SAND2021-2874PE

Past Examples and Current Efforts in Hydrogen for Rail

Presented by:

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CaFCP Working Group Meeting

SAND2021-XXXX PE

Past and Current Demonstration Projects

Past Projects - First Hydrogen Locomotive

Demonstration locomotive for mining applications

Testing in Nevada – 2002

Non-hybrid, PEM fuel cell

Metal-hydride storage (3 kg H2)

Multiple project partners, led by Vehicle Projects

Subsequently, Anglo American testing fuel cell locomotives in mines

- South Africa - 2012

https://www.nrel.gov/docs/fy02osti/32405a30.pdf
https://www.sciencedirect.com/science/article/pii/S1464285912701463

Past Projects – Passenger Rail

JR East railcar – Japan

- Testing in 2006 – 2007
- 1 railcar, 130 kW fuel cell system
- 35 MPa H2 storage
- 100 km/h (62 mph) max speed

RTRI railcars 2007 – 2008

- 2 railcars, 120 kW fuel cell system
- 35 MPa H2 storage, 18kg
- New testing – 2019

https://www.energy.gov/sites/prod/files/2019/04/f62/fcto-h2-at-rail-workshop-2019-hoffrichter.pdf
https://www.jreast.co.jp/e/press/20060401/
https://www.railwaygazette.com/traction-and-rolling-stock/rtri-tests-fuel-cell-multiple-unit/54518.article

Past Projects - BNSF Hydrogen Switcher

Joint project: BNSF, U.S. Army Corps of Engineers, Vehicle Projec

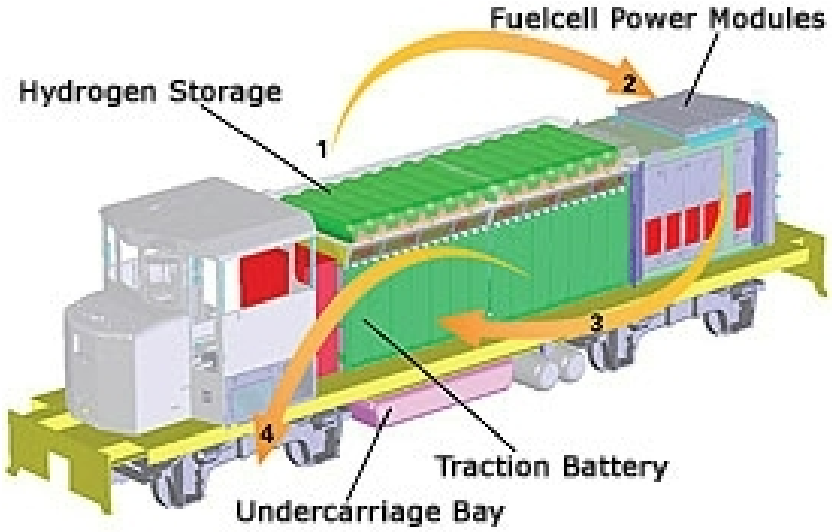
Testing in 2008 – 2009

14 carbon-fiber composite cylinders
- 68kg at 35 MPa

Two PEM fuel cell stack, 1.5 MW max power

Upgraded to road switcher:
- Additional power module
- 300 kg storage

Also demonstrated vehicle-to-grid power



https://www.bnsf.com/communities/environmental/fuel.html
https://www.energy.gov/sites/prod/files/2019/04/f62/fcto-h2-at-rail-workshop-2019-cleveland.pdf
http://www.railway-research.org/IMG/pdf/b6_miller_phd_arnold_r.pdf

Current Projects – Fuel Cell Trams

CRRC Tangshan – Chain

- Range: 40 km
- Fuel storage: 12 kg
  - 15 minute refueling
- 66 seats, 336 total passenger capacity
- Top speed: 70 km/h (44 mph)

CRRC Foshan – China

- Previous project in Qingdao

TIG/m – Doha, Qatar

- California supplier
- Operate for 20 hours before recharging

https://www.railwaygazette.com/technology-data-and-business/fuel-cell-tram-enters-service-in-tangshan/45399.article
https://www.railjournal.com/regions/middle-east/msheireb-tram-service-launched-downtown-doha/

Current Projects – Alstom Coradia iLint

Lower Saxony, Germany

Passenger service since September 2018

- 2 multiple units trains

530 days, >180,000 km in February 2020

Order placed for 12 additional trains to replace diesel multiple units (2022)

Hydrogen tanks and fuel cells mounted on roof

94 kg H2 per car

- Enough for ~1 day, 700 km (435 miles)
- GH2 storage at 35 MPa

Refueling station to be built by 2022

- Will replace current mobile refueling station
- Capacity: 1600 kg/day

https://www.alstom.com/press-releases-news/2020/5/successful-year-and-half-trial-operation-worlds-first-two-hydrogen
https://www.sciencedirect.com/science/article/pii/S1464285917301323
https://www.apta.com/wp-content/uploads/Coradia-iLint-%E2%80%93-Hydrogen-Fuel-Cell-Train_James_Varney-1.pdf
https://www.sciencedirect.com/science/article/pii/S1464285920303515

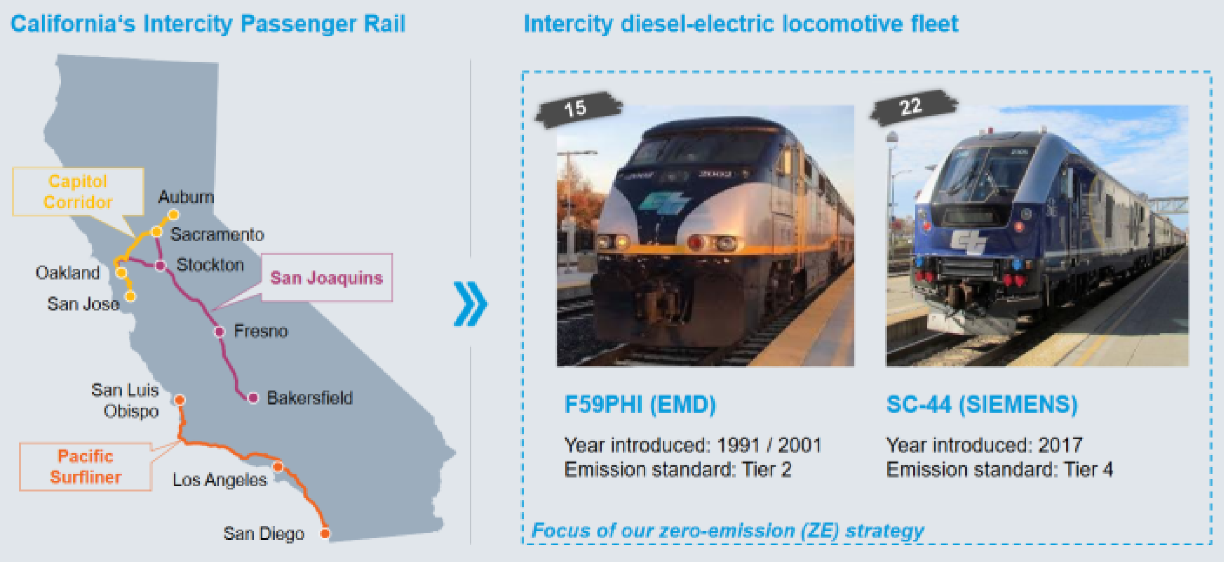
Upcoming Projects – California

San Bernardino

- Stadler FLIRT H2
- Seating space for 108 passengers
- Maximum speed of up to 79 mph (130 km/h)
- Planned introduction in 2024

Caltrans Intercity Passenger Rail Fleet

- Capital Corridor, San Joaquins, Pacific Surfliner
- Hydrogen identified as preferred solution
- First H2 pilot locomotive completed by 2025
- Full zero-emission fleet by 2035



https://www.gosbcta.com/from-dmu-to-zemu/
https://www.railwayage.com/passenger/light-rail/sbcta-first-u-s-hydrogen-fuel-cell-mu/
https://ww2.arb.ca.gov/sites/default/files/2020-10/Day%201%20Ext%205%20Caltrans%2020201026.pdf

Other Upcoming Projects

HydroFLEX – UK

- U. of Birmingham, Porterbrook
- Mainline testing began September 2020

Breeze – UK

- Alstom
- First trains in service ~2024

HYBARI – Japan

- JR East, Toyota
- Testing in 2022

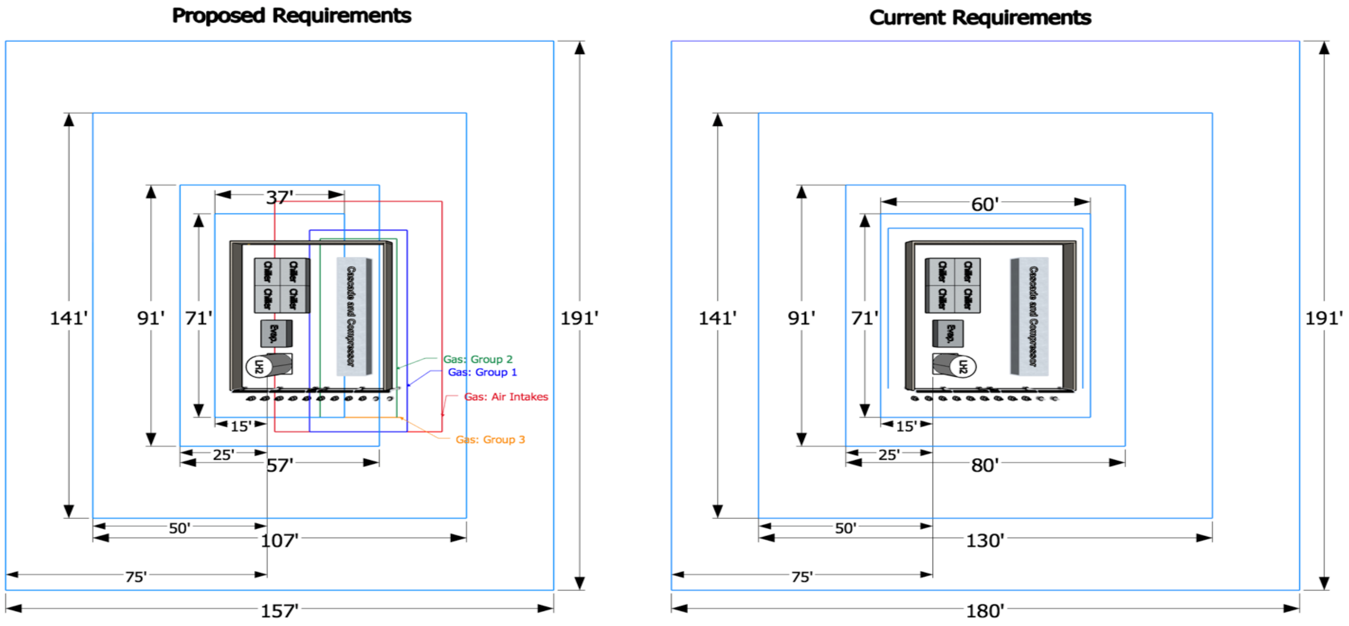
https://www.theengineer.co.uk/uks-first-hydrogen-train-makes-mainline-debut/
https://www.alstom.com/press-releases-news/2020/7/eversholt-rail-and-alstom-invest-further-ps1-million-breeze-hydrogen
https://global.toyota/en/newsroom/corporate/33954855.html

Background and Current Efforts at Sandia

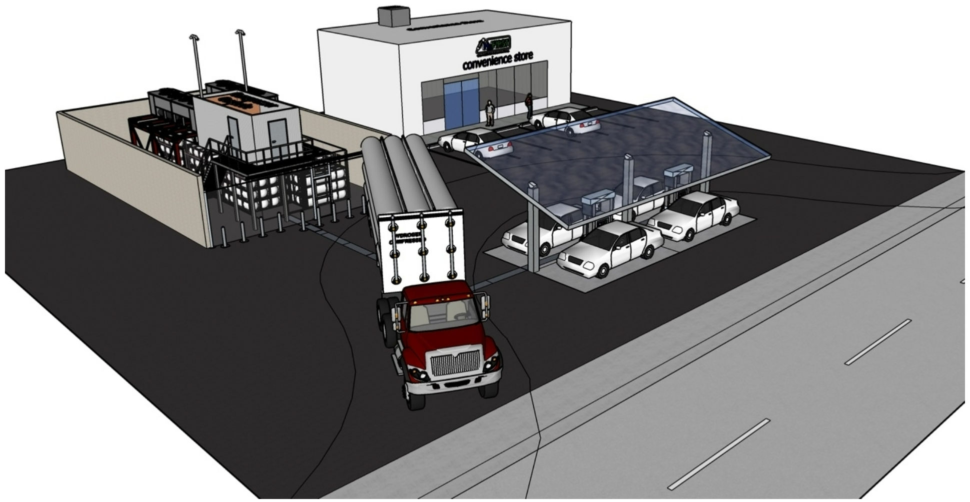
Light-Duty Vehicle Infrastructure Studies

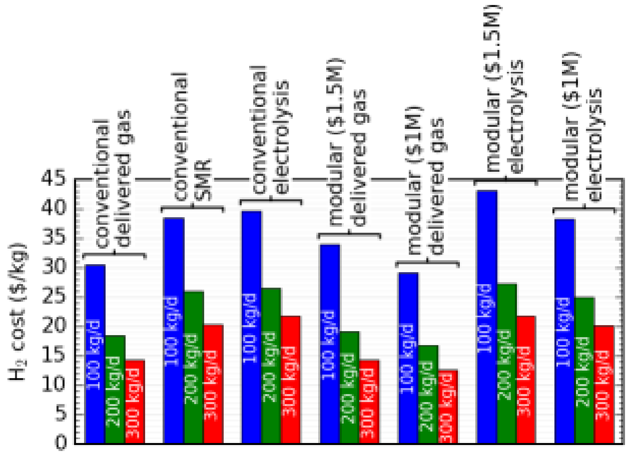
Publicly available system designs for stakeholders

Focusing on NFPA 2 code



Layout footprint quantification and comparison

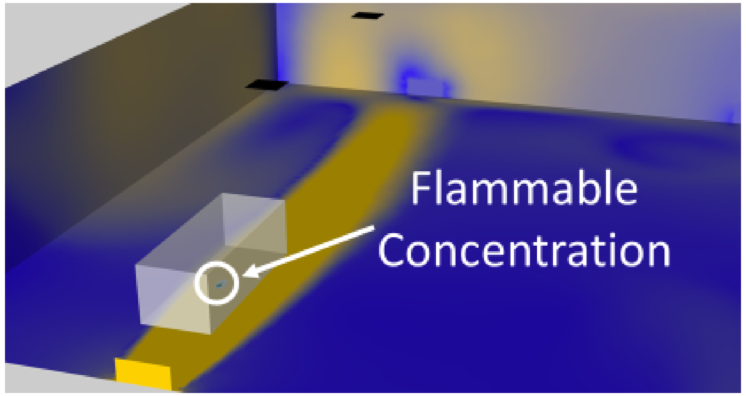




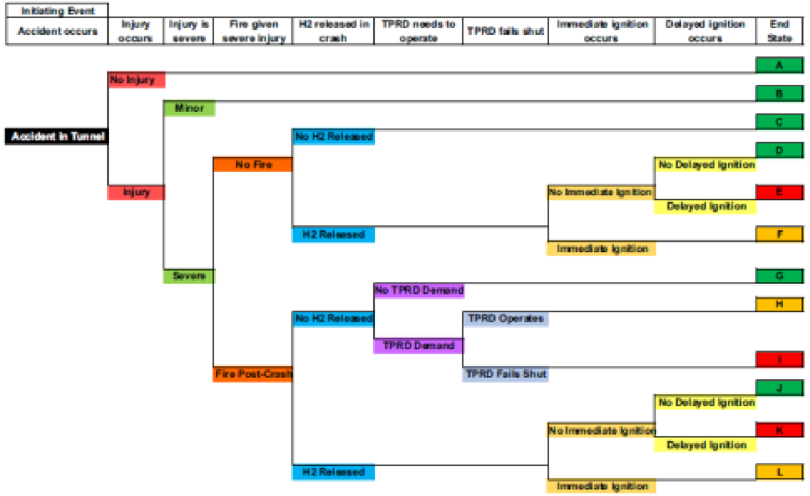
Economic Comparisons

https://www.osti.gov/biblio/1604872
https://www.hydrogen.energy.gov/pdfs/review17/pd139_hecht_2017_o.pdf

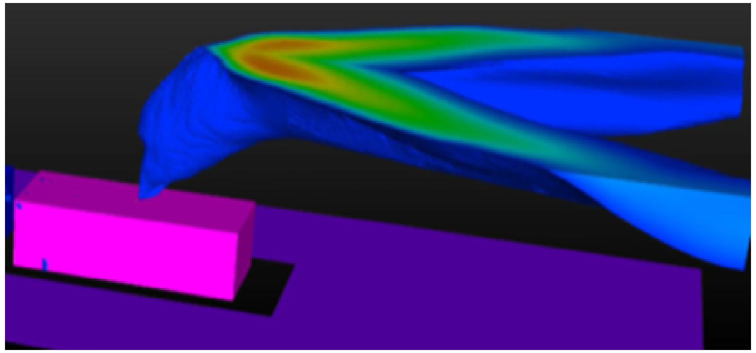
Hydrogen Risk Assessments and Consequence Modeling



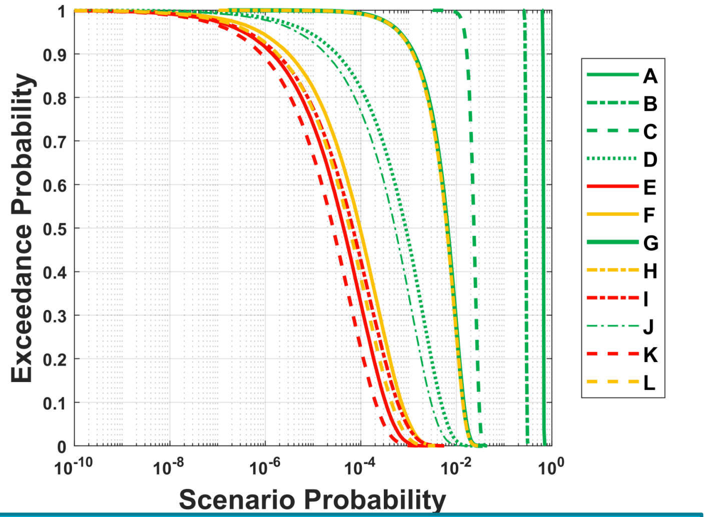
Dispersion modeling of leak with ventilation in repair garage



Event tree for hydrogen vehicle in crash



Jet fire modeling of effect of hydrogen leak on tunnel



Probability/likelihood of outcomes with uncertainty

https://energy.sandia.gov/programs/sustainable-transportation/hydrogen/hydrogen-safety-codes-and-standards/
https://energy.sandia.gov/programs/sustainable-transportation/hydrogen/hydrogen-safety-codes-and-standards/quantitative-risk-assessment/

Previous Work in H2@Rail – Impact Figure of Merit

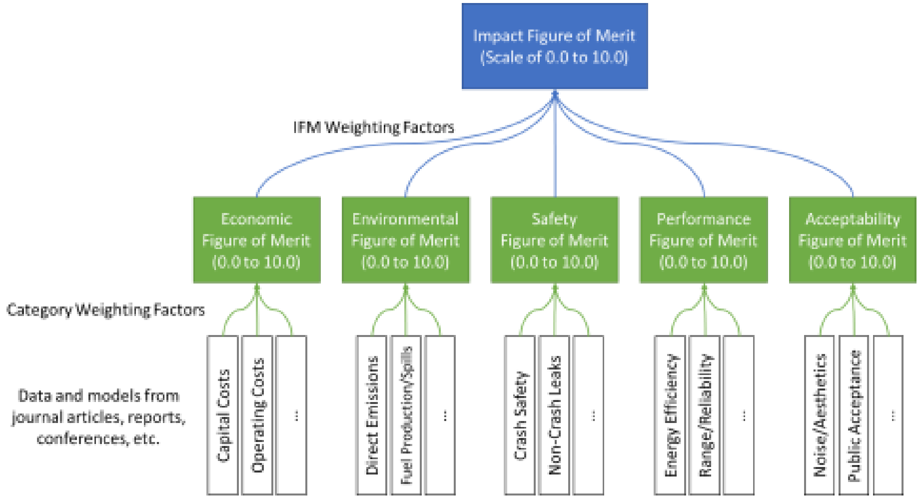
Preliminary results show trade-offs between all technologies
- More refinement and exploration needed, which will change rankings

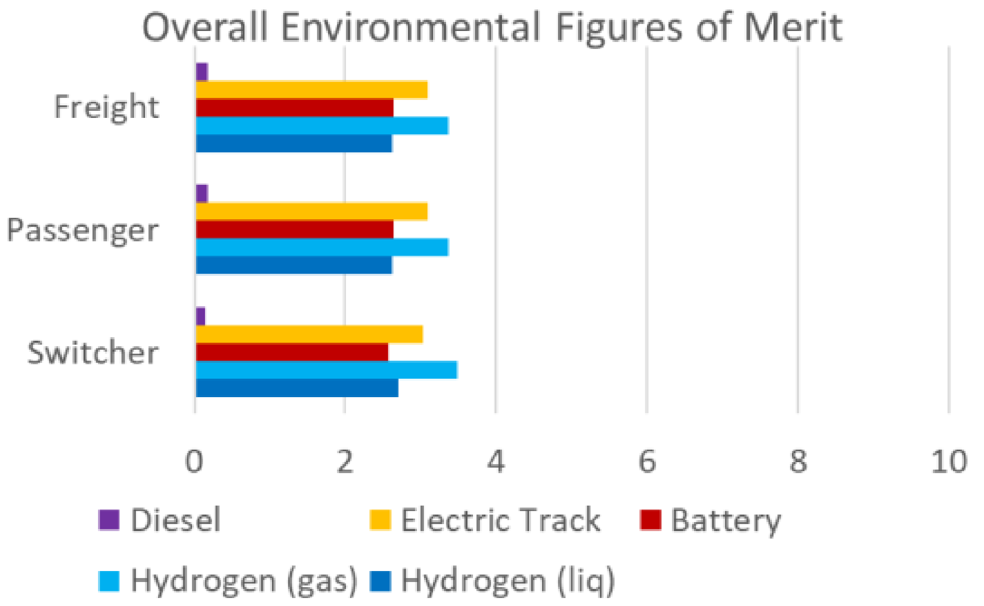
Emissions reduction benefit from hydrogen depends on the source of hydrogen

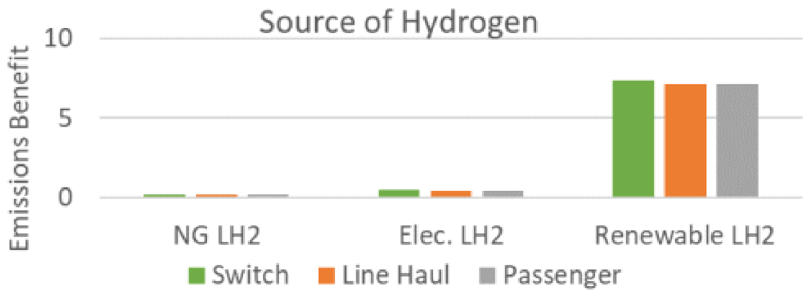
Reliability and cost of hydrogen locomotives needs to be investigated
- Impacts performance and economics

Fueling infrastructure needs to be investigated further

Safet







https://www.energy.gov/sites/prod/files/2019/04/f62/fcto-h2-at-rail-workshop-2019-ehrhart.pdf

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
  - Focus on 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 and passenger rail hydrogen refueling

Areas of Focus:

- Evaluation of GH2 and 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 refueling facilities
  - Production/delivery of H2 from collaborators at ANL
  - At least 5 example designs with different capacities, location (urban, rural, port), and application (freight, passenger, MU)
- Basic cost estimate for fueling infrastructure
  - Can be scaled or used in other analyses to estimate the overall cost of fu

Current 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

Thank you! Questions?

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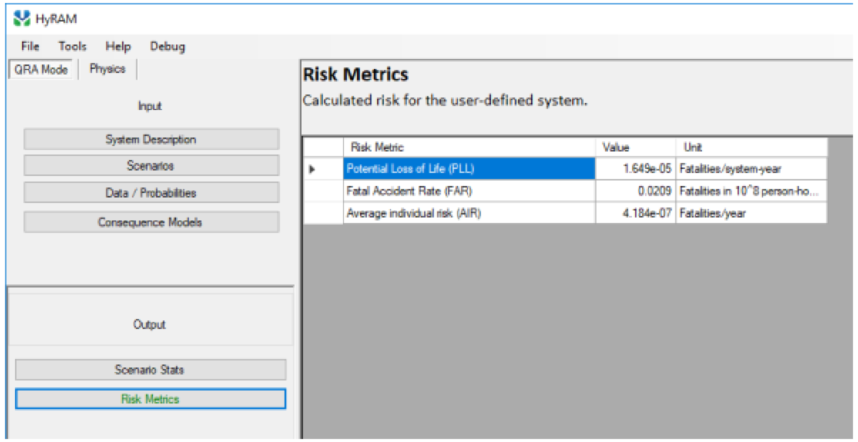
Hydrogen Risk Assessment Models (HyRAM)



Core functionality:

Quantitative risk assessment (QRA) methodology

Frequency & probability data for hydrogen component failures

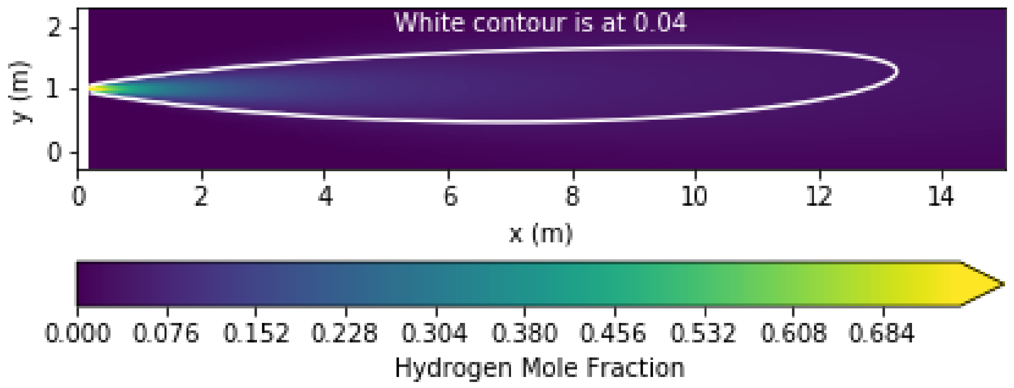
Fast-running models of hydrogen gas and flame behaviors

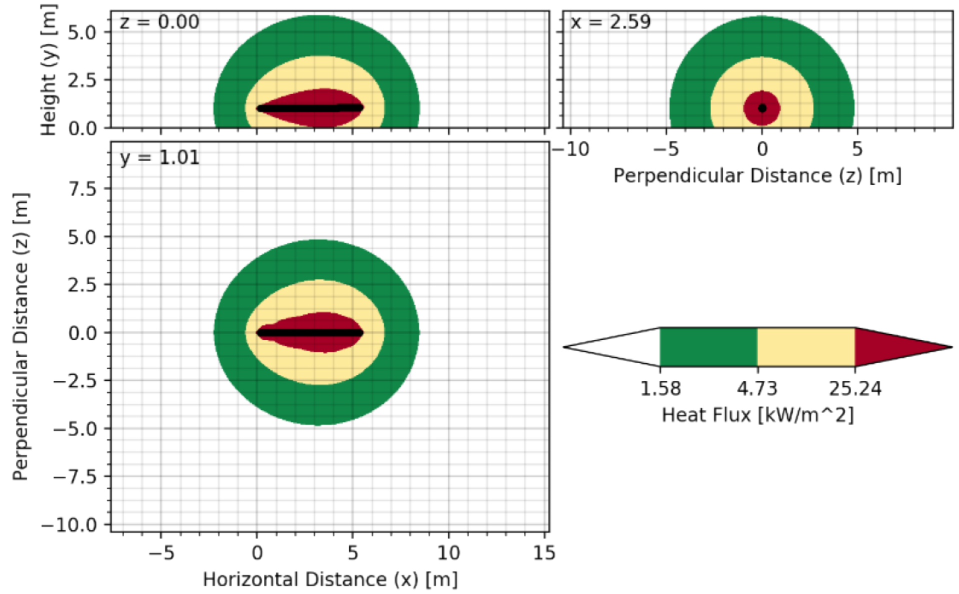
Key features:

GUI & Mathematics Middleware

Documented approach, models, algorithms

Flexible and expandable framework; supported by active R&D





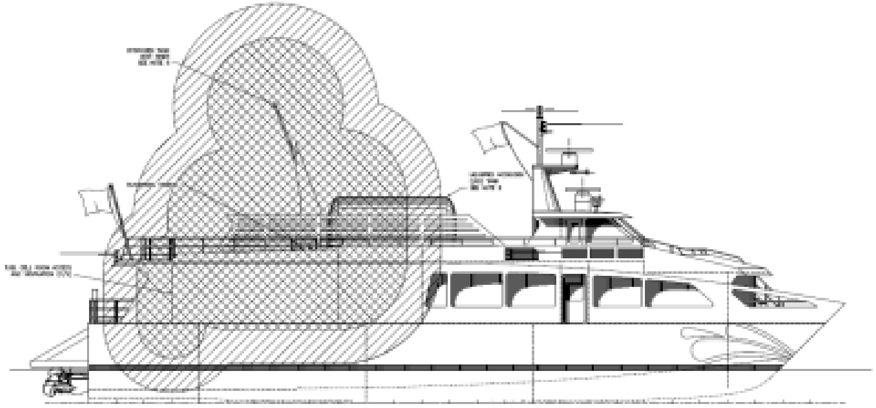
https://hyram.sandia.gov

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



https://energy.sandia.gov/programs/sustainable-transportation/hydrogen/market-transformation/maritime-fuel-cells/

QRA estimates frequency and consequence for different leak sizes

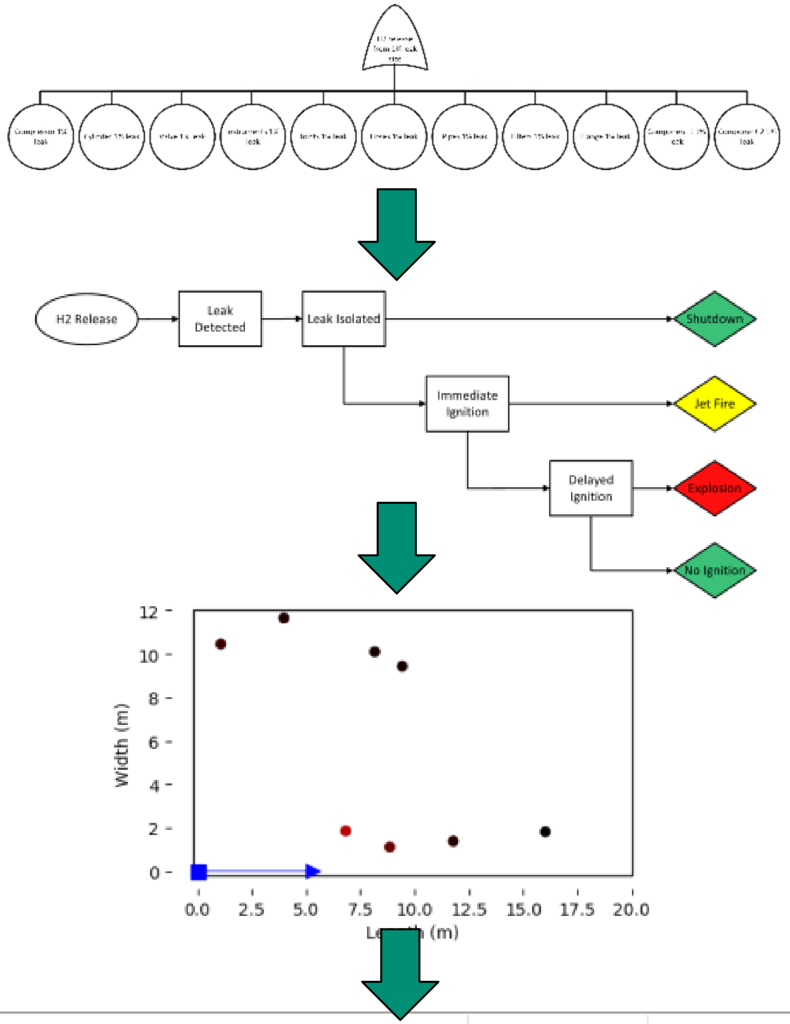
Frequency of Leak
- 0.01%, 0.1%, 1%, 10%, 100%

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