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Sandia National Laboratories

Trade-Offs and Current Efforts in Hydrogen for Rail

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Decarbonizing Heavy Duty Transport

Workshop by the Stanford Hydrogen Focus Group

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Introduction to Sandia

Multi-Mission DOE NNSA Lab: ***"Exceptional Service in the National Interest"***

Federally Funded Research and Development Center (FFRDC)

- Government owned, contractor operated

Main sites: Albuquerque, NM and Livermore, CA

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

Hydrogen and Fuel Cells Research Program

- 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

Past Examples of Hydrogen for Rail

Demonstration **mining locomotive**

- Nevada – 2002

Passenger rail - JR East and RTRI

- Japan – 2006-2008

Switcher locomotive – BNSF

- California and Utah – 2008-2009
- Switch yard, road switcher, power-to-grid

Current projects: passenger trams and Coradia iLint

https://www.nrel.gov/docs/fy02osti/32405a30.pdf
https://www.energy.gov/sites/prod/files/2019/04/f62/fcto-h2-at-rail-workshop-2019-hoffrichter.pdf
https://www.energy.gov/sites/prod/files/2019/04/f62/fcto-h2-at-rail-workshop-2019-cleveland.pdf

Potential Benefits for Hydrogen for Rail

Fast fueling – easier to move molecules than electrons at scale

Same track – no need to electrify all routes

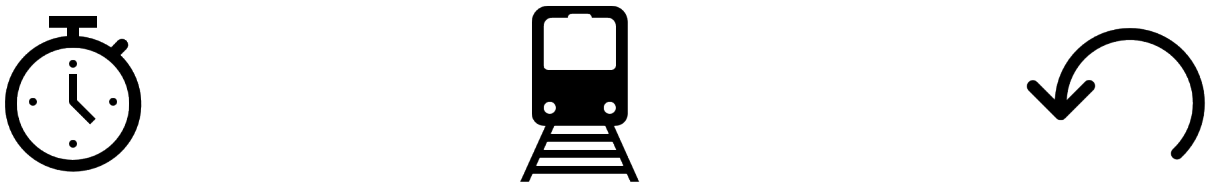
Captive fleets – specific routes, specific yards can be supplied by single refueling point

Already electric – diesel-electric already uses electric traction motors

- Conversion of existing rolling stock possible

Zero tailpipe emissions – no distributed emissions at point-of-use

- Rail lines go everywhere: urban/rural, residential/industrial, etc.



Trade-Offs in Hydrogen for Rail – Environment and Safety

Emissions depend on **source** of hydrogen

- Can be carbon-free, but steam methane reforming (without CCS) is not
- Emissions from electricity (used for electrolysis) depend on grid-mix

Hydrogen takes **energy to store** at high densities

- Compression and liquefaction take energy

All fuels have **safety** hazards

- Different flammability characteristics than diesel
- Gaseous hydrogen stored at high pressure
- Liquid hydrogen may need to vent occasionally
- No contamination due to leak (e.g., groundwater)

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

Trade-Offs – Acceptance and Economics

No diesel **engine noise**

- Not a large impact; train noise is mostly wheel noise

Local aesthetics may benefit from hydrogen

- No hanging catenaries like electrified track
- No local smog-producing emissions like diesel

Acceptability and **Reputation**

- Public may be initially concerned by nearby hydrogen

Total cost of introducing a new fuel includes:

- Locomotives, refueling/maintenance facilities, training/transition

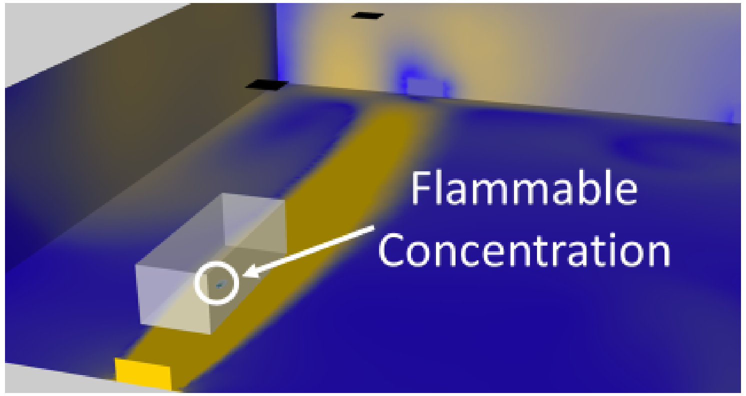
Potential **future markets** for hydrogen:

- Electricity storage/grid services/arbitrage
- Refueling of other transportation modes (vehicles, maritime)

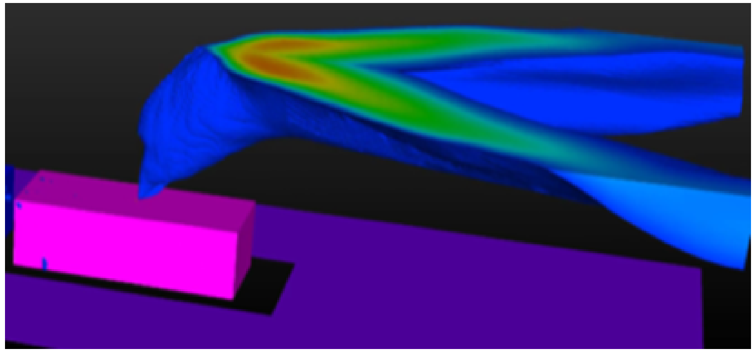
D. H. Cato, Prediction of Environmental Noise from Fast Electric Trains, Journal of Sound and Vibration 46(4) 1976, pp. 483-500
http://blog.amtrak.com/2014/01/catenary-wire/

Current Efforts at Sandia

Leveraging Hydrogen Risk and Consequence Modeling



Dispersion modeling of leak with ventilation in repair garage

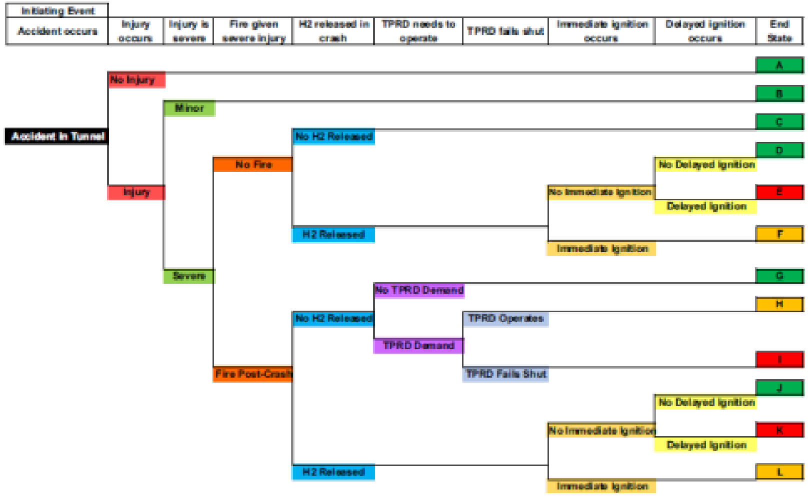


Jet fire modeling of effect of hydrogen leak on tunnel

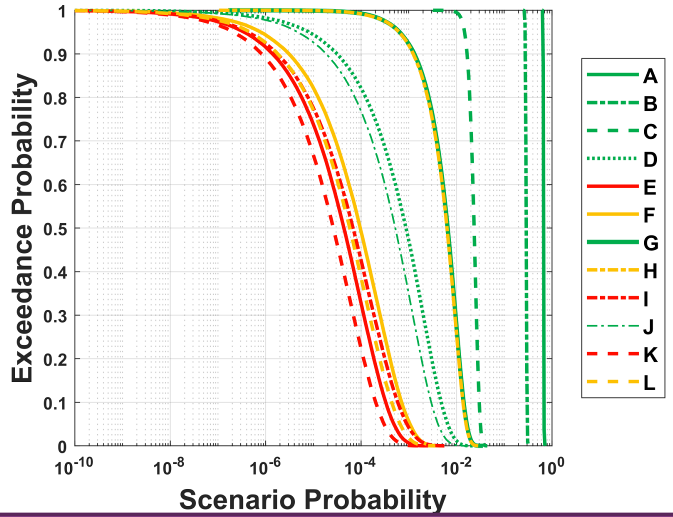
HyRAM
HYDROGEN RISK ASSESSMENT MODELS

https://hyram.sandia.gov

Open-source hydrogen safety calculation toolkit



Event tree for hydrogen vehicle in crash



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/

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

https://railroads.dot.gov/
https://www.aar.org/

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)

https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=2

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

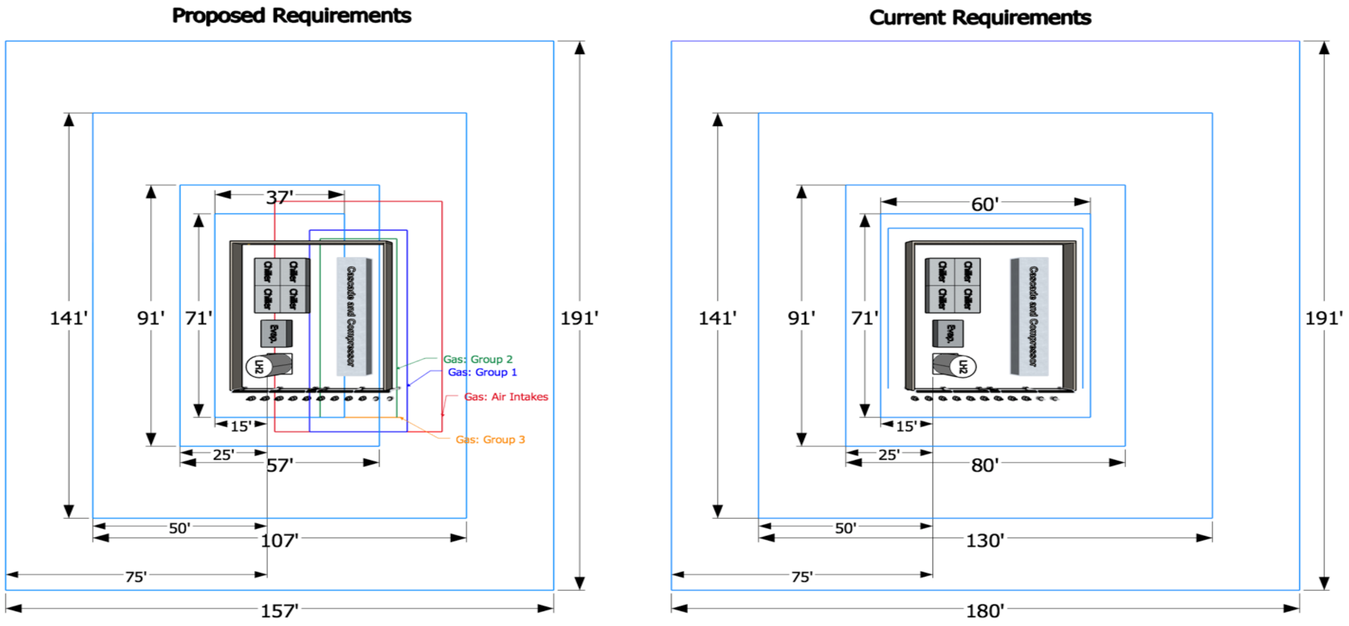
Identify potential mechanical loading environments experienced in railroad operations that may lead to **hydrogen embrittlement** concerns

- 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

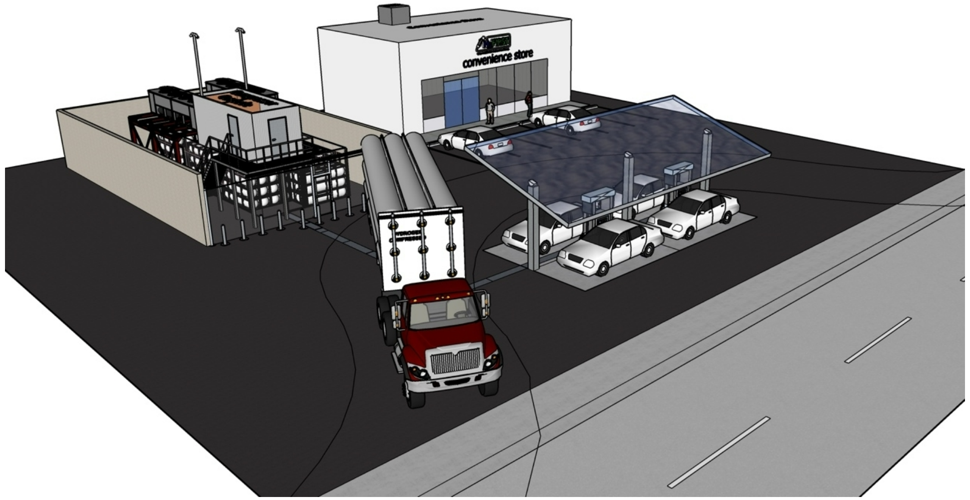
Leveraging Light-Duty Vehicle Infrastructure Studies

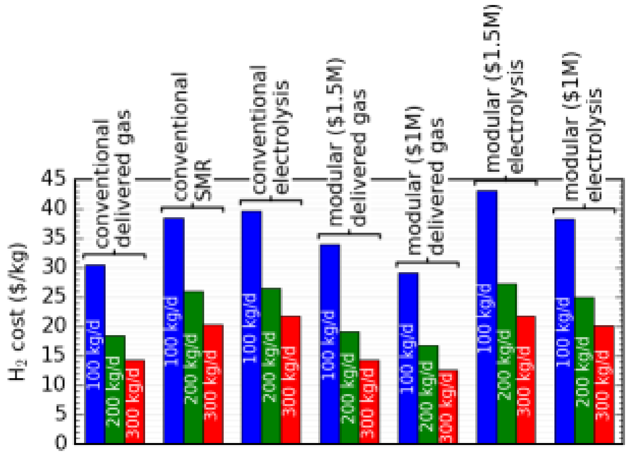
Publicly available system designs for stakeholders

Focused 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

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

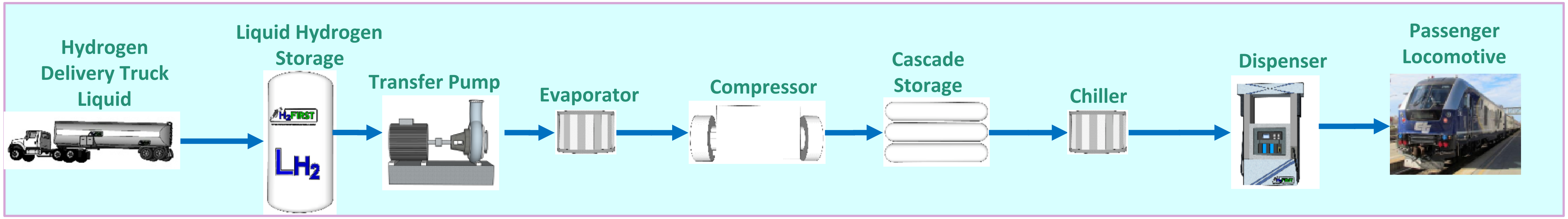
Objective: Assess the capability of current and near-term technologies to meet the needs of **freight and passenger** rail hydrogen refueling

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 fuel

https://www.railwayage.com/passenger/light-rail/sbcta-first-u-s-hydrogen-fuel-cell-mu/
https://www.progressiverailroading.com/csx/article/Freight-and-passenger-railroads-seek-cooperation-compromise-on-jointly-used-lines--51535

Draft Preliminary Refueling Design



Example draft preliminary refueling facility

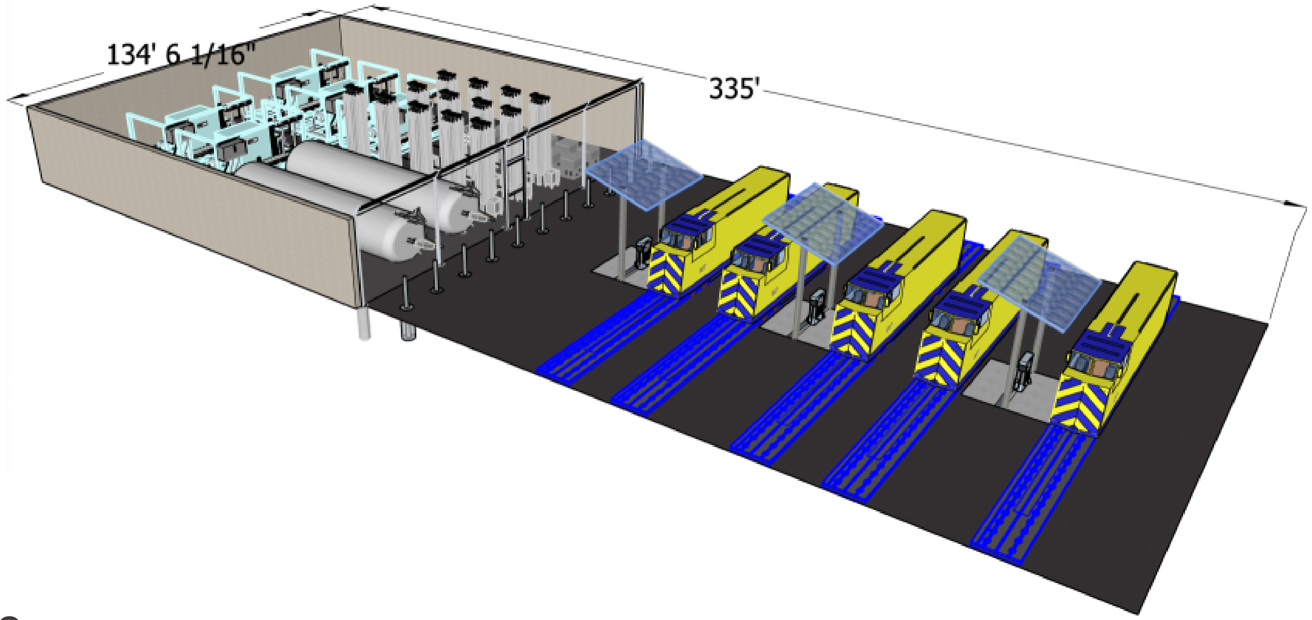
- Refueling 50 locomotives in 10 hours
- 10 kg/min fueling rate, 1 hour total time

Liquid H_2 stored on-site, dispensing gaseous H_2

- Larger facilities could dispense LH2

Evaporator and compressor used directly

- Could also use cryopump
- Cascade storage and compressor sizing trade-off



Summary and Future Work

Hydrogen may be good fit for some rail applications

- Fast refueling and captive fleets

Safety is important consideration for all different fuels

- Codes and standards should be based on scientific justification
- Early review of requirements may help to enable hydrogen applications

Infrastructure is important to consider alongside the trains themselves

- New fuel requires new infrastructure with important differences

Potential Future Work

- Assessing indoor releases for rail maintenance facilities
- More refined analyses for different scale applications (e.g., short- vs. long-haul)

Thank you!

Questions?