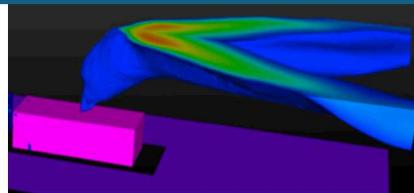


Background and Current Work on Hydrogen for Rail



Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

SAND2020-XXXX PE

Presented by:

Brian Ehrhart

8/21/2020

ZEHTRANS Monthly Meeting

Sandia National Laboratories Overview

“Exceptional Service in the National Interest”

Multi-Mission for DOE NNSA Lab

Federally Funded Research and Development Center (FFRDC)

- Government owned, contractor operated

Main sites: Albuquerque, NM and Livermore, CA

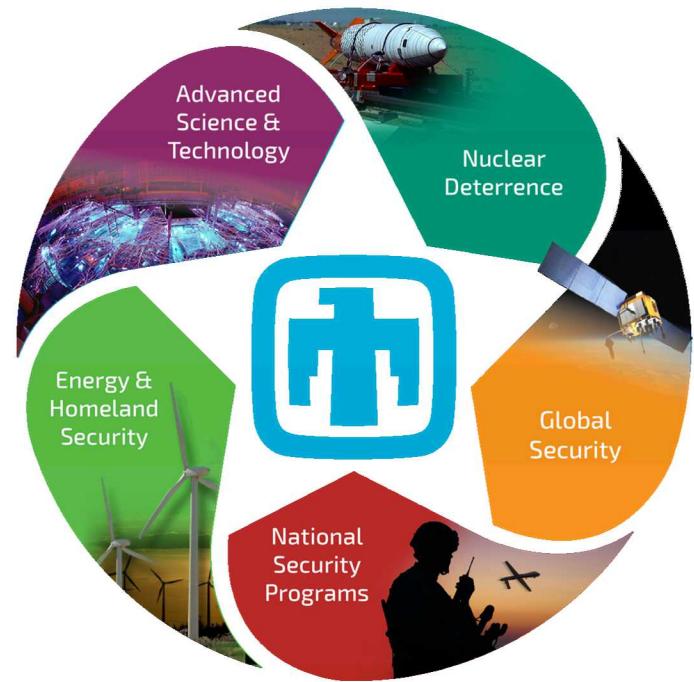
- Other sites: Kauai, HI; WIPP, Carlsbad, NM; Pantex Plant, Amarillo, TX; Tonopah, NV

FY19 Budget: \$3.8B

- Sponsors: DOE, DOD, DHS, DOT, NRC, etc.

>14,000 employees (>12,000 in NM; >1,600 in CA)

- Staff has grown by over 5,000 since 2009 to meet all mission needs



Sandia's Hydrogen and Fuel Cells Research Program

Sandia provides deep, quantitative understanding and a scientific basis for...

Materials - for hydrogen production, storage and utilization

Safety - risk analysis and the creation of risk-informed standards

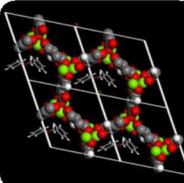
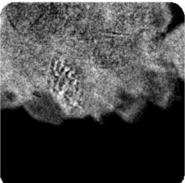
Hydrogen Production from Renewables



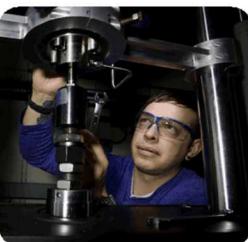
Advanced water-splitting materials and technologies for large-scale H₂ production

Hydrogen Storage Materials and Solutions

Discovering the behavior and performance of solid storage materials



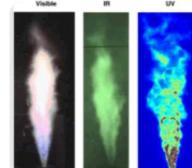
Hydrogen-Materials Compatibility



Low-cost, hydrogen-compatible materials and the science basis for their qualification



Hydrogen Fueling Infrastructure



H₂ release behavior and risk assessment to define the safety envelope for storage & delivery

Technologies for Non-Vehicle Applications

Marine and rail applications



Fuel Cells

Membrane systems for enhanced electrochemical performance



Hydrogen Risk Assessment Models (HyRAM)



Core functionality:

Quantitative risk assessment (QRA) methodology

Frequency & probability data for hydrogen component failures

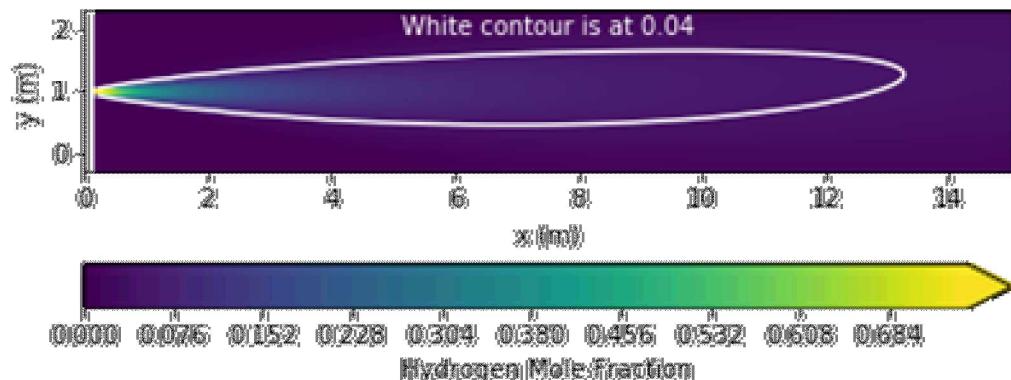
Fast-running models of hydrogen gas and flame behaviors

Key features:

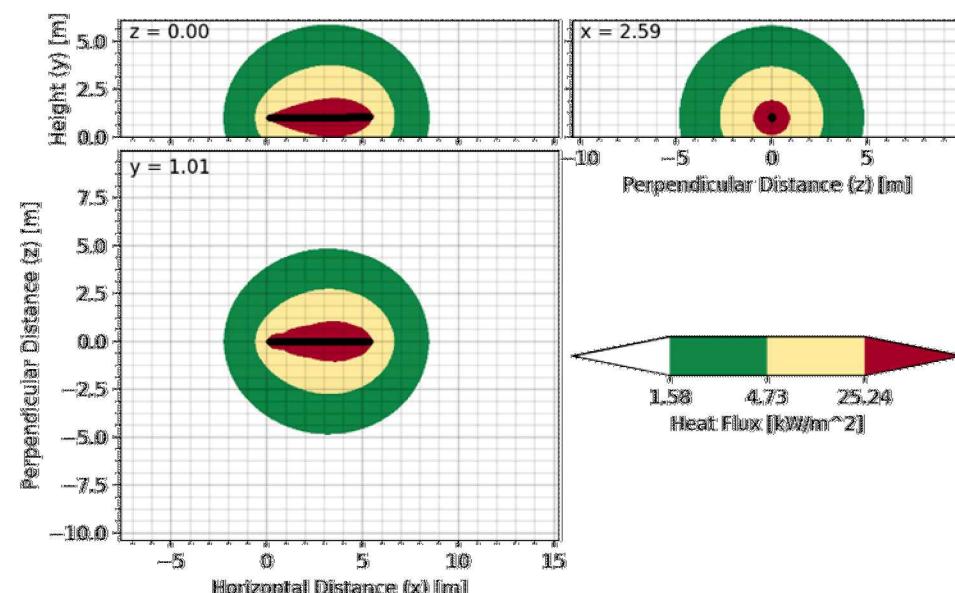
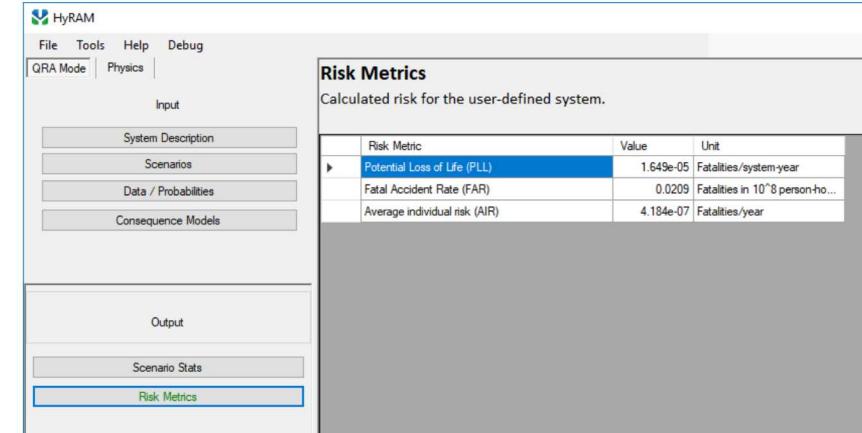
GUI & Mathematics Middleware

Documented approach, models, algorithms

Flexible and expandable framework; supported by active R&D



<https://hyram.sandia.gov>



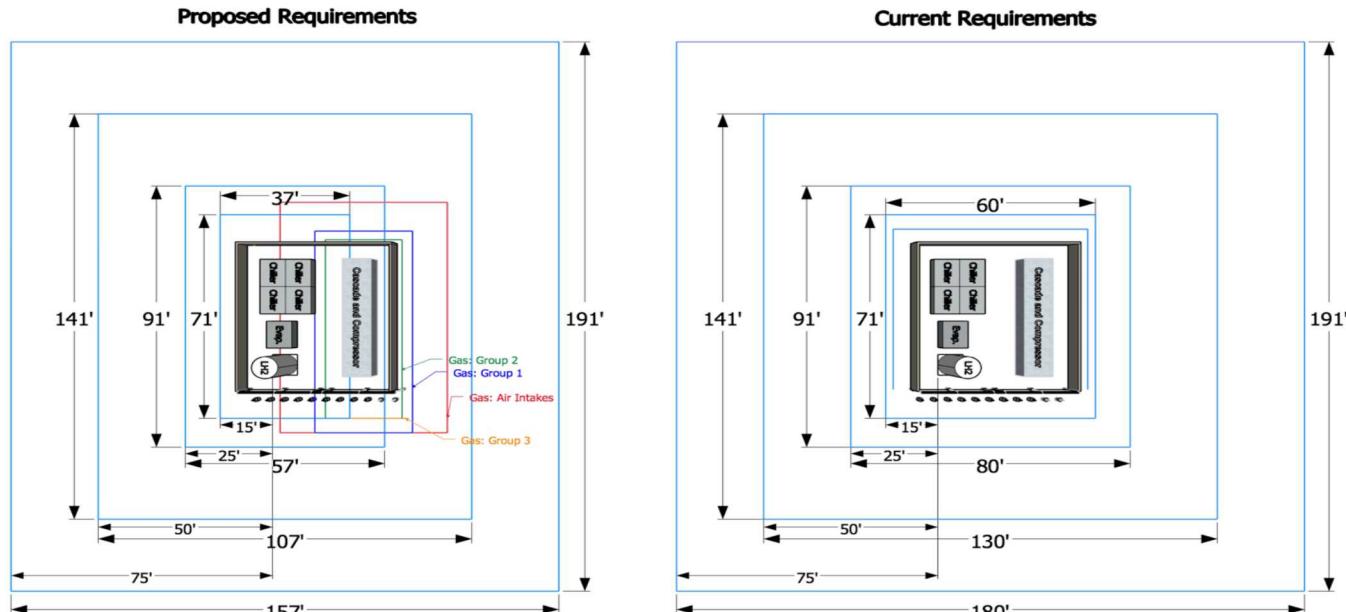
Light-Duty Vehicle Infrastructure Studies



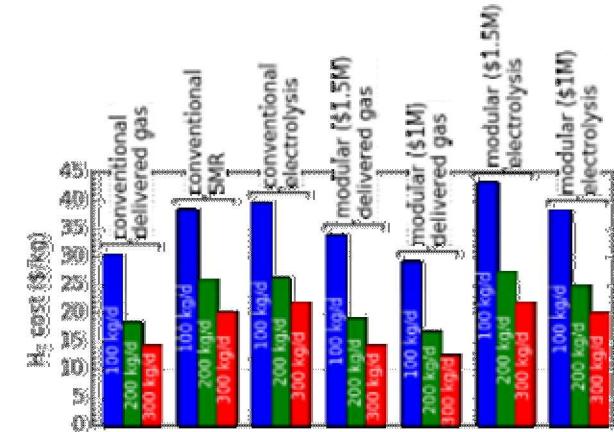
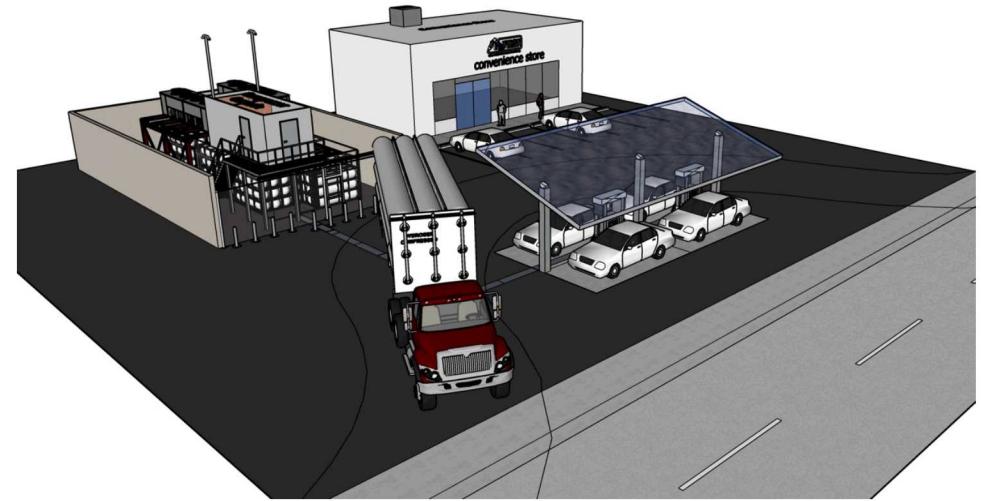
Hydrogen Fueling Infrastructure Research and Station Technology

Publicly available system designs for stakeholders

Focusing on NFPA 2 code

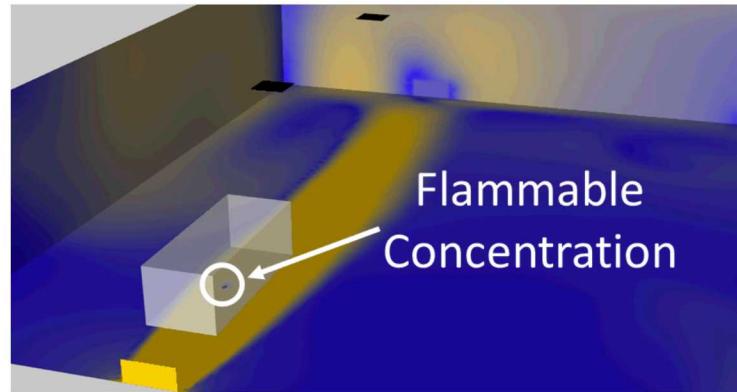


Layout footprint quantification
and comparison

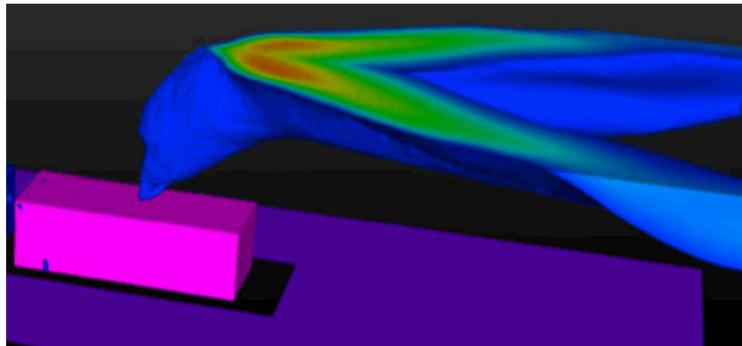


Economic Comparisons

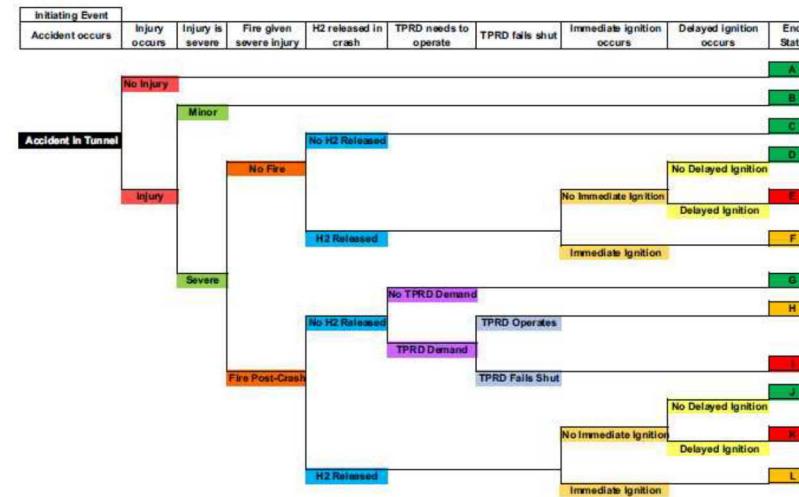
Hydrogen Risk Assessments and Consequence Modeling



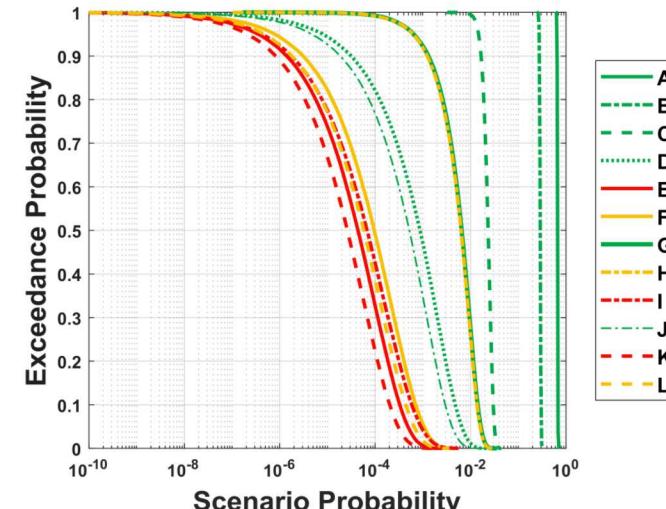
Dispersion modeling of leak with ventilation in repair garage



Jet fire modeling of effect of hydrogen leak on tunnel



Event tree for hydrogen vehicle in crash



Probability/likelihood of outcomes with uncertainty

Maritime Feasibility and Safety Analyses



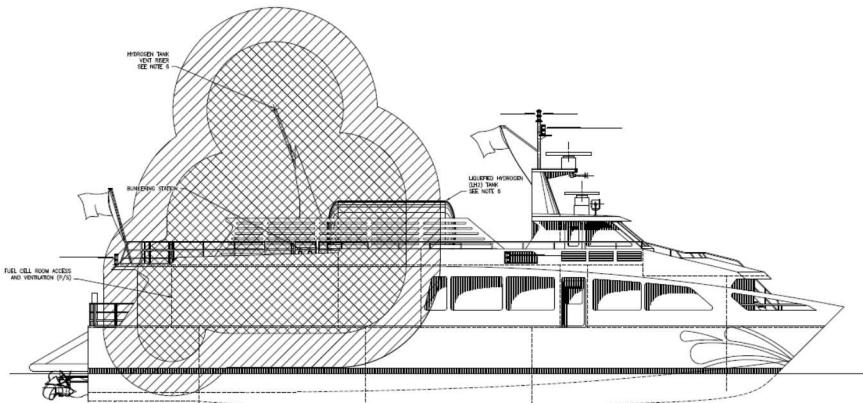
Feasibility studies funded by DOT/MARAD

SF-BREEZE high-speed hydrogen fuel cell ferry

- 1,000+ kg/day hydrogen demand

Zero-V hydrogen fuel cell coastal research vessel

- 2,400 nautical mile range
- Refueled with ~11,000 kg of LH₂



Previous Work in H2@Rail – Impact Figure of Merit

Preliminary results show trade-offs between all technologies

- More refinement and exploration needed, which will change rankings

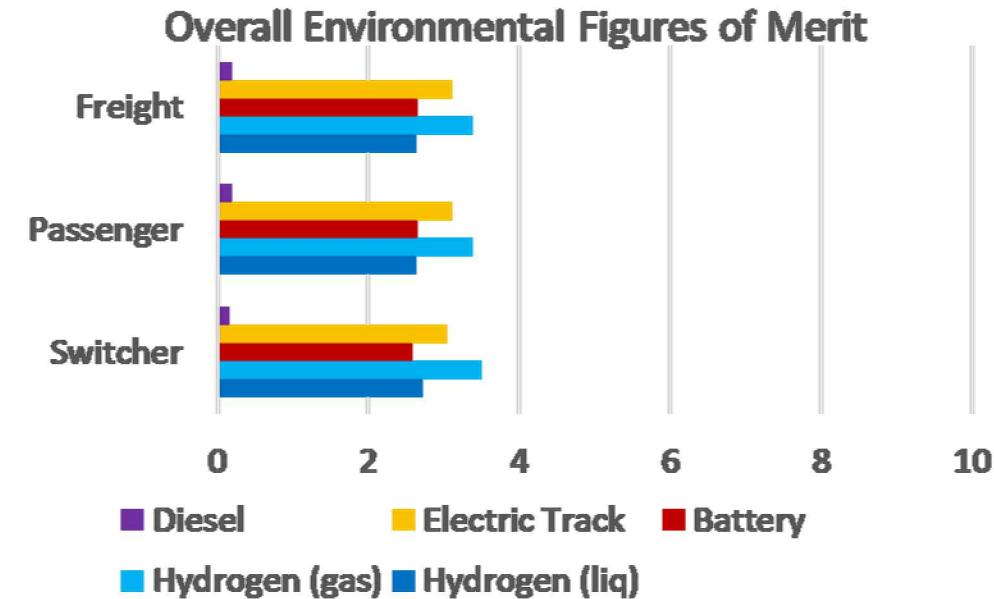
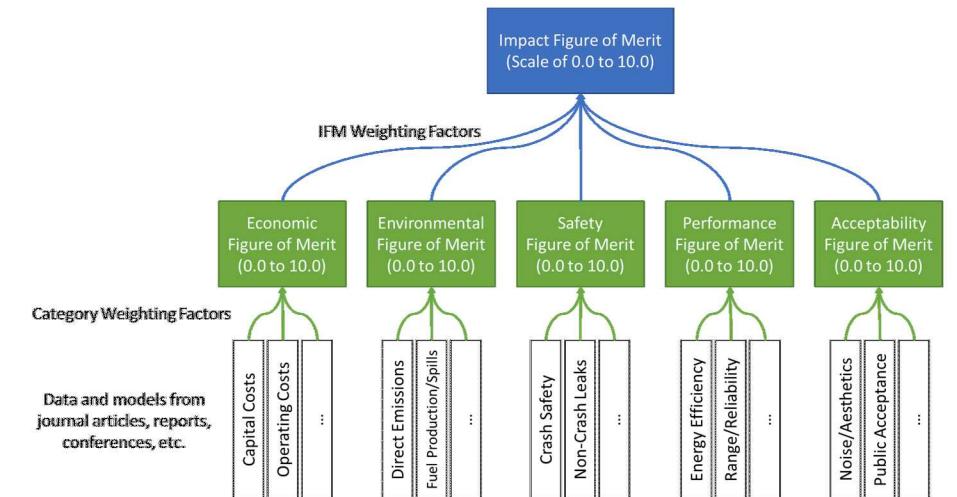
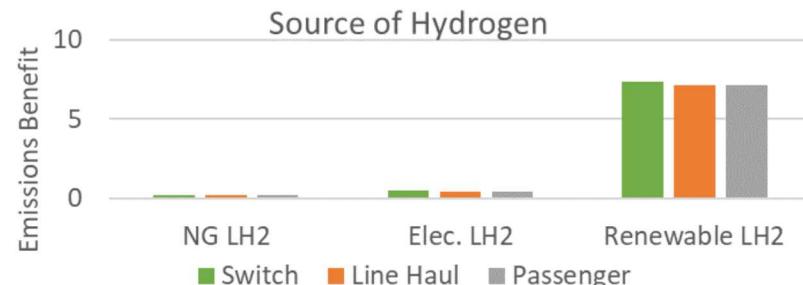
Emissions reduction benefit from hydrogen depends on the source of hydrogen

Reliability and cost of hydrogen locomotives needs to be investigated

- Impacts performance and economics

Fueling infrastructure needs to be investigated further

Safety needs to be investigated further



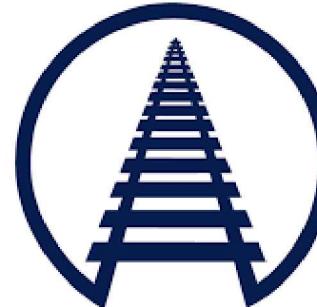
9 | Current Work – Safety Codes and Standards (DOT FRA)



Objective: Identify, collect, and summarize relevant domestic and international codes, standards and regulations with potential applicability for storing **hydrogen on-board** as a locomotive fuel.

Areas of Focus:

- Assess safety and design features for *on-board hydrogen as fuel rather than cargo*
 - E.g., fuel transfer connection on side of tender rather than top of tanker
 - Freight rail specifically
- **Best practices and gaps** in existing safety regulations and standards will be identified



Current Work – Safety Codes and Standards (DOE HFTO)

Objective: Identify rail-specific codes and standards requirements, best practices, and gaps for the use of hydrogen fuel cells for locomotive power applications

Areas of Focus:

- Identify safety standards and regulations applicable to the storage of hydrogen for a *wide variety* of rail applications
 - Storage in compressed gas cylinders (passenger or switcher) or cryogenic tank cars (freight)
 - Storage on **both rolling stock** (locomotive, railcars) and **stationary fueling infrastructure**
- **Gaps** in existing safety regulations and standards will be identified and recommended actions will be described (where possible)



Current H2@Rail Work – Fueling Infrastructure (DOE HFTO)

Objective: Assess the capability of current and near-term technologies to meet the needs of **freight locomotive hydrogen refueling**

Areas of Focus:

- **Evaluation of LH2 current fueling technologies** including a determination of basic conditions (flow rate, temperature, pressure)
- Capacity on locomotive and tender from collaborators at ANL
- **Basic design of LH2 refueling facility**
 - Production/delivery of H2 from collaborators at ANL
 - Three example designs with different capacities, location (urban, rural, port), and effect on similar technologies (e.g., light- and heavy-duty vehicles)
- **Basic cost estimate** for fueling infrastructure
 - Can be scaled or used in other analyses to estimate the overall cost of fuel



Future Work – Hydrogen Rail Safety Topics (DOT FRA)



Assessment of **post-crash outcomes** for passenger and freight rail

- Developing event sequence diagram with uncertainty quantification for hydrogen on both freight and passenger rail
- Modeling of consequences scenarios (CFD and/or reduced-order)

Recommendations on **emergency response**

- Recommendations on the minimum evacuation times and distances for passenger or freight rail following accidental release of hydrogen fuel

Recommendations on best-practices for **human performance** to ensure and maintain **safety during refueling operations**

- Review of the human factor issues surrounding refueling of hydrogen fueled train
- Develop recommendations on best practices and procedures for refueling

Identify potential mechanical loading environments experienced in railroad operations that may lead to **hydrogen embrittlement** concerns

- Literature review to identify where existing hydrogen studies overlap the mechanical loading conditions experienced in normal railroad operations and identify potential areas where further experimental research would be beneficial

(subject to change)

Future Work – Hydrogen Heavy-Duty Trucks (DOE HFTO)

Multiple proposals submitted on multiple projects to analyze refueling facilities for heavy-duty trucks

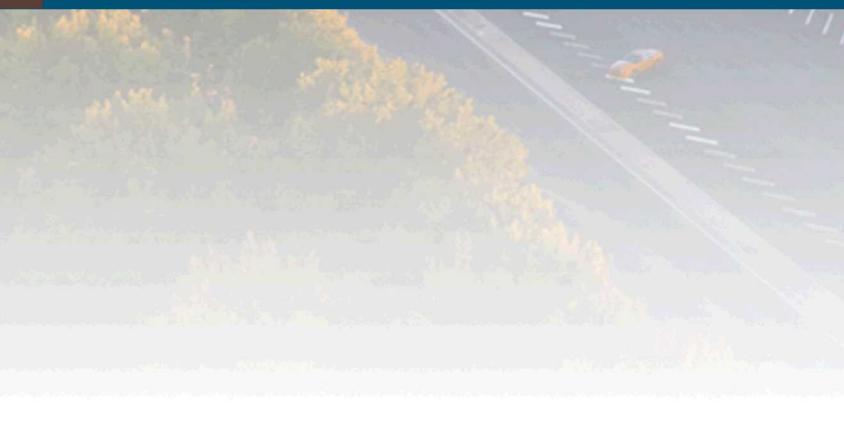
- Leveraging past work on H2FIRST Reference Station Projects

Stay tuned...





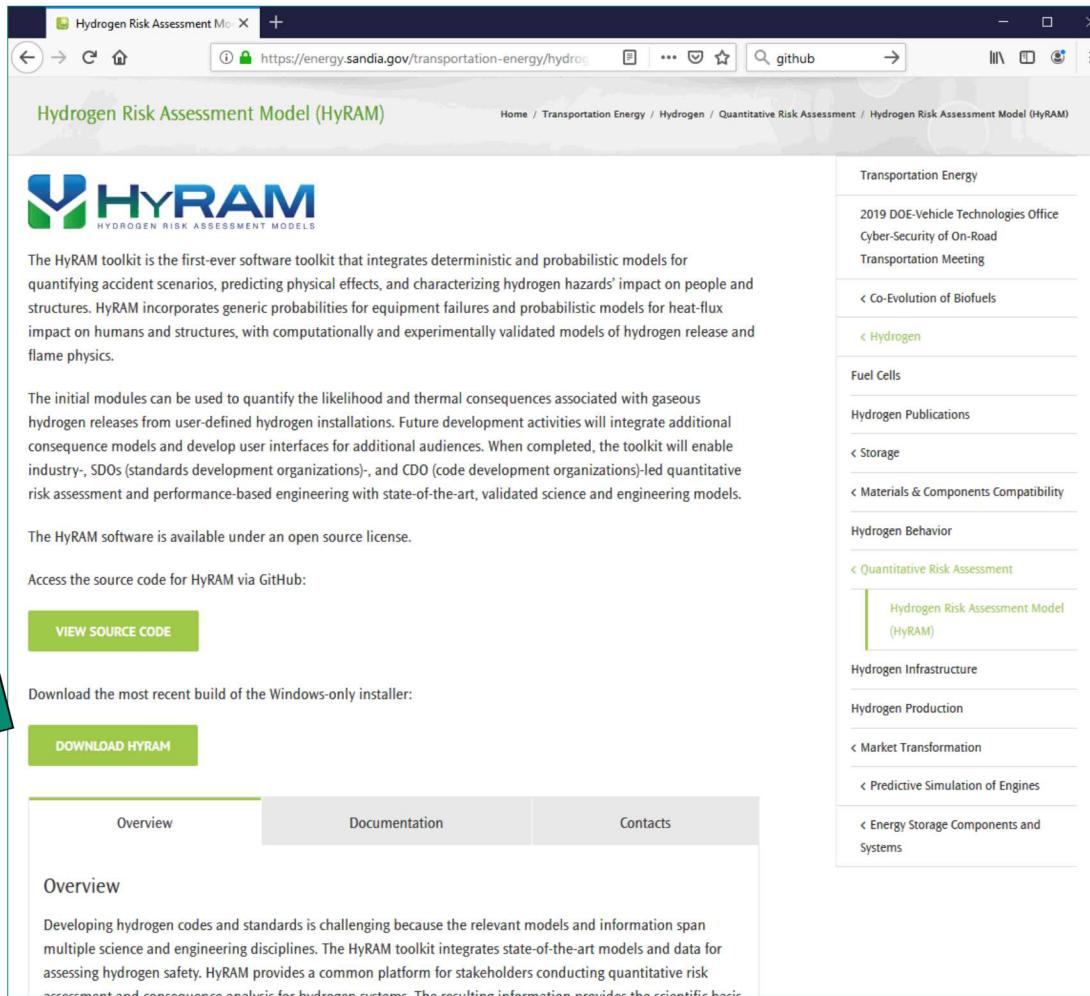
Thank you! Questions?



Brian Ehrhart

bdehrha@sandia.gov

HyRAM 2.0 can be installed as a Windows executable and as an open-source software, users have access to the source code



Hydrogen Risk Assessment Model (HyRAM)

HyRAM HYDROGEN RISK ASSESSMENT MODELS

The HyRAM toolkit is the first-ever software toolkit that integrates deterministic and probabilistic models for quantifying accident scenarios, predicting physical effects, and characterizing hydrogen hazards' impact on people and structures. HyRAM incorporates generic probabilities for equipment failures and probabilistic models for heat-flux impact on humans and structures, with computationally and experimentally validated models of hydrogen release and flame physics.

The initial modules can be used to quantify the likelihood and thermal consequences associated with gaseous hydrogen releases from user-defined hydrogen installations. Future development activities will integrate additional consequence models and develop user interfaces for additional audiences. When completed, the toolkit will enable industry-, SDOs (standards development organizations)-, and CDO (code development organizations)-led quantitative risk assessment and performance-based engineering with state-of-the-art, validated science and engineering models.

The HyRAM software is available under an open source license.

Access the source code for HyRAM via GitHub:

VIEW SOURCE CODE

Download the most recent build of the Windows-only installer:

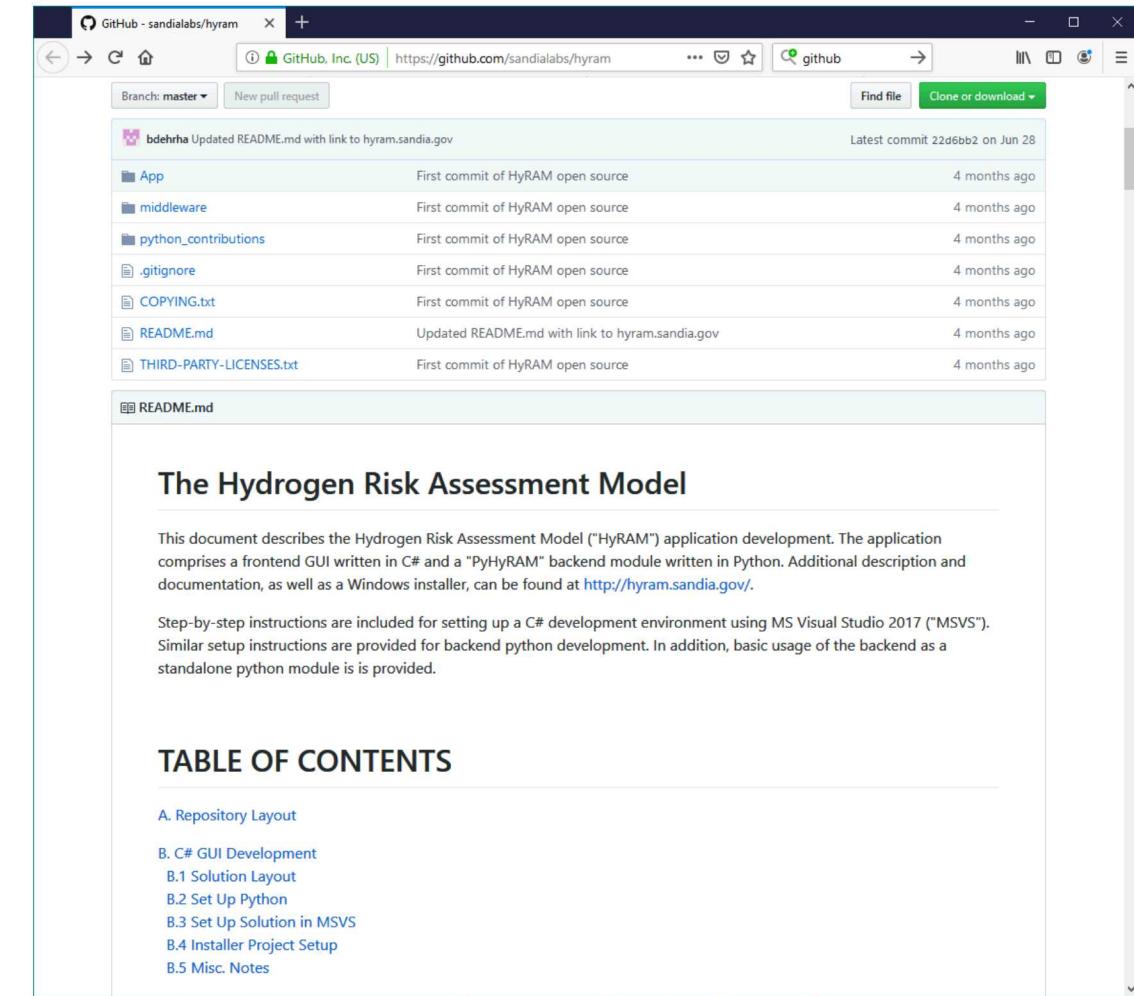
DOWNLOAD HYRAM

Overview **Documentation** **Contacts**

Overview

Developing hydrogen codes and standards is challenging because the relevant models and information span multiple science and engineering disciplines. The HyRAM toolkit integrates state-of-the-art models and data for assessing hydrogen safety. HyRAM provides a common platform for stakeholders conducting quantitative risk assessment and consequence analysis for hydrogen systems. The resulting information provides the scientific basis for informed decision making in the development of hydrogen codes and standards.

hyram.sandia.gov



GitHub - sandialabs/hyram

Branch: master New pull request

bdehrha Updated README.md with link to hyram.sandia.gov

Latest commit 22d6bb2 on Jun 28

File	Description	Age
App	First commit of HyRAM open source	4 months ago
middleware	First commit of HyRAM open source	4 months ago
python_contributions	First commit of HyRAM open source	4 months ago
.gitignore	First commit of HyRAM open source	4 months ago
COPYING.txt	First commit of HyRAM open source	4 months ago
README.md	Updated README.md with link to hyram.sandia.gov	4 months ago
THIRD-PARTY-LICENSES.txt	First commit of HyRAM open source	4 months ago

README.md

The Hydrogen Risk Assessment Model

This document describes the Hydrogen Risk Assessment Model ("HyRAM") application development. The application comprises a frontend GUI written in C# and a "PyHyRAM" backend module written in Python. Additional description and documentation, as well as a Windows installer, can be found at <http://hyram.sandia.gov/>.

Step-by-step instructions are included for setting up a C# development environment using MS Visual Studio 2017 ("MSVS"). Similar setup instructions are provided for backend python development. In addition, basic usage of the backend as a standalone python module is provided.

TABLE OF CONTENTS

- A. Repository Layout
- B. C# GUI Development
 - B.1 Solution Layout
 - B.2 Set Up Python
 - B.3 Set Up Solution in MSVS
 - B.4 Installer Project Setup
 - B.5 Misc. Notes

github.com/sandialabs/hyram

QRA estimates frequency and consequence for different leak sizes

Frequency of Leak

- 0.01%, 0.1%, 1%, 10%, 100%

Probability of Outcome

- Shutdown, jet fire, explosion, no ignition

Calculate Effects

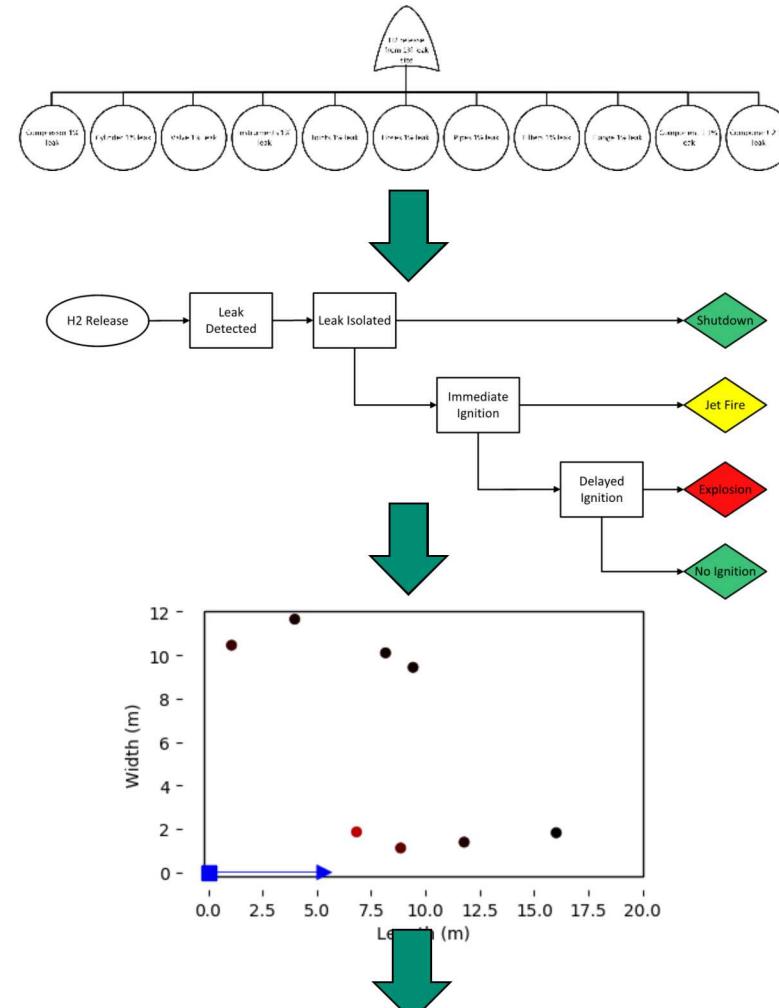
- E.g., thermal heat flux to occupant

Estimate Harm

- Probability of fatality based on effects

Risk Metrics

- 20 Scenarios



Risk Metric	Value	Unit
Potential Loss of Life (PLL)	1.246E-005	Fatalities/system-year
Fatal Accident Rate (FAR)	1.580E-002	Fatalities in 10 ⁸ person-hours
Average individual risk (AIR)	3.160E-007	Fatalities/year

Potential SCS Gaps for Hydrogen for Rail

AAR M-1004 Tender Cars

- Temperature for testing too high (LNG)
- Wall thickness too thin (LNG)
- Means of access to inner tank
- Refueling rate limited to 400 gpm

NFPA 2

- Bonding/grounding requirements for vehicles, something needed for rail
- Vague requirements for LH2 refueling
 - Risk assessment, personnel protection
- No requirements for LH2 non-public refueling
- Maximum LH2 storage likely prohibitive