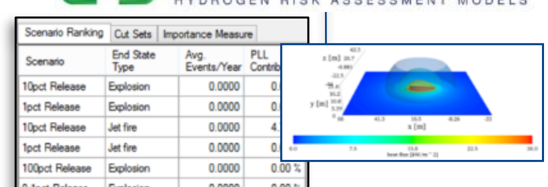


QRA-informed separation distances in NFPA 2



20% station penetration potential due to QRA

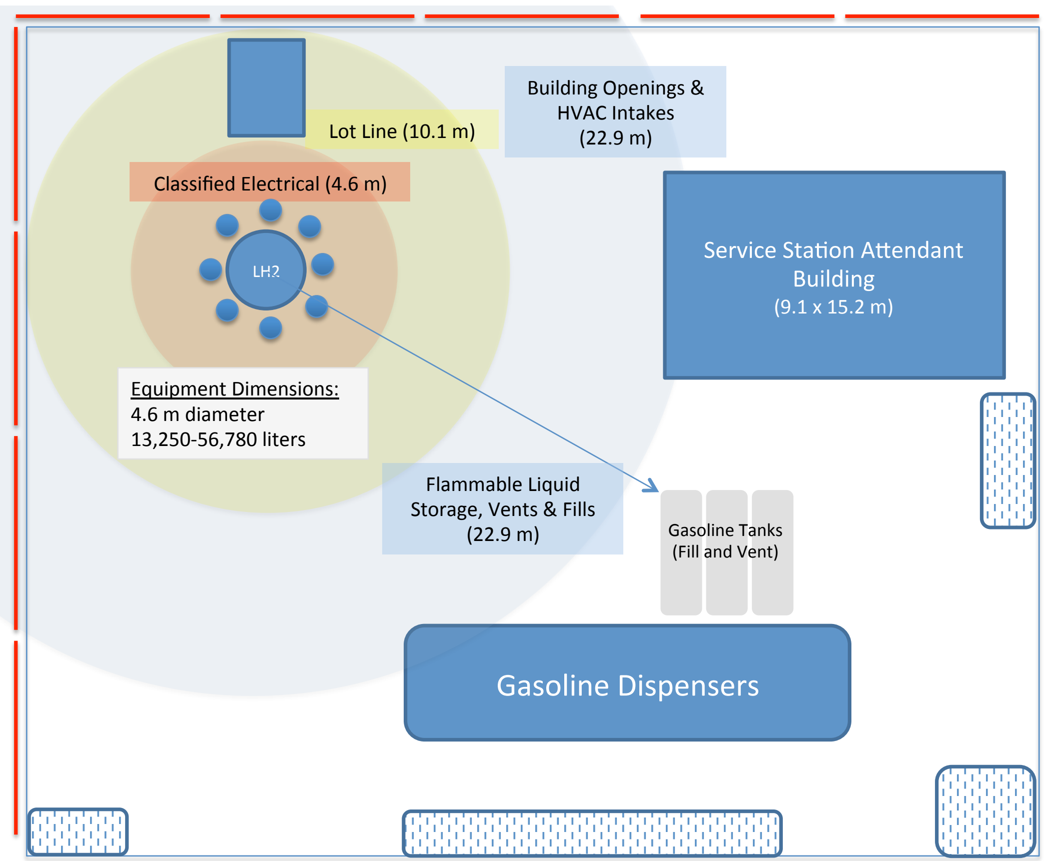
HyRAM HYDROGEN RISK ASSESSMENT MODELS



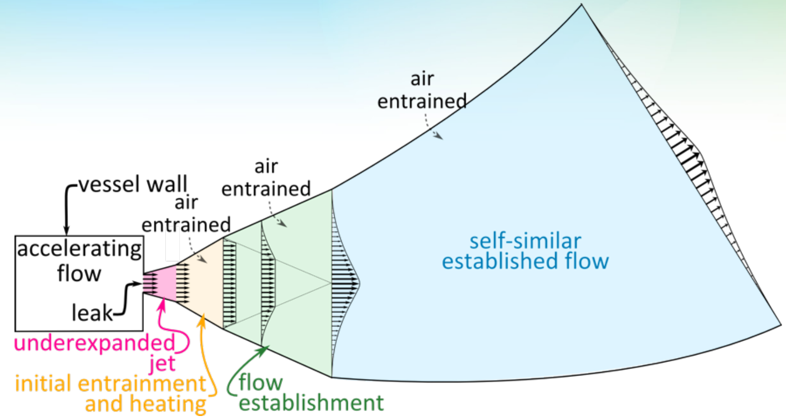
Public release of HyRAM

Developing risk models for liquid hydrogen storage

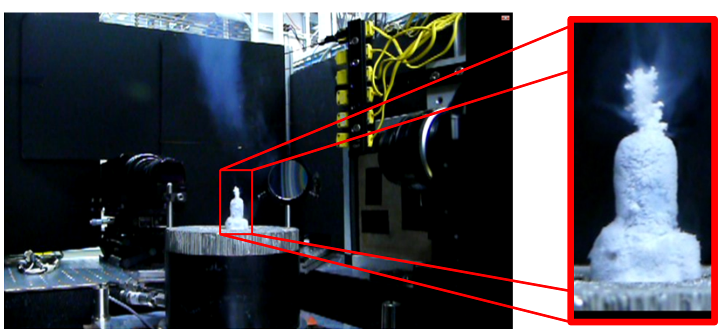
Temperature of LH_2 = 20K (-253˚C)



LH_2 storage

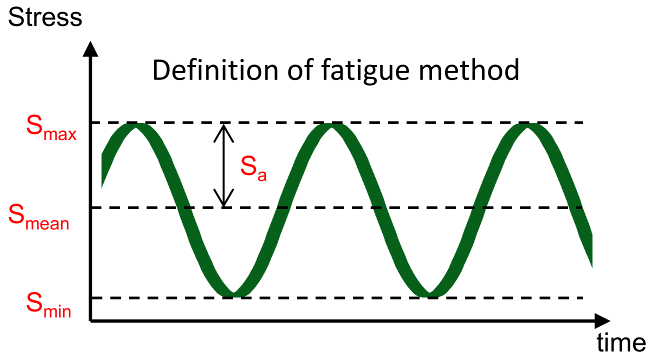


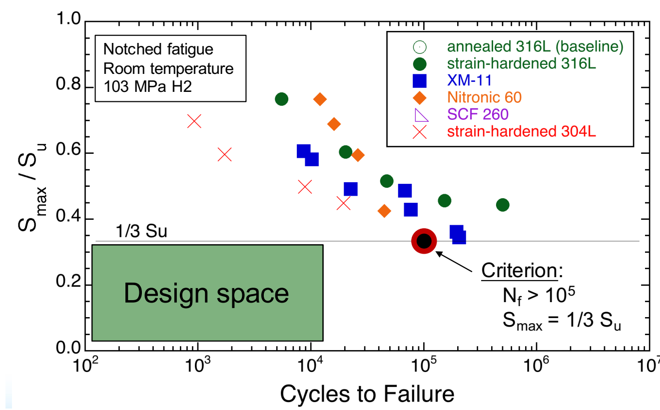
Laboratory experiments and validated models of cryogenic hydrogen releases inform safety requirements for LH_2 storage



International testing collaboration to develop common material qualification protocols

Develop international coordination → Harmonize preliminary test requirements → Identify consensus-based criteria





- Developing shared experience on capability deployment in Europe, Asia and North America for fatigue testing in high-pressure hydrogen (>700 bar) and low temperature (≤233K)
- Goals: (1) international consensus within SAE Fuel Cell Safety Task Force on materials test methods and performance metrics for FCEV fuel systems; and (2) proposal for Phase II of UN GTR no. 13a