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Hydrogen Safety – Best Practices, Codes, and Standards

Presented to EAPUOC

April 14, 2026

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Agenda

1. Hydrogen Accidents
2. Hydrogen Projects
    - National, and local
3. Codes and Standards
    - Special mentions
    - Gaps
4. Conclusion

Hydrogen Related Incidents

- **Electrolysis:** Hydrogen storage tank explosion in electrolysis unit, Gangneung, South Korea, 2019 (Link)
  - Cause: design flaw, lacked O2 removal, no static charge prevention in H2 tank

- **Tanker:** Explosion and fire during hydrogen transportation trailer filling in Santa Clara, California, June 2019 (Link)
  - Leak in transfer hose, resulted in the temporary shutdown of multiple hydrogen fueling stations in the San Francisco area.

- **Pipeline:** Fire from a hydrogen pipeline, The Netherlands, 2007 (Link)
  - Cause: leak due to ground movement in several years (unauthorized heavy traffic, heavy equipment on ground cover, lack of inspection, etc.)
- **Hydrogen Refueling Station :** Norway 2019 – H2 Refueling Station Explosion Link
- **Hydrogen bus:** Bakersfield California, 2023 (link) video link
  - Cause : not known

Electrolysis South Korea 2019

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South Korea 2019

- **Electrolysis:** Hydrogen storage tank explosion in electrolysis unit, Gangneung, South Korea, 2019 (Link)
  - Cause: design flaw,
  - lacked O2 removal,
  - no static charge prevention in H2 tank

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South Korea 2019

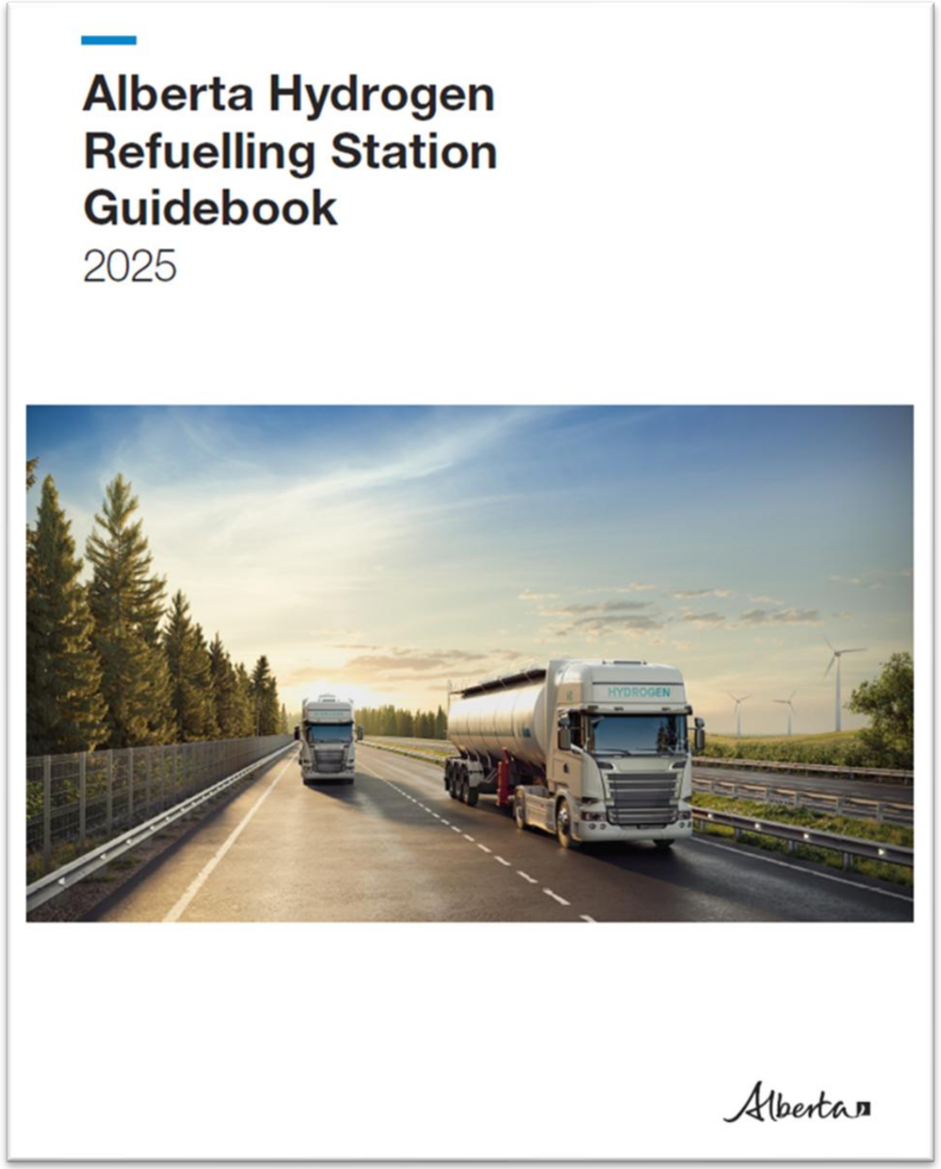
South Korea 2019

Norway 2019 – H2 Refueling Station Explosion

- A hydrogen refueling station exploded and caught fire in Sandvika, Norway on June 10. According to reports from the Uno-X station, the explosion was very powerful. It triggered airbags in nearby cars and caused closures to the busy E18 and E16 intersection. A safety zone of 500 meters was recommended by the fire service. Link

Take away from Norway Incident

- 500 meters of land use planning
- Facility Siting – consequence analysis-based plant layout or equipment placement
- Fire Protection Design
  - Preference of passive protections (blast walls) over active protections (detection/alarms)



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Santa Calara California June 2019

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Figure 7. Incident Trailer Cab and Front Module

Figure 8. Doors on Rear Module Incident Trailer

Figure 9. Rear Incident Trailer with Open Doors

Figure 10. Front and Side Panels on Adjacent Module in Bay #2

The conditions of the 24 vessel PRDs on the incident trailer front module and release mechanism during the incident are shown in Table 1. Ten of the cylinders vented from PRDs that actuated either fully or partially. Depressurization from the other 14 cylinders occurred due to PRD cracking or connector/tubing/seal leakage.

Table 1. PRD Actuations and Damage

PRD Condition after Incident	Number (%)
Actuated PRD	5 (21%)
Partially Actuated PRD	5 (21%)
No Actuation; Leaking connection	10 (42%)
Failed/cracked PRD	4 (17%)

Results of Blast Wave

- *The front module explosion produced minor blast wave damage to at least one nearby structure. A window broke in a small control building about 125 ft. (38 m) away from the module. The broken glass was found outside the building, indicating that the suction pressure of the blast wave was responsible.*

*The Santa Clara Fire Department responded and ordered an evacuation radius of 500 yards (**457 m),** but relatively few people were affected because there were not many people working in the surrounding industrial premises at the time of the incident.*

Human Error – Drivers (2 injuries)

Consequences

- Suspension of hydrogen deliveries up to 4 months
- The initial hydrogen leak was caused by either a cracked O-ring or leaking cone and thread fitting on the front module hydrogen isolation valve.
- The trailer driver attempted an *unauthorized repair* of the leaking valve without properly isolating the hydrogen supply piping
- There was a *misunderstanding* of the senior driver's instructions to the trainee. The senior driver told the trainee to stop the trailer fill, but the fill control process had been stopped ten minutes previously. When the trainee attempted to stop the fill a second time, the trainee accidentally actuated the "Purge/Enable Trailer" control button which opened the pneumatic valves and *allowed hydrogen flow into the disconnected manifold pipe.*

Aftermath

- **Hydrogen Explosion** –caused by the accumulation and subsequent ignition of hydrogen released into the front module. Confinement by the module walls and vessels prevented free dispersal of the released hydrogen. The open module roof did not provide adequate venting to prevent damaging overpressures from developing upon ignition of the accumulated flammable mixture within the module.
- Hydrogen Jet Fires
- Subsequent diesel fuel fires and tire fires.
- NFPA 2 had no set back distances

Report Recommendations

1. NFPA should consider providing additional guidance on GH2 system repairs in NFPA 2-2020 section 7.1.10 Considerations should also include requirements for training all personnel with responsibilities on mobile and stationary hydrogen systems.

2. CGA and other standards organizations (e.g., CSA Group) to explore

improvements in their standards for PRDs intended to actuate and relieve cylinder pressures during fire exposure. Improvements are needed to specify direct fire exposure requirements and vent line thrust restraint requirements.

3. DOT and CGA should conduct an in-depth examination on fire protection of highpressure hydrogen cylinders and the requirements for PRDs. Transportation regulations allow cylinders without PRDs under certain conditions and should be part of the evaluation. All potentially affected parties, including the fire service/protection community, should participate in the review and discussion of pertinent research, testing, and incident compilations. This discussion would be facilitated by a comprehensive quantitative risk assessment comparing risks of cylinder use with and without PRDs as well as consideration of other fire protection measures.

Report Recommendations

4. NFPA should consider including recommendations (or requirements) for hydrogen process and transfer controls to implement best practices (such as those described in guidelines and standards cited in this report) in NFPA 2 for clarity and operator understanding. A proposal to this effect is under review for inclusion in the next edition of NFPA 2.

Hydrogen Pipeline Fire

IMPEL - French Ministry for sustainable development DGPR/ SRT/ BARPI – Dutch Inspectorate

ARIA No. 35860

Leakage of a hydrogen-pipeline due to an inadequate inspection philosophy

12 october 2007

Binnenmaas (South Holland)

The Netherlands

Leak
Pipeline
Hydrogen
Cathodic Protection
Stressing factors
Inspection

- Fire from a hydrogen pipeline, The Netherlands, 2007 (Link)

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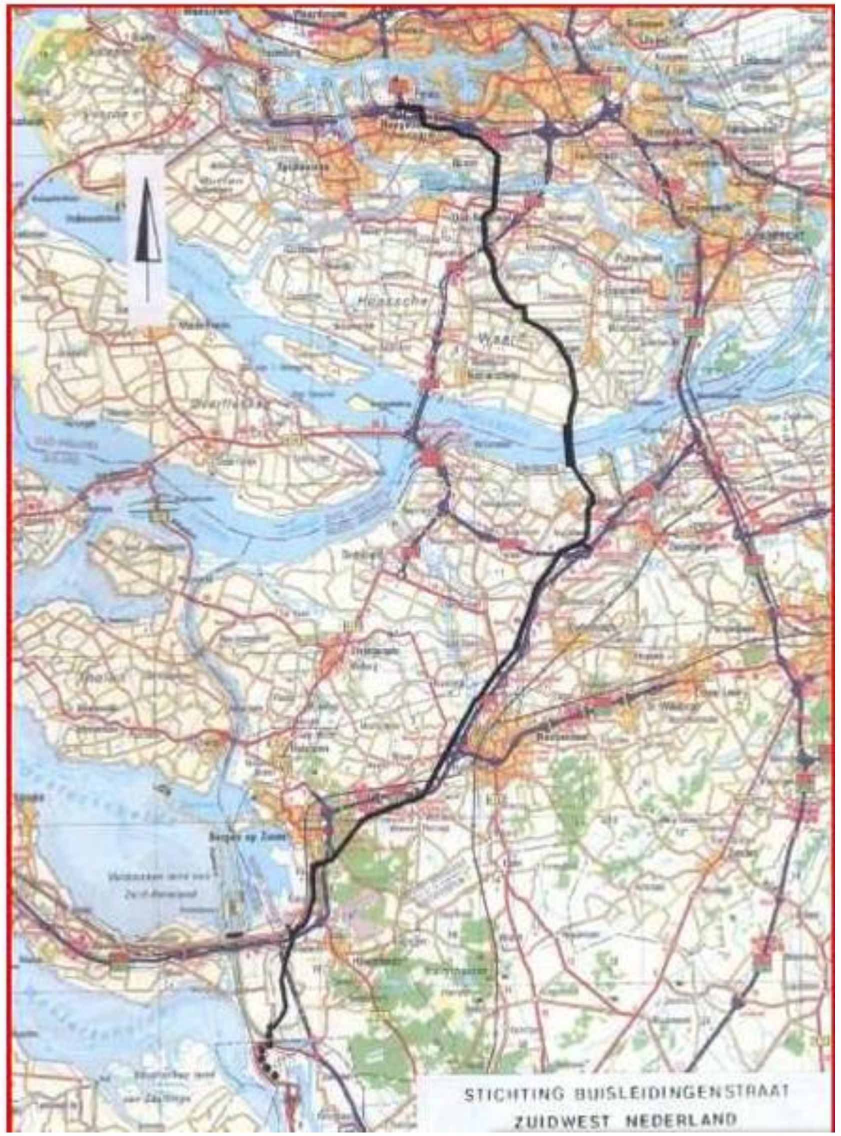
H2 Pipeline Fire, 2007

The site:

- The Netherlands Pipeline Corridor (location of the accident: 300 metres from the village of Heinenoord (municipality of Binnenmaas) in the province of South Holland.

The involved unit:

- A pipeline, transporting pressurized hydrogen gas (75 bar, 6 inch, steel) from Antwerp (Belgium) to Rotterdam (the Netherlands). The leakage occurred at a location at which the pipeline entered a building and contained a “CP coupling” (a device to interrupt the cathodic protection).



H2 Pipeline Incident

- An underground hydrogen gas pipeline developed a leak
- Possibily discovery was after weeks/months of leakage
- Lasted for at least several hours
- Occurred at a specific “weak spot” … partial failure of a so-called “CP Coupling”
- ignited by welding activities on another pipeline in the corridor. The ignition resulted in a small fire on top of the soil covering several existing pipelines transporting several types of gases.
- As a precaution, residents of the village nearby were advised to stay indoors for about three hours. Busy traffic on a nearby waterway to and from the Rotterdam harbour area was halted for several hours. After the conclusion that it was a hydrogen release and fire restrictions were lifted.

H2 Pipeline Incident

- *Although the transport of hazardous substances by pipeline along the route of the pipeline corridor is considered to be a safe means of transport, and the management of the pipeline corridor is meticulous, deficiencies in that management have been identified, mainly in the way supervision is carried out during construction activities in the corridor.*

- *Nevertheless, the incident has been classified as serious, because the gas escape could have been more extensive, and other transport pipelines that were lying nearby might have developed leaks for the same reason, which might have caused the release of poisonous gases*.

H_2 Pipeline Incident

- Dangerous materials: At least 8.4 kilograms of hydrogen have escaped, which lasted about 7 hours. probably in excess of 50 kilograms.
- Human and social consequences :All inhabitants of the village of Heinenoord (3 400 people) were advised to stay indoors during 2.45 hours.
- Environmental damage: None
- Economical damage: estimates at least 1 million Euros

Cause

- Mix of several tension factors executed on hydrogen pipeline
- This includes
  - Unallowed heavy traffic
  - Placement of heavy equipment on the soil covering the pipeline
- There were 4 supervising bodies that in some ways were inspectors from foundation, separate pipeline owners, consortium and a notified body that was hired to inspect the safety aspects of construction of a new pipline
- As per investigation report, these inspections were uncoordinated.
- The inspectors all assumed that "the other inspection bodies" would do the inspections they did not do.

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Lesson Learned

Specific lessons (mostly of a technical nature):

- Criteria had to be established for the quality of CP couplings in pipelines and the installation and maintenance conditions associated with them in order to safeguard that the couplings are not exposed to any type of stress during their operational lifetime.
- Policies with regard to the measurement and interpretation of ground settlement had to be reassessed.
- A strict surveillance policy had to be developed to prevent infringements on rules regulating activities on top of pipelines in order to prevent the possible damage of these pipelines.

Lesson Learned

General lesson (of organisational nature):

- An abundant series of supervisors and inspectors on a project does not necessarily mean that the essential requirements to safeguard a safe environment are met.
- All parties involved in the management of the pipeline corridor (the management of the foundation as well as all individual pipeline operators) had to redefine supervision and inspection policies in order to get a *clear division between each other's tasks and responsibilities,* particularly during construction activities in the pipeline corridor.

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Hydrogen Bus Fire, 2023

- **Hydrogen bus:** Bakersfield California, 2023 (link) video link
  - Cause : not known

- A section of Golden State Highway was closed as firefighters battled the blaze.

- GET said in a release a portion of the new hydrogen fueling station and a hydrogen fuel cell bus was engulfed in flames.

A GET hydrogen bus, valued at $1.1 million, was destroyed and part of the fueling station was damaged during an early morning fire on Golden State Highway. PHOTO: Brandon

Bakersfield California, 2023

- The hydrogen buses were being fueled at the time of the fire.
- According to the release, one bus was destroyed and only the dispensing portion of the hydrogen fueling station was damaged.
- Explosions were heard and seen from the tanks on the bus that had just been filled, but the primary tanks of the actual fueling station did not ignite due to safety technology.
- The state-of-the-art fueling station opened up just seven months ago.
- Since it's the only hydrogen fueling station in town, Sanders said there will be delays.
- *"Because we are the only hydrogen fueling station in Kern County, we won't be able to fuel our 10 hydrogen buses, so it could possibly cause some delays on our service because there will be ten buses out of service because we aren't able to fuel them."*

A GET hydrogen bus, valued at $1.1 million, was destroyed and part of the fueling station was damaged during an early morning fire on Golden State Highway. (KBAK/KBFX)

More Incidents

- Wikipedia link
- Europe Link

(International Association for Hydrogen Safety)

HySafe

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28 June 2018
Thomas Jordan
No comments
Categories: Latest News

With more than 700 hydrogen events – accidents, incidents and near misses – collected in a database, HIAD was one of the main results of the NoE HySafe (2004-2009) and still represents one of the largest collections for hydrogen specific data.

With support of the FCH 2 JU and the Clean Hydrogen JU JRC has regularly maintained, populated and upgraded the database.

The hydrogen incidents database HIAD is now available as an EXCEL file. Version HIAD 2.1 can be downloaded from https://minerva.jrc.ec.europa.eu/en/shorturl/capri/hiadpt . There you can also access an interactive tool providing data visualisation and user-customised analytical functions (still in a beta version). A feedback would be highly appreciated, to be sent to the two address below.

For all questions related to HIAD, as well as for providing new entries, please contact JRC-PTT-H2SAFETY@ec.europa.eu and Pietro.MORETTO@ec.europa.eu

Analyses and further details can be found in these publications:
https://www.sciencedirect.com/science/article/pii/S0360319922012976 and
https://www.sciencedirect.com/science/article/pii/S0098135423000686

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Local Hydrogen Related Incidents

- Hydrogen Furnace Explosion
  - Cause: hydrogen entered furnace piping - it was not intended
  - Aftermath: shutdown in fort mac plant for weeks
- Close call – Hydrogen Bus on fire:
  - Cause: battery
  - Aftermath: hydrogen containment was not to blame
  - HVAC Design of the building storing Hydrogen Bus

Strathcona County Fuel Cell Zero-Emission Bus

HYDROGEN PROJECTS

Local Hydrogen Projects

1. **ATCO/CPKC Hydrogen Refueling Station for Rail Fleet**
2. Commercial Hydrogen Refueling Stations at Air Products
3. Mobile Hydrogen Fueling Station – City of Edmonton
4. ATCO – Hydrogen Pipeline
5. **Strathcona County Hydrogen house**
6. **Strathcona County/Edmonton Hydrogen bus**
7. **Ualberta Regulatory Gap Analysis of Hydrogen Standards & Codes**

CPKC – ATCO Enpower

ATCO EnPower and CPKC Complete Hydrogen Fuel Facilities in Calgary and Edmonton

November 25, 2024 by Robert Lewis

- Facility features a 1-megawatt (MW) electrolyzer, compressor, storage, and dispensing systems designed specifically for locomotive refuelling.

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Strathcona County H2 House

Government of Canada | Gouvernement du Canada

Search the website

MENU

Canada.ca > Natural Resources Canada > Funding and partnerships

Bremner: A Strathcona County Hydrogen Community

Strategic Area

Renewables

Lead Proponent

ATCO Gas and Pipelines LTD.

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Edmonton

Proposed hydrogen-heated community in Alberta gets $2M for feasibility study

Alberta Innovates announces $20M in funding for 18 hydrogen projects

CBC News · Posted: Feb 21, 2023 6:09 PM MST | Last Updated: February 21, 2023

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H2 House

- Hydrogen Furnace in mechanical room with SIL 2 hydrogen detection and shutoff valve
- Mechanical Room closes automatically.
- HVAC of Mechanical Room is separate from HVAC of rest of the house
- Pressures Trailer:2995L@3625 psig, supply line 80 psi, house 0.25 psi.

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H2 House

- Consequence-analysis based set back distances
- Engineer Stamps on performance of hydrogen furnace
- Engineering Assessments
  - Risk Assessment
  - Fire Protection Design Basis

Site Details

- Hydrogen Storage Vessel on the pad
- Hydrogen line going into the house
- Mechanical Room with hydrogen furnace, SIL 2 detection and shutoff monitored by SCADA
- 6 air changes an hour – HVAC
- Trailer:2995L@3625 psig, supply line 80 psi, house 0.25 psi.

Gaps in Standards

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CLEAN RESOURCES

CLEAN TECHNOLOGY

HYDROGEN

Codes, Standards, Regulatory and Insurance Gap Analysis for Hydrogen value chain development in Alberta

This project aims to develop a risk-informed framework to assess the safety and feasibility of H_2-Combined Heat and Power (CHP) systems. Using MCS alongside quantitative tools like HyRAM+ and SAFETI, this study aims to quantify leak sizes, ignition probabilities, and consequence event frequencies to determine appropriate separation distances. Additionally, a regulatory gap analysis identifies deficiencies in existing Canadian codes and compares them with international frameworks. Ultimately, the research aims to support Alberta's sustainable energy transition by providing data-driven insights to enhance safety standards, optimize risk mitigation strategies, and support informed decision-making for

FUNDING DETAILS

RECIPIENTS:
Dr. Lianne M. Lefsrud
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Dr. Fereshteh Sattari

PARTNERS:
Strathcona County
Sturgeon County
ATCO Gas
Transition Accelerator
Alberta Infrastructure
Alberta Energy & Mines
AXAXL Insurance

Report available at the link

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UAlberta Research Collab

Pseudo-HRS

Pseudo-HRS (PHRS) was divided into three areas based on their pipe-flow area:

- Tube-Trailer Area (TTA)
- Hydrogen System Area (HSA)
- Dispenser Area (DA)

Two operating scenarios were considered

- Scenario 1: Refuelling HHDVs at 350 bar dispensing pressure
- Scenario 2: Refuelling LHDVs at 700 bar dispensing pressure

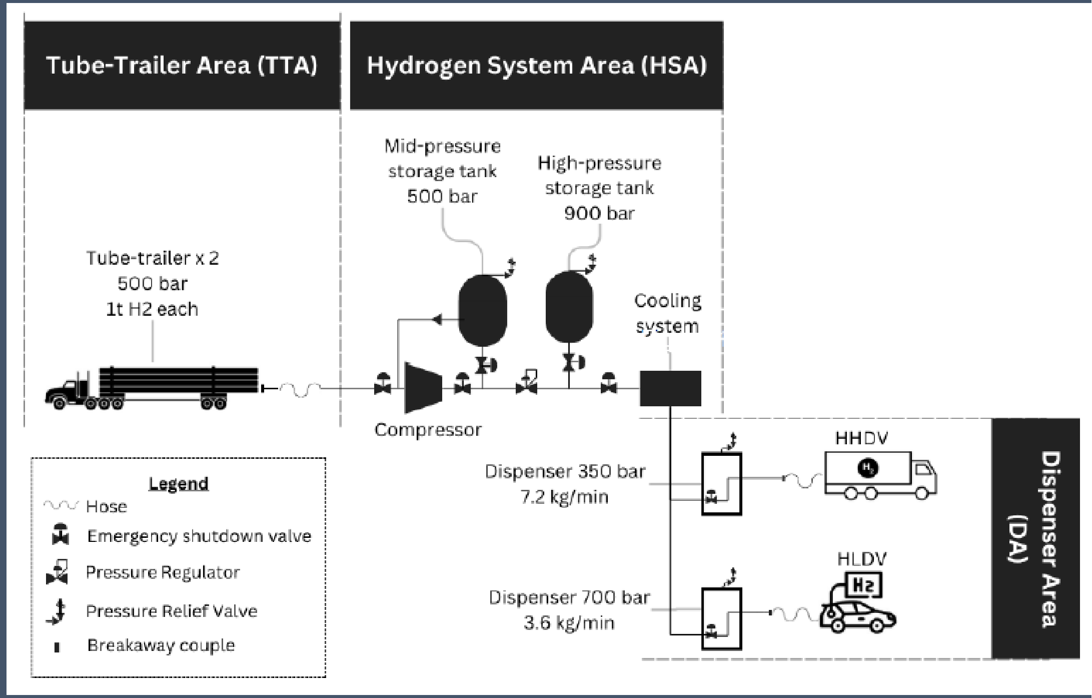

Figure 5: A pseudo-hydrogen refueling station

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Ref: Codes, Standards, Regulatory and Insurance Gap Analysis for Hydrogen value chain development in Alberta link

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Research Collaboration - UAlberta

- 10% of pipe leak scenario

350 bar eqt.

- 11.8 m HAS
- 28 m DA
- 19 m TTA

700 bar eqt.

16 m HAS

39.1m DA

19 m TTA

TTA – tube trailer area

HAS – Hydrogen system area

DA- Dispenser Area

Conclusion

- Frequency analysis indicated comparable likelihood for 1% and 10% leak sizes, leading to the choice of 10% for determining separation distances.
- For a 350 bar operating pressure, the recommended distances are 11.8 m (HSA), 28 m (DA), and 19 m (TTA), and for 700 bar, the distances are 16 m (HSA), 39.1 m (DA), and 19 m (TTA).
- These zones prevent unintended ignition sources. Implementing safety measures reduced annual jet fire occurrence by 10^2 times and flash fires by 2×10^1 times.
- Without safety measures, the initial frequencies were 1.42×10^{-4} (jet fires) and 3.84×10^{-6} (flash fires) per year.
- With measures, frequencies dropped to 1.45×10^{-6} (jet fires) and 6.98×10^{-7} (flash fires) per year. Additional safety barriers like breakaway couples and firewalls can further mitigate hazards.

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Annual frequency of leak and consequences

Leak size	Annual Frequency of occurrence			
	Hydrogen leak in PHRS	Jet fire (E1)	Flash fire (E2)	Safe dispersion (E3)
0.1%	1.35E-01	7.16E-03	1.93E-04	6.96E-03
1%	2.38E-02	1.26E-03	3.41E-05	1.23E-03
10%	2.68E-03	1.42E-04	3.84E-06	1.38E-04
100%	6.87E-04	3.64E-05	9.83E-07	3.54E-05

The annual frequency of occurrence for a leak size of 1% is 2.38E-02/year, while for a leak size of 10%, it is 2.68E-03/year, indicating a relatively small difference between the two

Separation distances considering a leak size of 1% can undermine the consequences for 10% leak scenarios, which will potentially cover greater distances – **Separation Distance Criteria**

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Separation distance criteria

The separation distances for the PHRS were determined by considering either a thermal radiation level of 4.7 kW/m^2 or the LFL (4% hydrogen concentration of hydrogen in air), whichever covers a larger distance aligned with the methodology used in NFPA 2.

Thermal radiation level (kW/m^2)	Degree of Damage
25	Significant injury in 10s; 100% lethality in 1 min
4.7	Pain for 20s exposure; first-degree burn
1.6	No harm from long exposures

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Technica Ltd.: Techniques for Assessing Industrial Hazards - A manual (World Bank Technical Paper No. 55). (1988)
NFPA 2, https://www.nfpa.org/product/nfpa-2-code/p0002code

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Individual risk

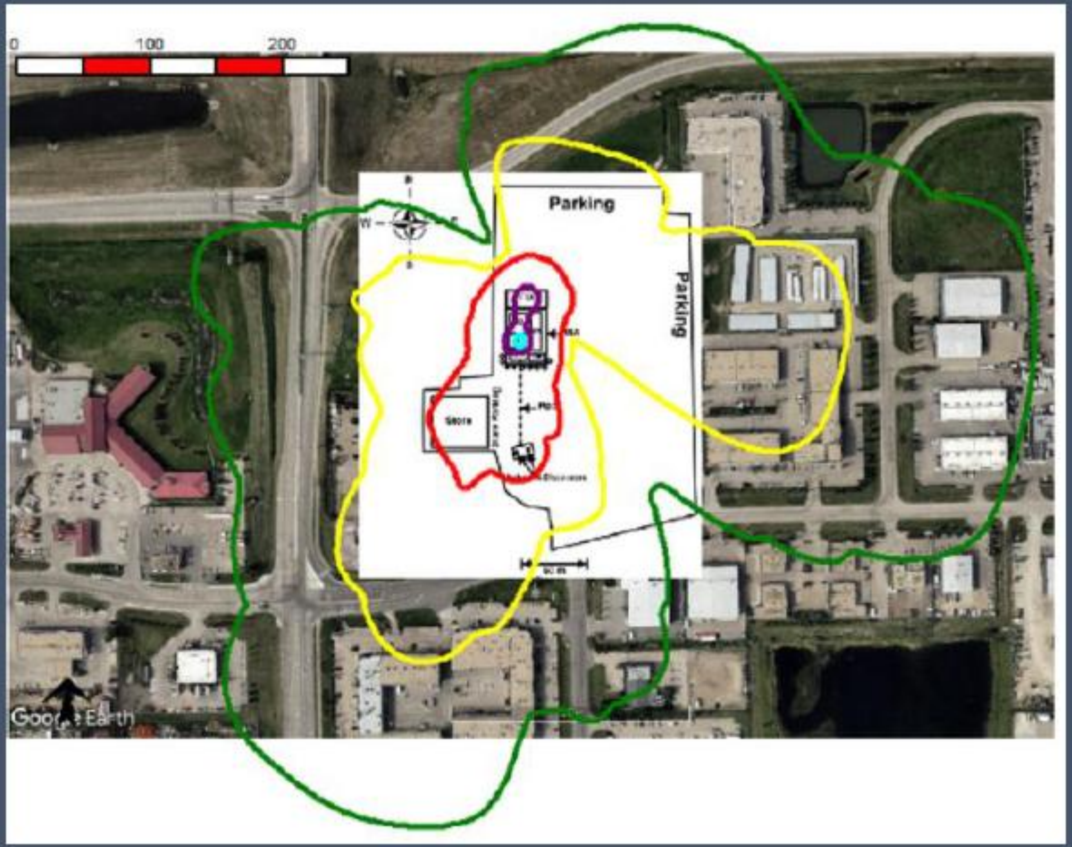

Figure 12: Scenario 1 - Dispensing pressure of 350 bar

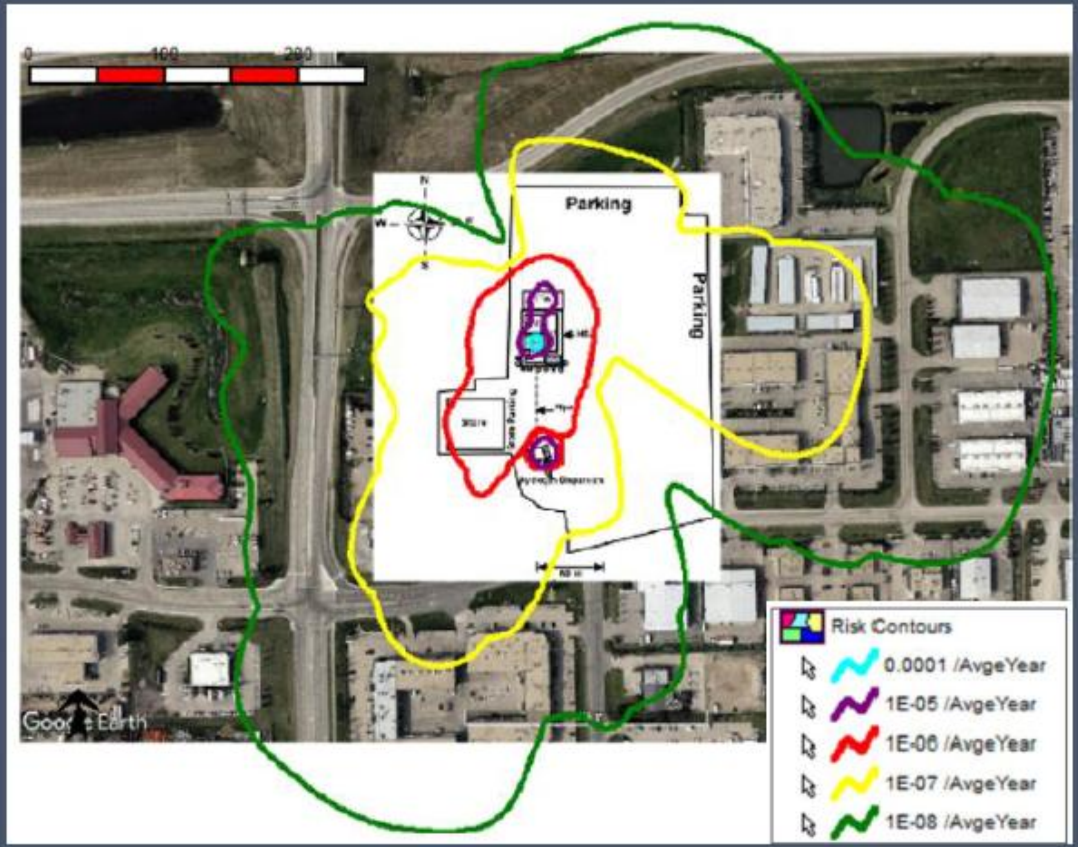

Figure 13: Scenario 2 - Dispensing pressure of 700 bar

Workers engaged in unloading hydrogen in TTA, and the maintenance operators in HSA, are all exposed to a tolerable IR of 1×10^{-5} per year. Humans near HSA, within the shop and near DA are subject to an IR of 1×10^{-6} per year

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Separation distance

Recommended separation distances

Scenario 1:

Area in HRS	Separation distance
TTA	19 m
HSA	11.8 m
DA	28 m

Scenario 2:

Area in HRS	Separation distance
TTA	19 m
HSA	16 m
DA	39.1 m

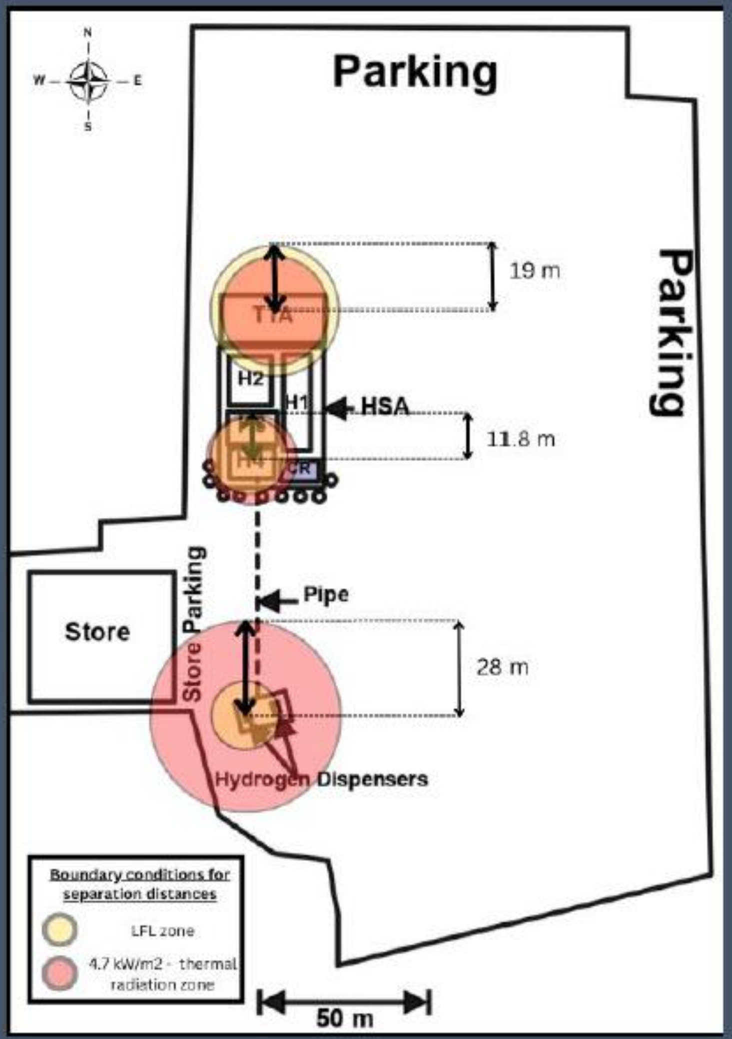

Figure 14: Recommended separation distance for scenario 1

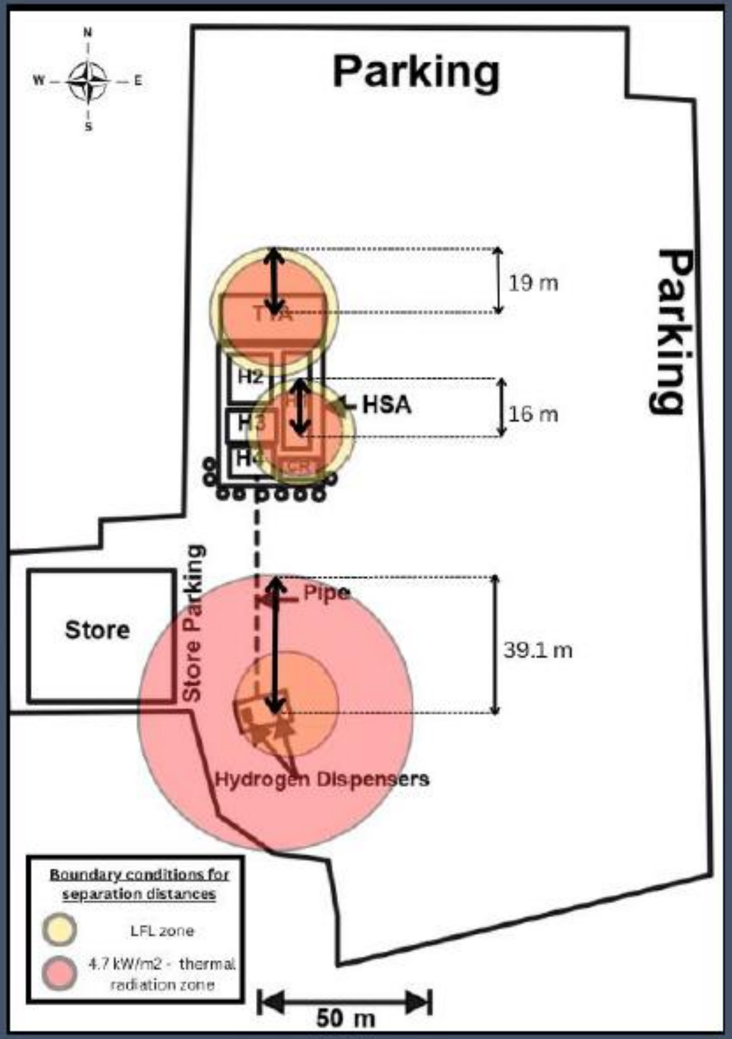

Figure 15: Recommended separation distance for scenario 2

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Impact of safety barriers

Safety barrier	Probability of failure on demand
Gas detection system	0.001
Automatic shutdown system	0.49
Emergency ventilation	0.02

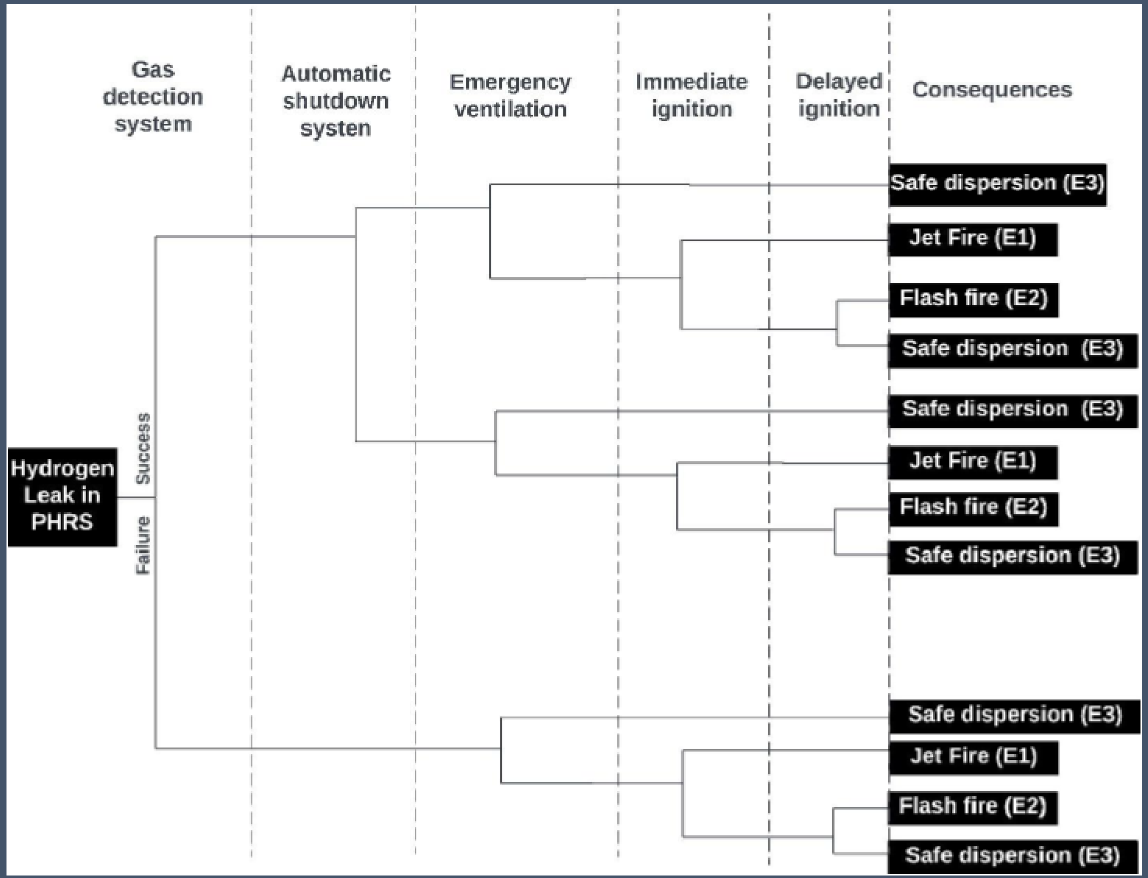

Figure 16: Event tree presenting risk reduction using safety barriers

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Markert, F., Nilsen: A BARRIER ANALYSIS OF A GENERIC HYDROGEN REFUELLING STATION. 98.
Wang, X., Gao, W.: Hydrogen leakage risk assessment for hydrogen refueling stations. Int J Hydrogen Energy. 48, 35795–35808 (2023). https://doi.org/10.1016/J.IJHYDENE.2023.05.340

Ref: Codes, Standards, Regulatory and Insurance Gap Analysis for Hydrogen value chain development in Alberta [link]

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Impact of safety barriers

	Frequency of occurrence without safety barriers		Frequency of occurrence with safety barriers	
Leak size	Jet fire/year (E1)	Flash fire/year (E2)	Jet fire/year (E1)	Flash fire/year (E2)
10%	1.42E-04	3.84E-06	1.45E-06	6.98E-07

The frequency of occurrence of jet fire event was reduced by nearly 10^2 / year and flash fire event by 2 x 10^1 per year

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Regulatory gap analysis

Canadian codes and standards

1) Tube-trailer delivery

Gap:
CSA B339-18

Lacks specifications on filling pressure limits for hydrogen containers in this edition: New edition to be released in 2024

Country	Standard	Standard description
CAN	CSA B339-18	Cylinders, Spheres, and Tubes for the Transportation of Dangerous Goods
CAN	CSA B340-18	Selection and use of cylinders, spheres, tubes, and other containers for the transportation of dangerous goods, Class 2
CAN	CSA B341-18	UN pressure receptacles and multiple-element gas containers for the transport of dangerous goods
CAN	CSA B342-18	Selection and use of UN pressure receptacles, multiple-element gas containers, and other pressure receptacles for the transport of dangerous goods, Class 2

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CSA B339-18: https://www.csagroup.org/store/product/B339-18/

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Regulatory gap analysis

Canadian codes and standards

2) HRS component design standards

Gap:
Canadian Hydrogen Installation Code

Does not provide guidelines for classifying hazardous zones and determining risk-informed separation distances for electrical equipment at stations through detailed quantitative analyses

Country	Standard	Standard description
CAN	CAN/BNQ-1784-000-22	Canadian Hydrogen Installation Code
CAN	CSA B51-19	Boiler, pressure vessel, and pressure piping code
CAN	CSA/ANSI HGV 4.4-21	Gaseous Hydrogen - Fuelling Stations – Valves
CAN	CSA/ANSI HGV 4.10-21	Standard for fittings for use in compressed gaseous hydrogen refuelling station
CAN	CSA/ANSI HGV 4.2-22	Hoses for compressed hydrogen fuel stations, dispensers, and vehicle fuel systems
US	ASME B31.12-23	Hydrogen Piping and Pipelines
US	ASME B31.1-22	Power Piping
US	ASME B31.3- 22	Process Piping
US	CGA S Series -1.1-3-20	Pressure Relief Device Standards
US	CGA-G-5.5-21	Hydrogen Vent Systems
US	CGA H-5-14	Standard For Bulk Hydrogen Supply Systems - Second Edition
US	SAE J2600-15	Compressed Hydrogen Surface Vehicle Fueling Connection Devices
US	UL 2075-23	Standard for Gas and Vapor Detectors and Sensors

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Bureau de normalisation du Quebec: Canadian Hydrogen Installation Code. , Québec (2022)

Ref: Codes, Standards, Regulatory and Insurance Gap Analysis for Hydrogen value chain development in Alberta link

Regulatory gap analysis

Canadian codes and standards

3) Refueling station operations

Country	Standard	Standard description
CAN	CAN/BNQ-1784-000-22	Canadian Hydrogen Installation Code
CAN	CSA/ANSI HGV 4.1-20	Hydrogen-Dispensing Systems
CAN	CSA/ANSI HGV 4.3-19	Test Methods for Hydrogen Fuelling Parameter Evaluation
CAN	CSA/ANSI HGV 4.9-20	Hydrogen Fuelling Stations
INT	ISO 17268-20	Gaseous Hydrogen Land Vehicle Refuelling Connection Devices
US	SAE J2600-15	Compressed Hydrogen Surface Vehicle Fuelling Connection Devices
US	SAE J2601-20	Fuelling Protocols for Light Duty Gaseous Hydrogen Surface Vehicles
US	SAE J2601-2-23	Fuelling Protocol for Gaseous Hydrogen Powered Heavy Duty Vehicles
US	SAE J2601-3-23	Fuelling Protocol for Gaseous Hydrogen Powered Industrial Trucks
US	SAE J2799-19	Hydrogen Surface Vehicle to Station Communications Hardware and Software
US	SAE J2719-20	Hydrogen Fuel Quality for Fuel Cell Vehicles

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Regulatory gap analysis

Canadian codes and standards

4) Safety Standards

Country	Standard	Standard description
US	NFPA 2	Hydrogen Technologies Code
US	NFPA 1	Fire Code
INT	ISO 19880	Gaseous hydrogen - Fuelling stations.
AB, CAN	Alberta Fire Code	The code does not explicitly mention requirements for hydrogen-fueling station

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Regulatory gap analysis: Conclusion

- The existing codes and standards applicable currently across the existing HRSs provides for all the necessary requirements for design and operation of HRSs.
- The CHIC does not provide guidelines for classifying hazardous zones and determining risk-informed separation distances for electrical equipment at stations through detailed quantitative analyses. This can lead to improper classification and sitting of electrical installations near hydrogen systems
- The absence of hydrogen-specific regulations in the Alberta Fire Code, zoning laws and Canadian standards emphasizes the necessity of harmonizing codes and standards across the province

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Table 7
Applicable codes, standards, and regulations for hydrogen combined heat & power systems – Gap analysis and potential enhancement areas

Type*	Code / Standard / Regulation	Observed Gap	Potential Enhancement Areas
C	National & Alberta Building Codes [116], Alberta Building Code [117]	• Limited reference to hydrogen storage, venting, and pressure-based separation • No explicit inventory categorization for gaseous or liquid hydrogen	• Hydrogen ventilation and vent-dispersion guidance • Inventory classification: < 35 kg / 35 kg–2 t / > 2 t H_2 • Pressure-dependent separation (250–1000 bar) • Provisions for high-pressure system controls
S	CSA B51 [118]	• Partial hydrogen coverage; limited inspection and composite-vessel provisions	• Defined inspection intervals (250–1000 bar) • Composite-cylinder inclusion • Reference to probabilistic leak-frequency data
S	CSA B149.1 [119]	• Generalized pressure-equipment requirements; limited hydrogen specificity	• Hydrogen piping and ancillary design (≤ 10 bar / > 250 bar) • QRA-based leak and ignition probability assessment criteria
R	ABSA Regulations [21]	• Broad equipment certification framework; limited hydrogen differentiation	• Hydrogen-specific certification and leak-testing for > 35 kg H_2 • Pressure / configuration-dependent compliance methodology
R	Alberta Fire Code [120]	• Limited reference to composite high-pressure hydrogen systems	• Pressure- and inventory-based hazard-zone definition • Emergency-response planning criteria

*Note – C stands for Code, S stands for Standard, and R stands for Regulation

Reference: Anirudha Joshi, Fereshteh Sattari, Lianne Lefsrud, M.A. Khan,
Hydrogen combined heat and power Facilities: Risk-Informed modeling for safety and land-use planning,
Energy Conversion and Management,
Volume 348, Part C,
2026,
120793,
ISSN 0196-8904,
https://doi.org/10.1016/j.enconman.2025.120793.
(https://www.sciencedirect.com/science/article/pii/S0196890425013172)

Link

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UAlberta Insights for SCES

- Fire Code has no mention of hydrogen refueling station. California Fire Code has some clauses on setback distances based on volume of storage at site
- BNQ Hydrogen Standard and the setback distance of 5m needs to be evaluated and cannot be taken as is.
- Refer to gaps in hydrogen standards in UAlberta Reports (Link)
- Distances for safe releases

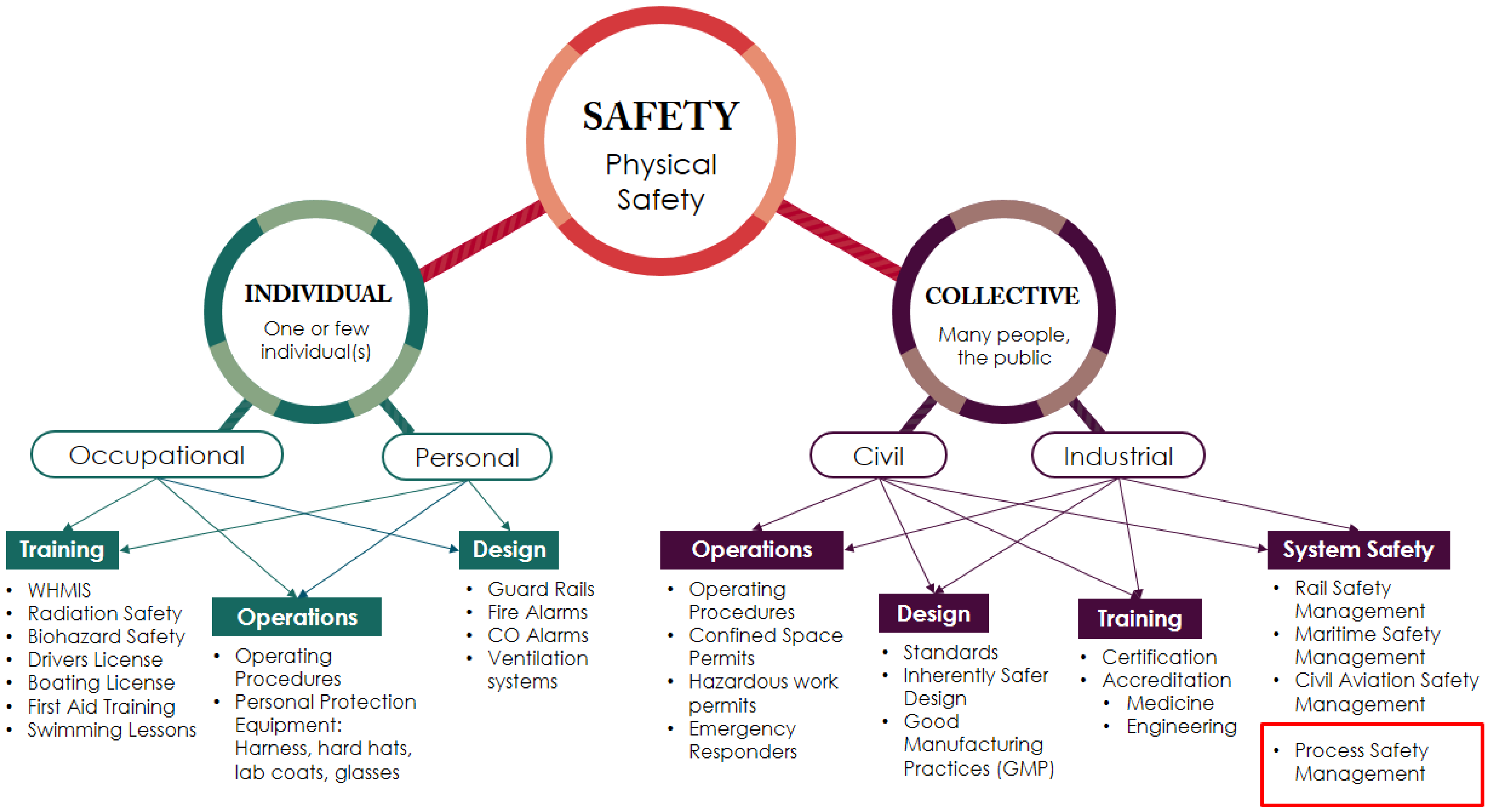
CSA Z662 Pipeline Code

- Hydrogen is considered as a gas OR blend of natural gas +vol %H2
- Risk Assessment and engineering assessment to lead
  - Flame visibility
  - Embrittlement and Rapid cracking
  - Low ignition energy
  - Welding in-service lines
  - Permeation
- Safety Class not covered in C5 for gas pipelines.
- Performance/specifications of CSA Z662 safeguards must come from engineering professional – gives a framework e.g. welding procedures and specifications, materials, coating, stresses, pipe thickness, etc.

Conclusion

- Engineering Assessments are key to prevention of incidents
  - Performance Based Design
  - Inspection Testing and Maintenance Plans
- Risk Management Programs
  - Mechanical Integrity
  - PSM
- Similarity to Journey of Propane
  - Sunrise Propane Accident 2008
  - Process Safety Plans: Layers of Protections
- Complex at interface of built environment and new construction - System Safety Topic (Elements of Process Safety Management)

Safety Management Systems



Reference: Minerva Safety Management Education

Process Safety Management

AIChE-CCPS PSM Elements

Pillar 1: Commit to Process Safety	
1. Process Safety Culture	11. Contractor Management
2. Compliance with Standards	12. Training & Performance Assurance
3. Process Safety Competency	13. Management of Change
4. Workforce Involvement	14. Operational Readiness
5. Stakeholder Outreach	15. Conduct of Operations
Pillar 2: Understand Hazards and Risk	16. Emergency Management
6. Process Knowledge Management	
7. Hazard Identification & Risk Analysis	**Pillar 4: Learn from Experience**
Pillar 3: Manage Risk	17. Incident Investigation
8. Operating Procedures	18. Measurement & Metrics
9. Safe Work Practices	19. Auditing
10. Asset Integrity & Reliability	20. Management Review & Continuous Improvement

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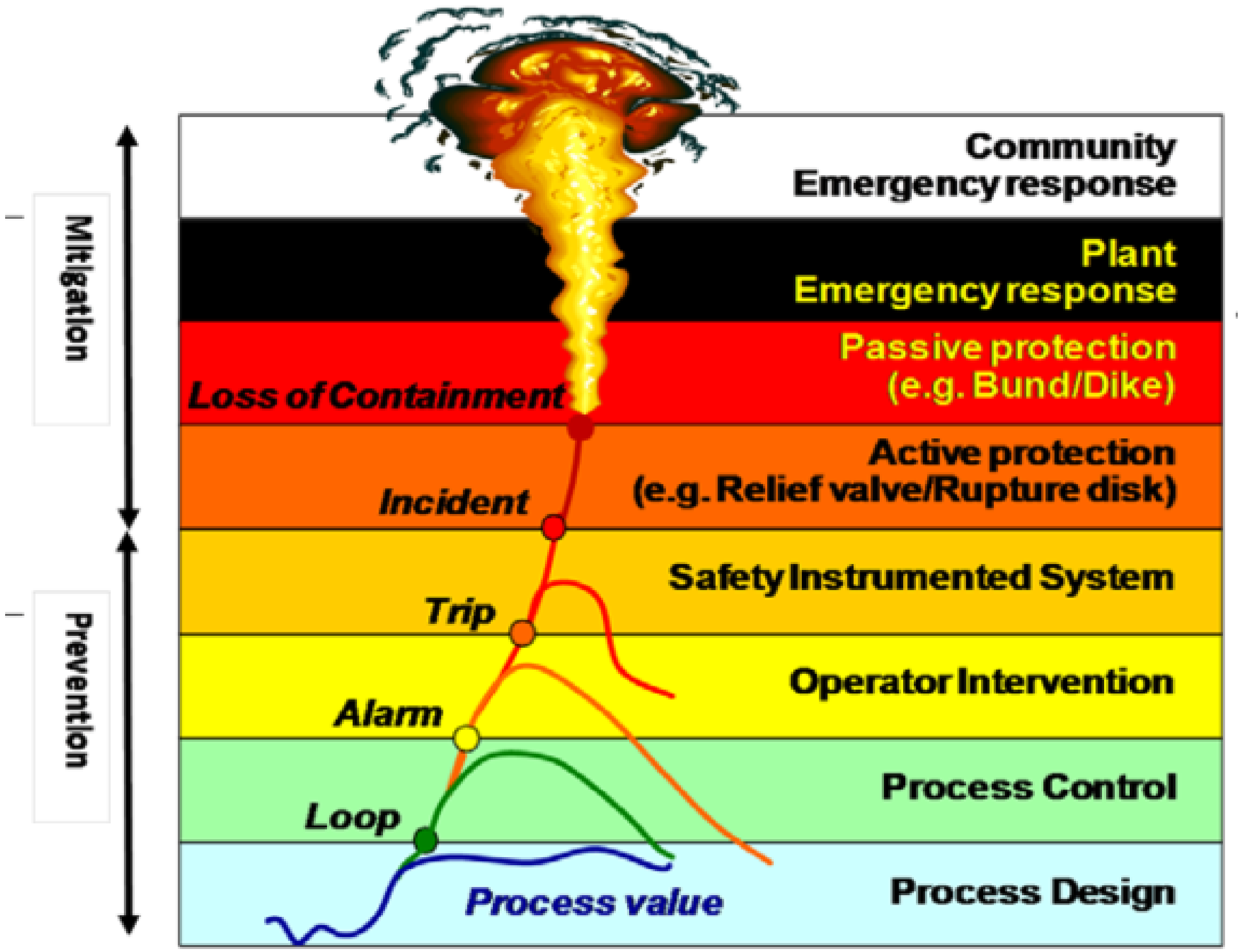
Layers of Protection



Reference: [Link]

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QUESTIONS?