RISK-INFORMED REGULATORY GAP ANALYSIS FOR HYDROGEN REFUELING STATIONS IN ALBERTA, CANADA

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The Transition Accelerator

STRATHCONA COUNTY

Sturgeon County

Introduction: Motivation

- In 2020, Canada was the 11th largest contributor to Green House Gas (GHG) emissions; 9% of Canada's emissions are from heavy-duty transportation
- To reduce the GHG emissions, it is crucial to introduce and regulate new energy systems that use zero-emission energy carriers like hydrogen
- Primarily it is important to analyze the high-priority end-use of hydrogen as a fuel in the province
- Regulatory gaps and safety creates uncertainty amongst stakeholders, increases investment risk and impedes the deployment of Hydrogen.

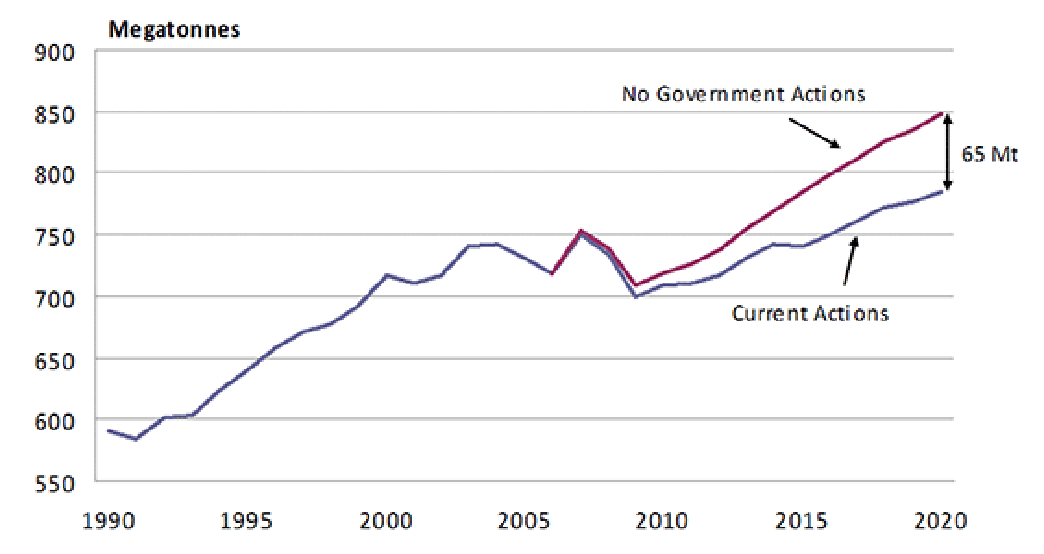

Figure 1: Baseline GHG Emissions Scenario with and without Government Actions

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Greenhouse gas emissions - Canada.ca, https://www.canada.ca/en/environment-climate-change/services/environmental-indicators/greenhouse-gas-emissions.html
https://www.ec.gc.ca/doc/publications/cc/COM1374/ec-com1374-en-s4.htm

Hydrogen

Figure 2: The pros of hydrogen fuel cell

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IEA, https://www.twi-global.com/technical-knowledge/faqs/what-are-the-pros-and-cons-of-hydrogen-fuel-cells

Hazardousness of hydrogen

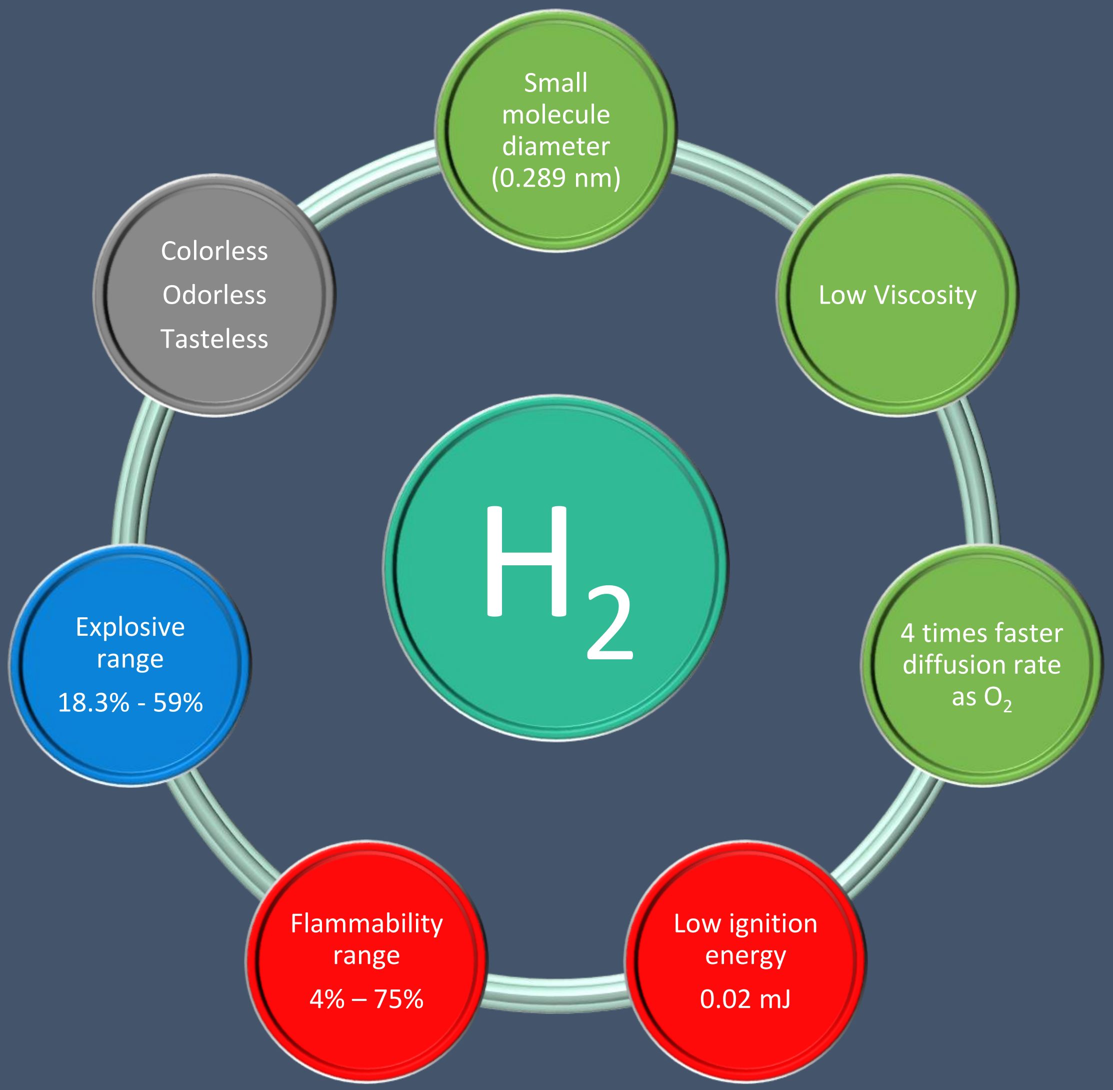

Figure 3: The cons of hydrogen fuel cell

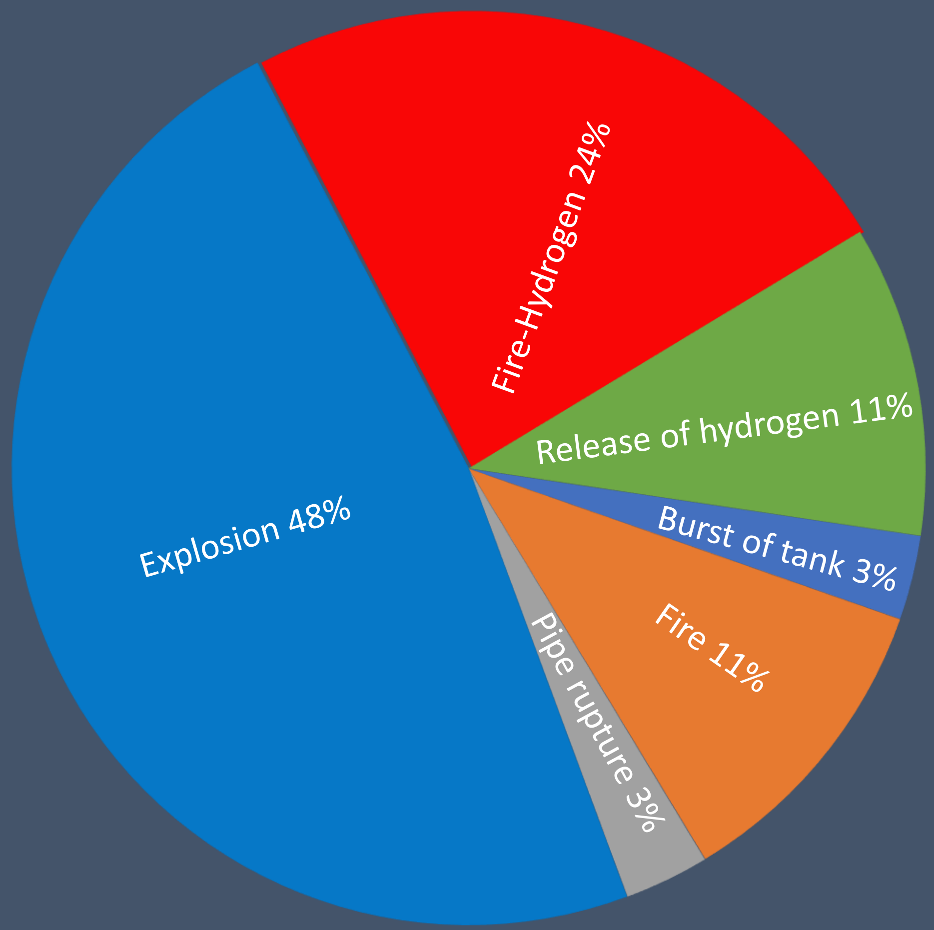

Figure 4: Hydrogen incidents since 1985 in EU

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Najjar, Y.S., & Mashareh, S. (2019). Hydrogen Leakage Sensing and Control: (Review). Biomedical Journal of Scientific & Technical Research.
Galassi, M. C., Baraldi, D., Funnemark, E., Jordan, & Tchouvelev, A. (2021). *HIAD-HYDROGEN INCIDENT AND ACCIDENT DATABASE*. http://www.h2incidents.org/

Agenda

- Our approach: CSA’s Standards Council of Canada also identified gaps but does not have a method of prioritizing these. Our study answers the call from NRCan (2022), CICE for BC (2023) and CSA (2023) and addresses these gaps for stakeholders in Alberta.

- Use Quantitative Risk Assessment (QRA) of specific use-case scenarios to determine where gaps exist in Alberta, compare its municipalities’ codes and standards vs. other jurisdictions (e.g., California, Japan) and enshrine a safety-first approach.

- Example: Hydrogen Refueling Station

- Next steps

Introduction: Hydrogen value chain

We follow the molecule… to analyze use cases

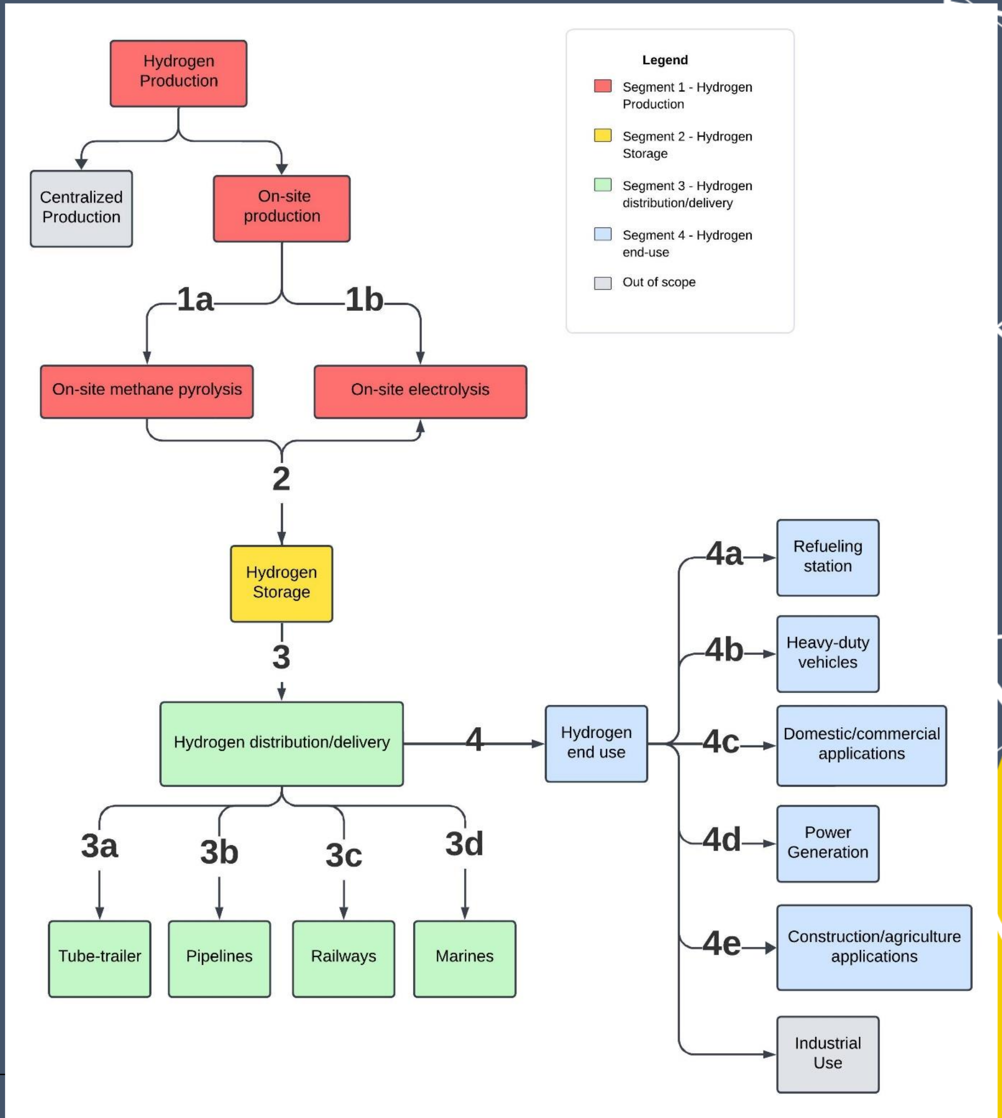
1) H2 vehicle fueling and servicing
- H2 Fueling Stations (incl. land zoning, hazard zones, permits, on-site compression, storage, dispensing, etc. up to 750 bar)
- H2 Vehicle Service and Parking Facilities
- H2 Vehicle Service Personnel training/certification requirements

2) H2 transportation including on-road requirements
- H2 distribution via road (compressed H2 or liquid H2 in a truck/trailer)
- H2 Vehicle on-road compliance requirements (incl. weight allowances, onboard storage requirements, crash safety, safety training, etc,)

3) H2 distribution via pipelines
- H2 distribution piping (low pressure lines only)

4) H2 microgeneration
- On-site microgeneration in behind the meter applications. Fuel cells and ICE CHP

5) H2 end-use
- H2 residential/commercial heating (furnaces and boilers)
- H2 heavy equipment (trucks, locomotives, and construction equipment)
- H2 storage at residential / commercial facilities
- H2 power generation using gas turbines or fuel cells



Introduction: Hydrogen Refueling Stations (HRS)

- Alberta called for interest from stakeholders and local parties willing to own a Hydrogen Refueling Stations (HRSs) in the province, primarily focusing on serving HHDVs, with an expected station capacity of 2tH_2 / day.
- The HRSs can have provision for fueling Hydrogen-powered Light Duty Vehicle (LHDVs) in future
- The priority end-use of hydrogen in Alberta is to deploy Hydrogen powered Heavy-Duty Vehicles (HHDVs)
- To support the HHDVs, it crucial to build a strong hydrogen refueling network in the province
- This leads to prioritizing the establishment of HRSs in the province

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Government of Alberta: Expressions of Interest for hydrogen fuelling stations, https://www.alberta.ca/expressions-of-interest-for-hydrogen-fuelling-stations#jumplinks-0

Research Motivations

- The hurdles that impede the facilitation of HRSs in the province are driven by:
  1. Various safety concerns regarding using hydrogen as a fuel
  2. Gaps in local zoning laws, Canadian codes and standards, and the process of permitting and approval, considering those safety concern

- For estimating separation distances in HRSs, a uniform leak size distribution is assumed throughout the HRS in most of the QRAs performed. This can lead to over/under-estimation of separation distances

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Research Objectives

- The objective of the study was to perform a QRA of a pseudo-HRS in Edmonton, Alberta and identify the potential risks associated to HRS
- Followed by the estimation of separation distances based on the leak sizes derived from different areas in the PHRS (based on their pipe-flow area)
- Scanning applicable codes, standards, provincial zoning laws for HRSs and identifying gaps

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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

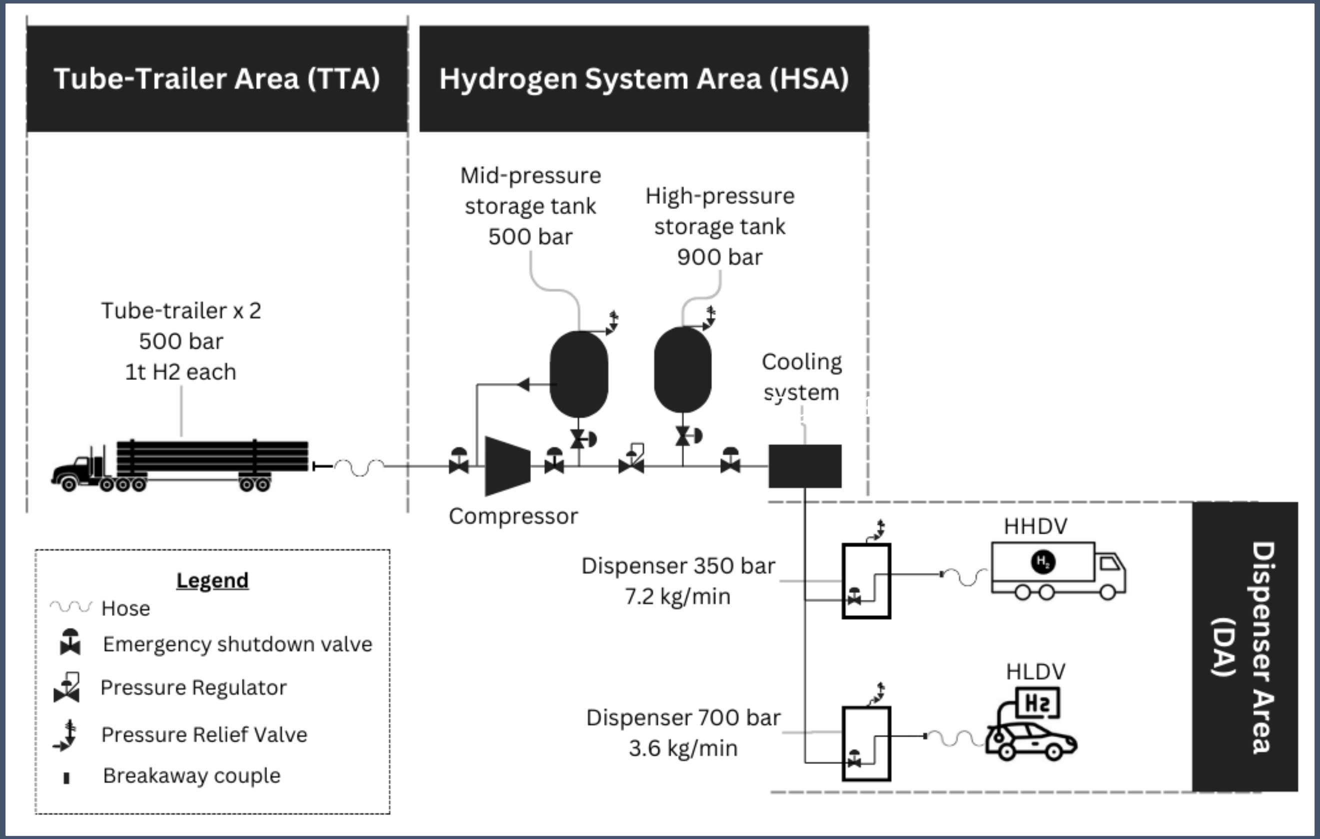

Figure 5: A pseudo-hydrogen refueling station

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Facility Description

Component	Pressure (bar)	Inventory (kg)
Scenario 1: Refueling HHDVs at 350 bar dispensing pressure		
Tube-trailer x 2	500	1000 each
Compressor (H3)	520	-
Medium-pressure storage tank (H4)	520	500
Dispenser	350	-
Scenario 2: Refueling LHDVs at 700 bar dispensing pressure		
Tube-trailer x 2	500	1000 each
Compressor (H3)	900	-
High-pressure storage tank (H1)	900	1000
Dispenser	700	-

Figure 6: operational diesel truck stop on Pembina road

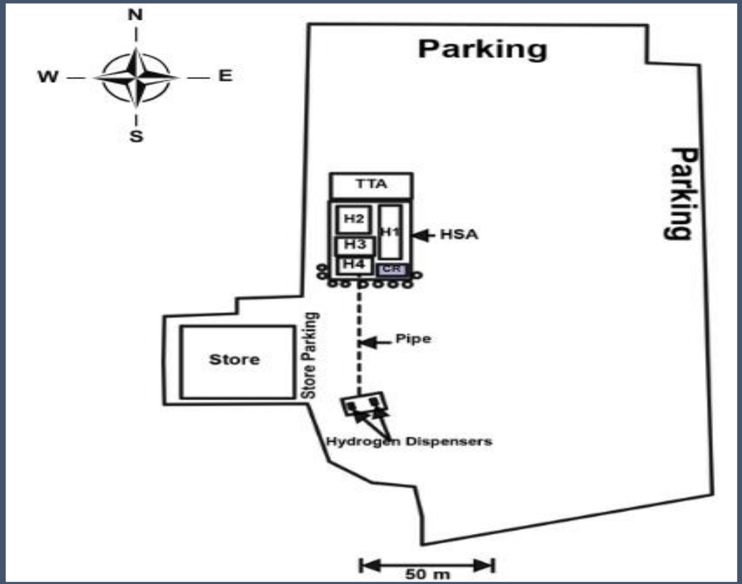

Figure 7: PHRS facility's layout

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Methodology

- The QRA methodology is based on the Purple Book and the risk-informed method of evaluating separation distances according to Sandia National Laboratory and NFPA
- For each area in the PHRS, the individual equipment failure frequency is calculated using the tool HyRAM+
- Bowtie was developed to evaluate the frequency of leak occurrence followed by the consequences associated
- A risk matrix in accordance with CCPS was developed for assessing the consequences
- Individual risk and separation distances were evaluated for both the scenarios
- Impact of relevant safety barriers on the PHRS was studied for intolerable and undesirable risks

Ujit de Haag, P., Ale, B.J.M.: Guidelines for quantitative risk assessment - TNO Purplebook. (2005)
Lachance, J., et al..,(2009).SANDIA REPORT Analyses to Support Development of Risk-Informed Separation Distances for Hydrogen Codes and Standards.

Research Results: Bowtie

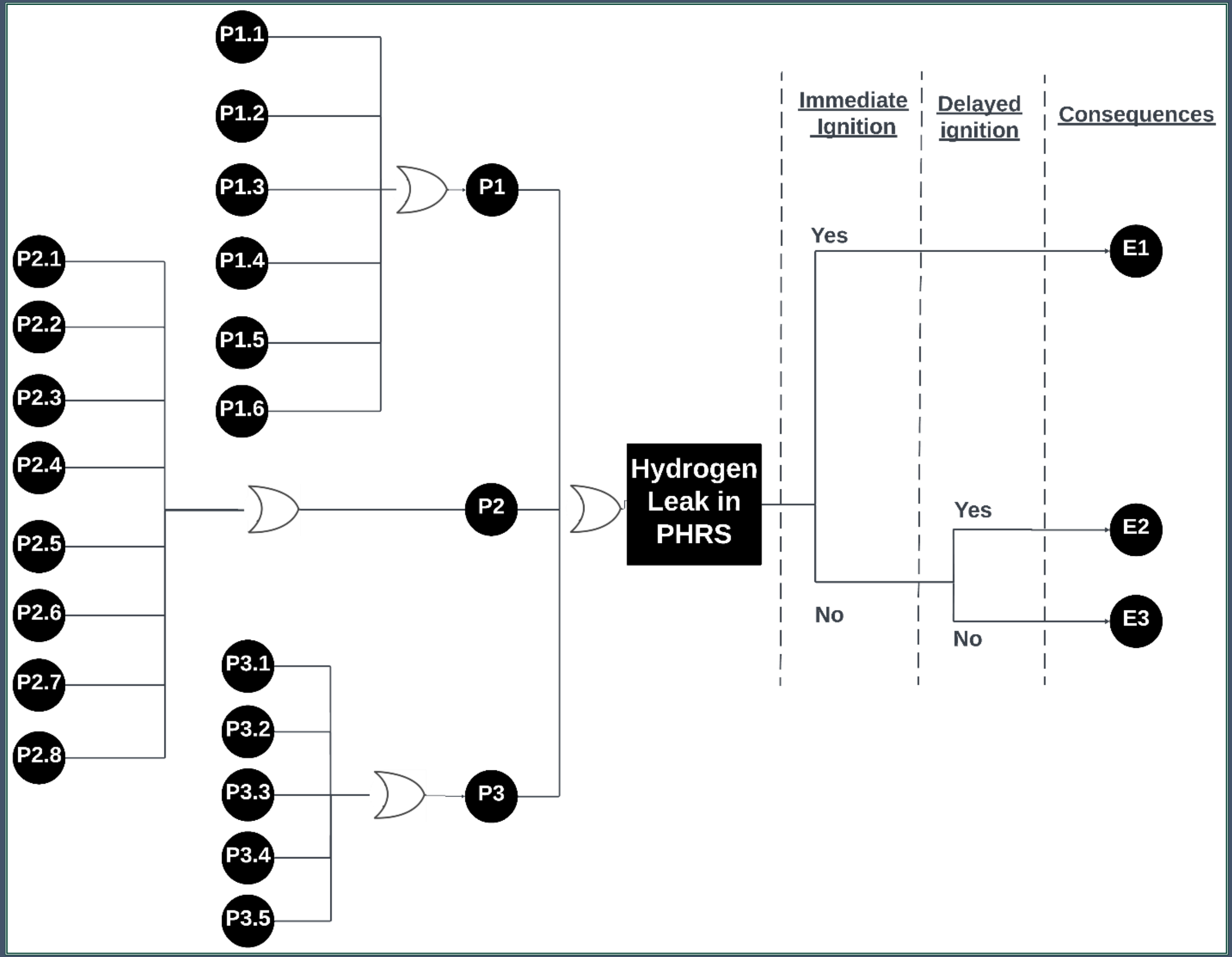

Figure 8: Bowtie with hydrogen leak as the top event

ID	Description
P1	Leakage from TTA
P1.1	Leak from cylinder
P1.2	Leak from valve
P1.3	Leak from joint
P1.4	Leak from instrument
P1.5	Leak from pipe
P1.6	Leak from flange
P2	Leakage from HSA
P2.1	Leak from compressor
P2.2	Leak from cylinder
P2.3	Leak from valve
P2.4	Leak from joint
P2.5	Leak from instrument
P2.6	Leak from pipe
P2.7	Leak from flange
P2.7	Mid-buffer storage leak
P3	Leakage from DA
P3.1	Rupture during fueling
P3.2	Hose failure
P3.3	Vehicle crash
P3.4	Intentional demolition
P3.5	Release due to drive-off

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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**

Risk Matrix

A risk matrix was developed in line with the CCPS's Guidelines for Hazard Evaluation Procedures

Jet Fire – Intolerable

Flash Fire – Not desirable

Safe dispersion – Conditionally acceptable with controls

Category / Frequency per year	Intolerable	Not desirable	Conditionally acceptable with controls	Tolerable
> 10^{-2}				
10^{-4} - 10^{-2}	Jet-Fire (E1)		Safe dispersion (E3)	
10^{-6} - 10^{-4}		Flash fire (E2)		
< 10^{-6}				

CCPS: Guidelines for Hazard Evaluation Procedures, 3rd Edition | CCPS. 576 (2008)

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

Consequence analysis

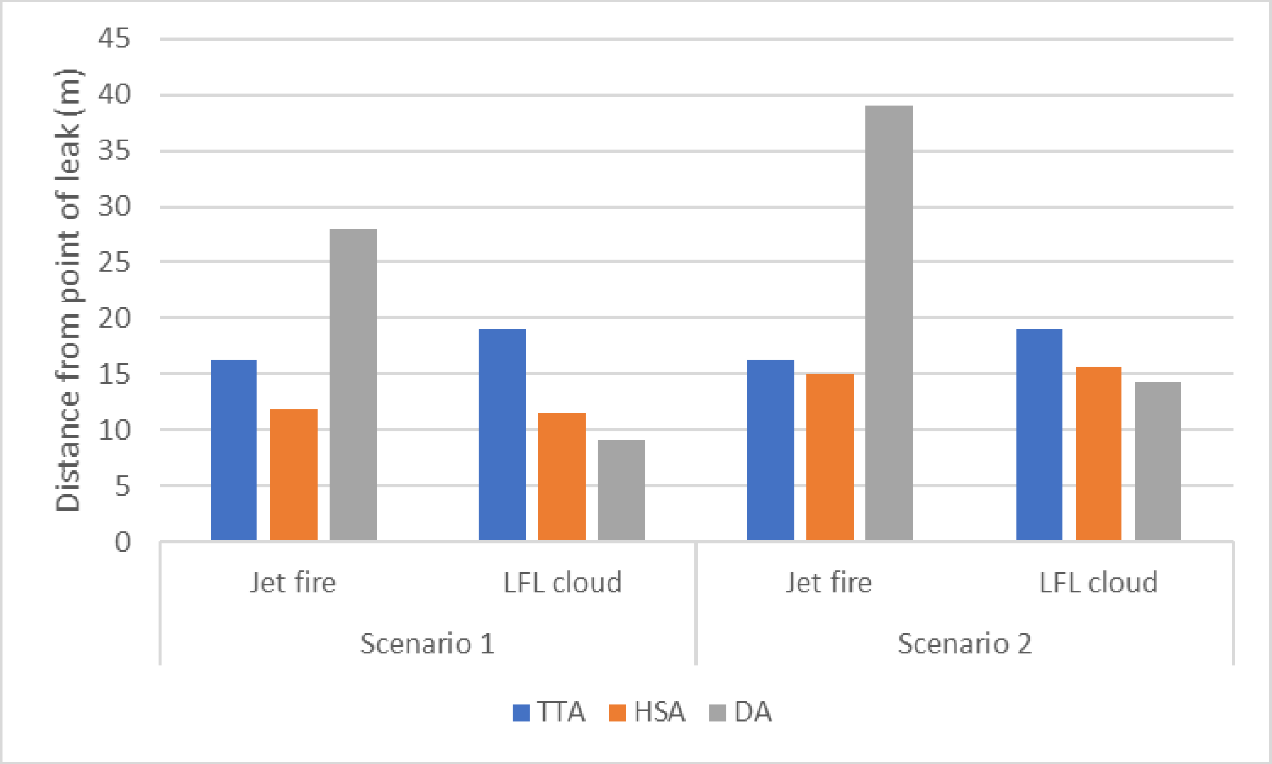

Figure 9: Harm distance for jet fire and LFL cloud in both scenarios

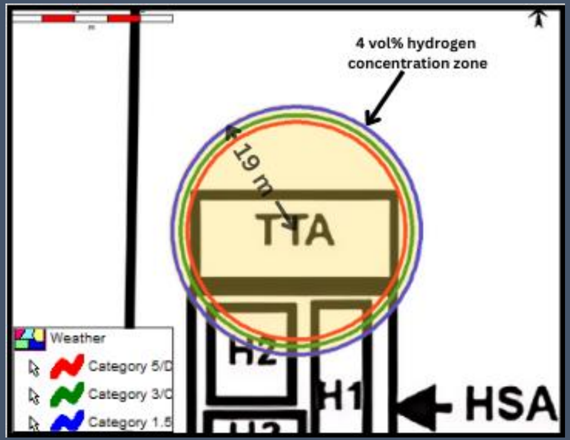

Figure 10: Scenario 1-Flammable LFL zone (4% vol H2 concentration) for 4.07 mm leak from Tube-trailer

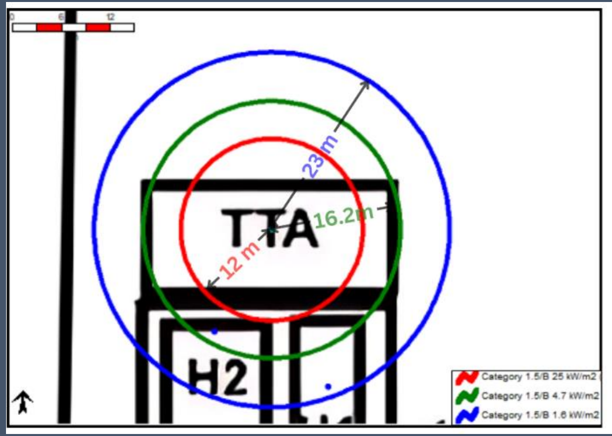

Figure 11: Scenario 2-Thermal radiation level distances caused by jet fire (a) 2.5 mm leak from H1

Hydrogen gas is fueled at -40^{o}C at a pressure of 700 bars for LHDV dispenser, if released, the colder gas will tend to move towards the ground because of higher density, before the hydrogen gas warms up and rise leading extended distances

Individual risk

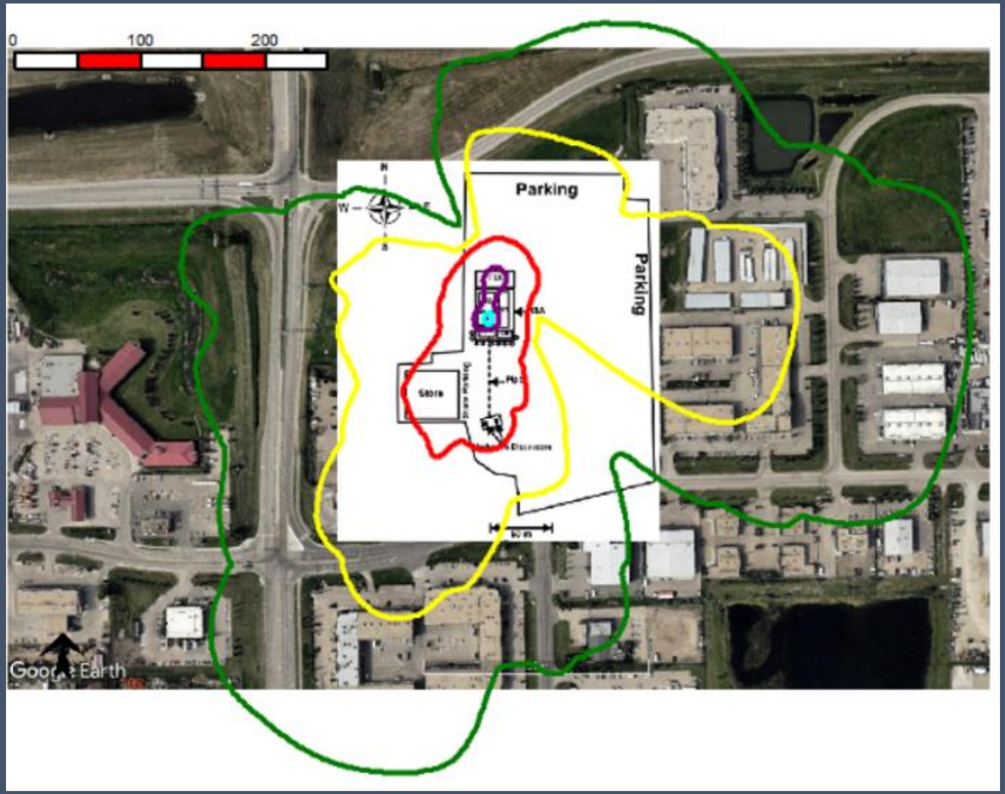

Figure 12: Scenario 1 - Dispensing pressure of 350 bar

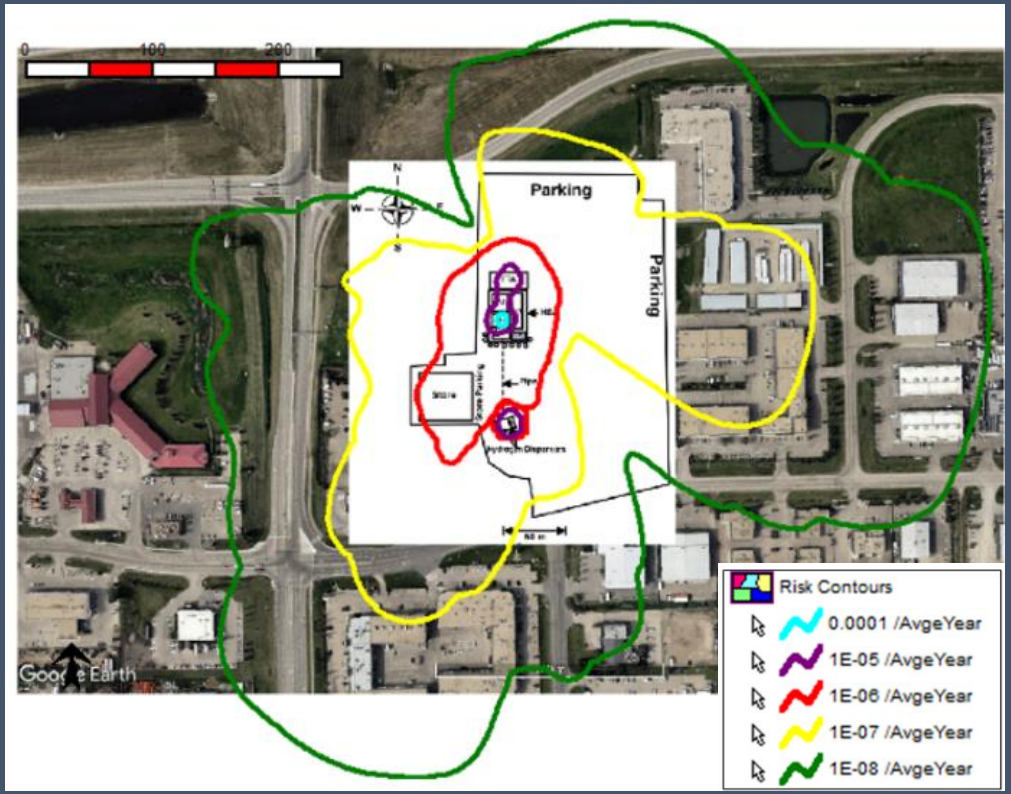

Figure 13: Scenario 2 - Dispensing pressure of 700 bar

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

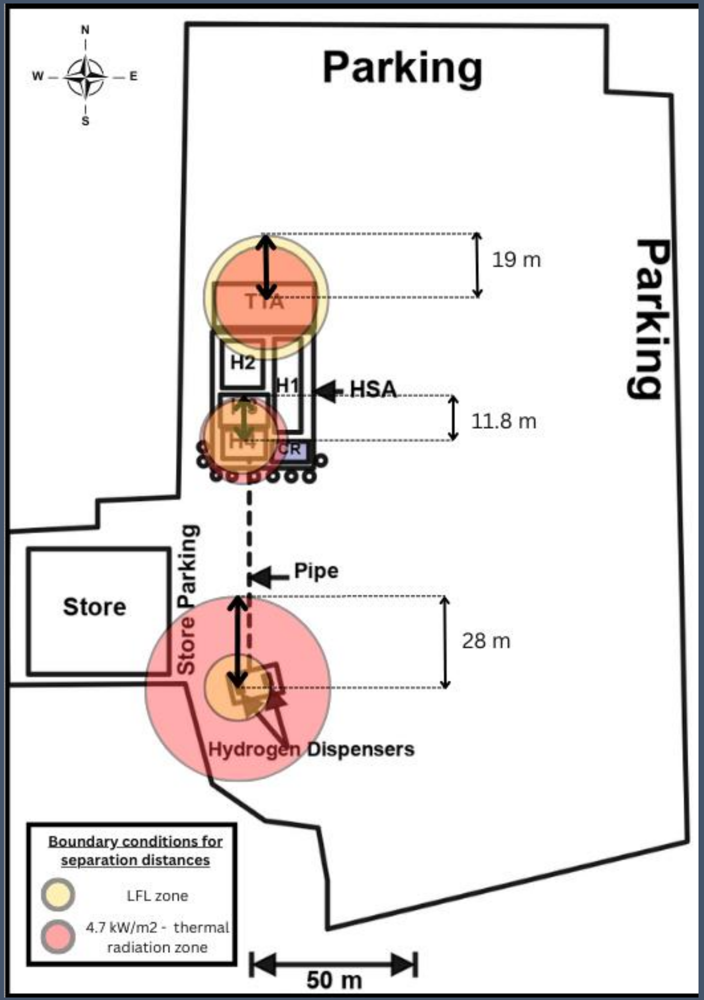

Figure 14: Recommended separation distance for scenario 1

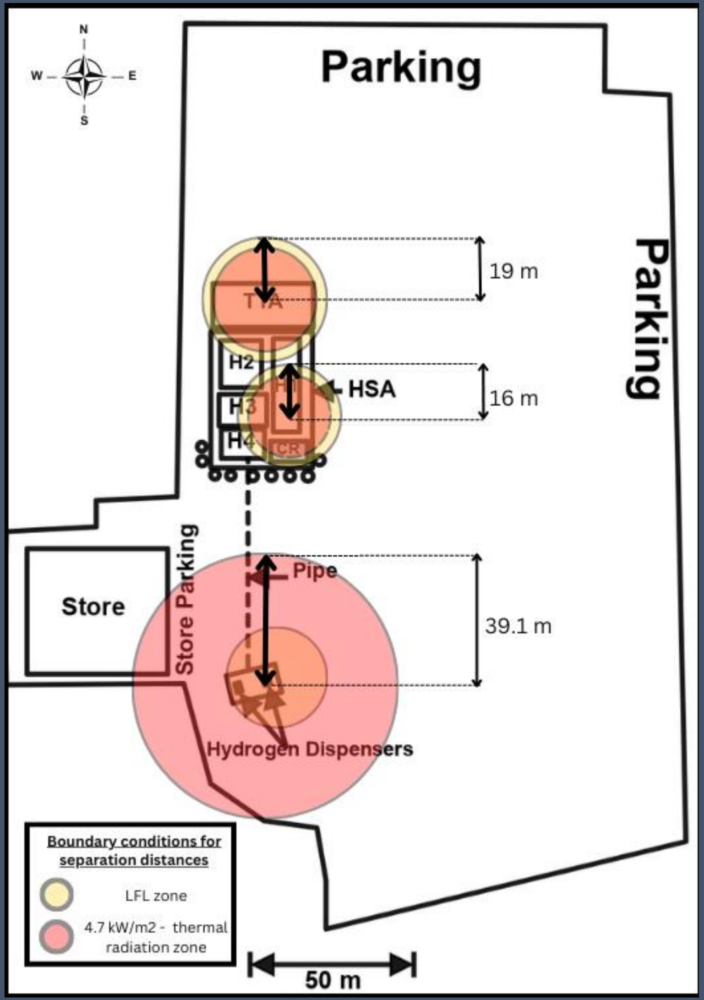

Figure 15: Recommended separation distance for scenario 2

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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

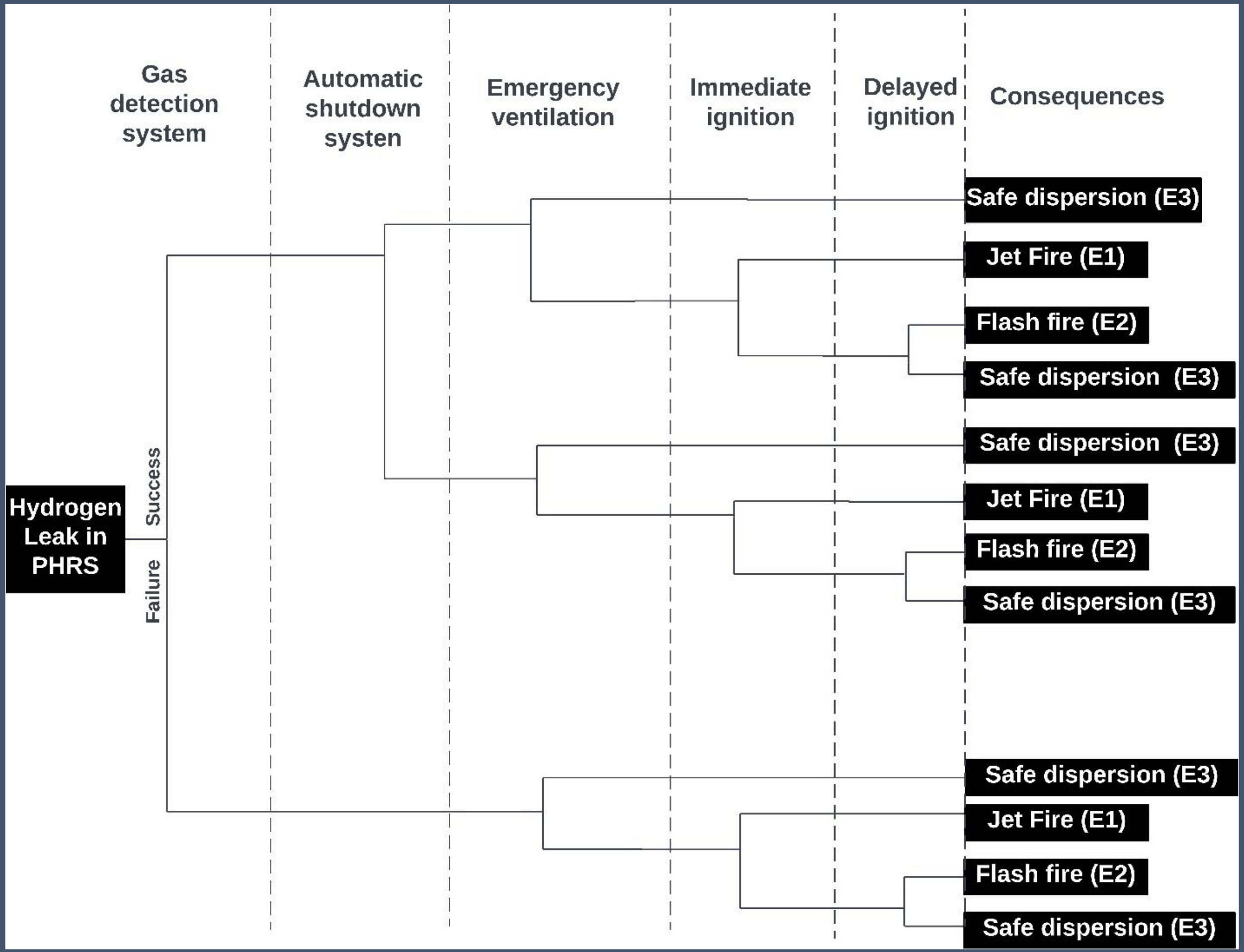

Figure 16: Event tree presenting risk reduction using safety barriers

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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

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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Recommendations

Hydrogen gas detectors:

The hydrogen detection, followed by the automatic shutdown of the PHRS, should occur before 1 vol% hydrogen in the air (20% LFL). Detectors should be able to activate audible alarm sounds in the facility, leading to an entire gas-supply shutoff

UL 2075: Gas and Vapor Detectors and Sensors ISO 26142: Hydrogen Detection Apparatus – Stationary Applications

Automatic shutdown systems:

The automatic shutdown must interrupt the electrical supply to the fueling components in the hydrogen system area, including compressors and dispensers, upon detection by the hydrogen gas detectors.

Venting systems:

For venting systems, NFPA 2 provides guidelines for the design of the venting systems in accordance with the specifications outlined in CGA G-5.5

UL 2075, https://www.techstreet.com/standards/ul-2075?product_id=1852913

ISO 26142:2010 - Hydrogen detection apparatus — Stationary applications, https://www.iso.org/standard/52319.html

Recommendations

Breakaway couple:

Breakaways are employed as a safety measure to safeguard the dispenser in the event of an unintentional "drive-off" while the nozzle is still attached to the vehicle. They enable a secure detachment of the nozzle from the dispenser, thereby preventing any harm to the dispenser

The dispenser fuel assembly and the hydrogen unloading hose should be equipped with an appropriate breakaway coupled with the requirements outlined in CSA/ANSI HGV 4.4-2021 (Gaseous Hydrogen - fueling stations – valves)

Staff training and certification:

Staff involved in the operations of the HRS must have a comprehensive understanding of hydrogen's properties and safety protocols associated with the particular HRS

- On-site staff training
- HRS Operational procedure training
- Hydrogen tube-trailer staff

CSA HGV4.4 Gaseous Hydrogen – Fueling Stations - Valves | Hydrogen Tools, https://h2tools.org/fuel-cell-codes-and-standards/csa-hgv44-gaseous-hydrogen-fueling-stations-valves

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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COMMENTS?
QUESTIONS?

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Regulatory gap analysis

Alberta Fire Code (2019)

- The National Fire Code - 2019 Alberta Edition (NFC(AE)) regulates fire safety in Alberta. The code specifies technical requirements for building construction, use, demolition, and fire protection
- All fuel-dispensing stations in Alberta comply with NFC(AE) as per the requirements set in Part 4: Flammable and Combustible Liquids. The code does not explicitly mention requirements for hydrogen-fueling
- The California Fire Code addresses this gap with section 5473, which sets out minimum separation requirements for regulating hydrogen systems based on the station's capacity

Canadian Commission on Building and Fire Codes (CCBFC): National Fire Code - 2019 Alberta Edition. (2019)
California Code of Regulations, Title 8, Section 5473. Specific Requirements., https://www.dir.ca.gov/title8/5473.html

Regulatory gap analysis

Zoning laws for HRSs in Alberta

- The identified land for the PHRS falls within the Strathcona County Municipality (SCM) jurisdiction under the Alberta Municipal Government Act
- A list of permitted uses and activities on a property under the jurisdiction of SCM is outlined in the Land Use Bylaw (2015)
- Currently, the zoning laws in Edmonton do not include the distance requirements for establishing hydrogen refueling stations
- Considering the consequences and associated harm distances for such stations, risk-based land use, as performed in this study, can assist in evaluating appropriate distances of such stations from residential zones

Strathcona County: Land Use Bylaw - Part 1: Interpretation of this Bylaw, https://www.strathcona.ca/council-county/bylaws-and-policies/land-use-bylaw/

Regulatory gap analysis

Standards

- The codes and standards applicable for HRSs are divided in four categories

1) Tube-trailer delivery

2) HRS Component design

3) Refueling Operations

4) Safety Standards

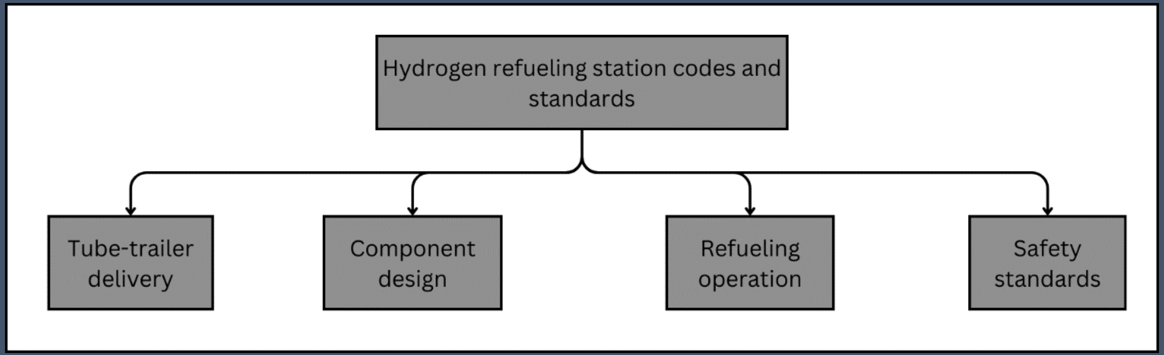

Figure 17: HRS codes and standards categories

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Regulatory gap analysis

Canadian codes and standards

1) Tube-trailer delivery

Gap:
<u>CSA B339-18</u>

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/

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)

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

COMMENTS?
QUESTIONS?

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Next steps - Introduction

To perform Quantitative risk assessment of hydrogen delivery/distribution pathways

There are three primary pathways for hydrogen delivery/distribution from production plants to the end users are:

1. Delivery via pressurized cylinders/tubes (gas delivery) carried by tube-trailer
2. Delivery via cryogenic tankers (liquid delivery) carried by tank truck
3. Delivery via distribution pipelines (Hydrogen-natural gas blend)

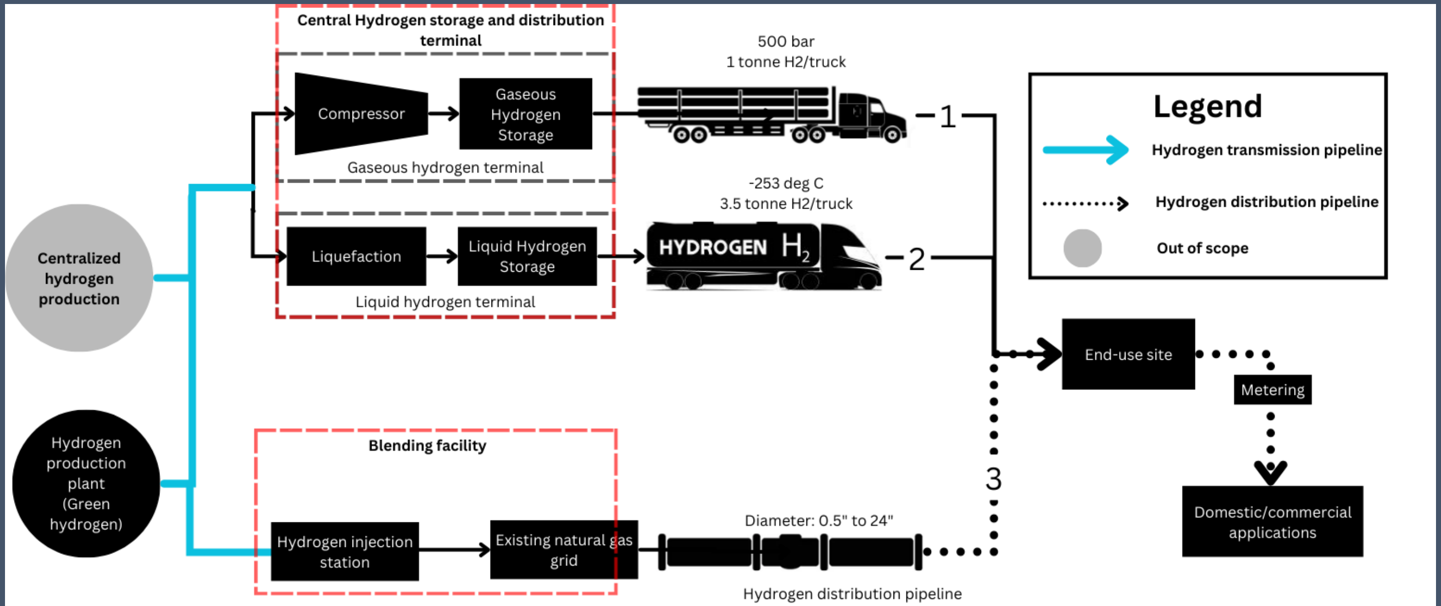

Figure 18: Pathways of delivering/distributing hydrogen

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A. Elgowainy, M. Mintz and M. Gardiner, Distribution networking, in: Handbook of Hydrogen Energy, 2014, 935–956
M. Demir, I. Dincer, Cost assessment and evaluation of various hydrogen delivery scenarios, Int. J. Hydrogen Energy 43 (22) (2018) 10420–10430.

Methodology

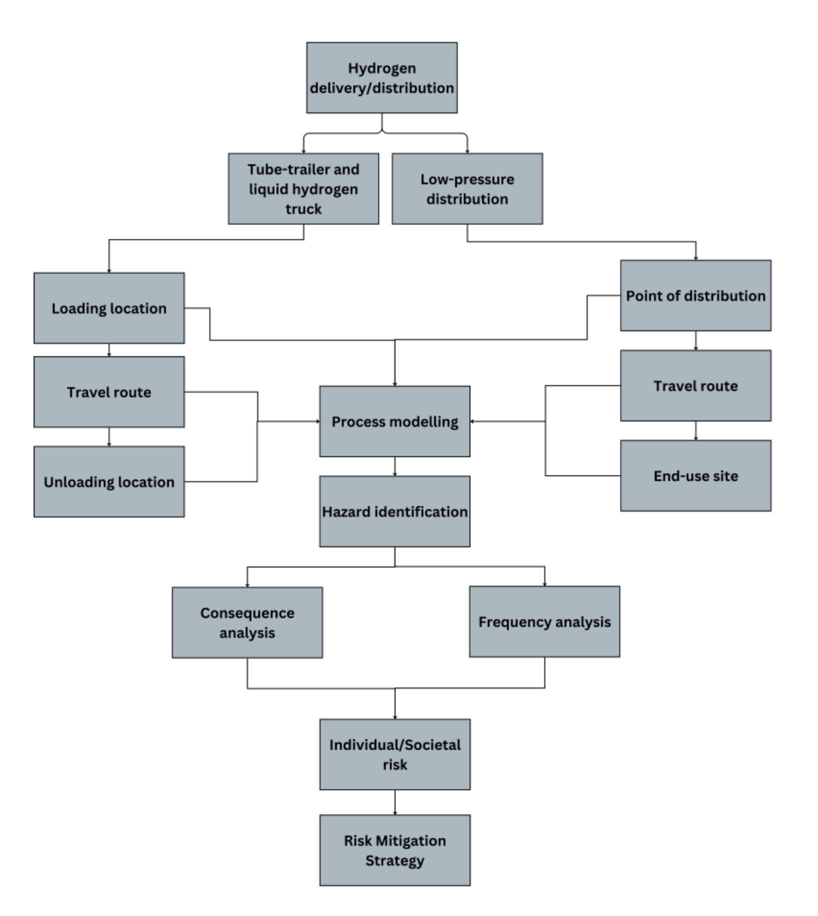

Figure 19: Quantitative Risk Assessment methodology for delivery/distribution of hydrogen

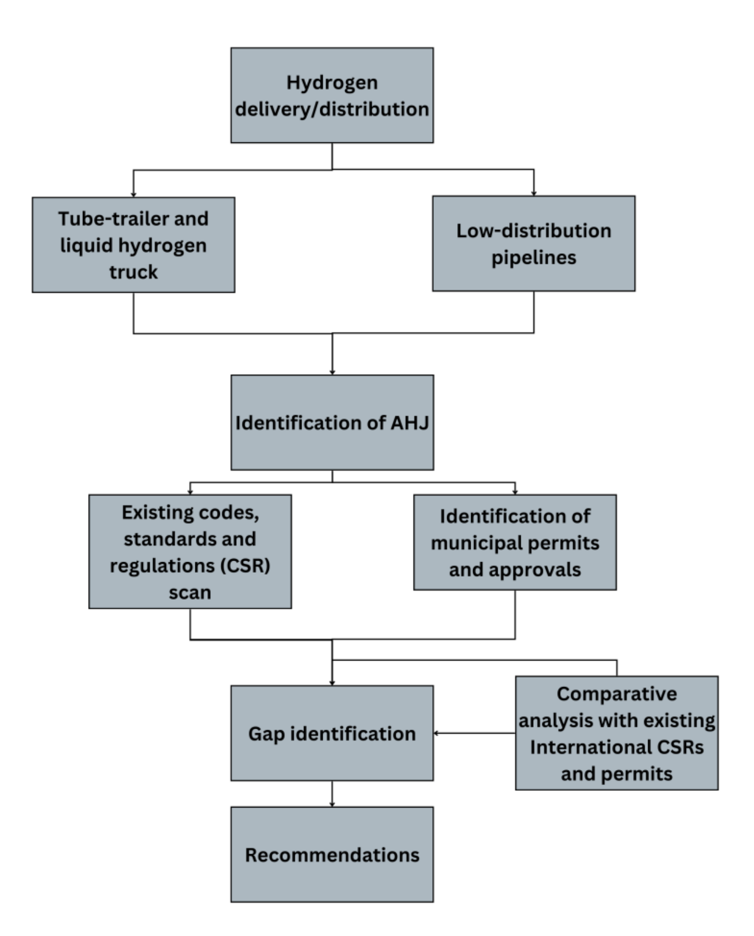

Figure 20: Regulatory gap analysis for delivery/distribution of hydrogen

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Location of Central distribution terminal

- The location considered as the Central Distribution terminal is an existing Linde's tube filling facility at 119 St, Fort Saskatchewan, Alberta, Canada.

- This location will be considered for risk assessment for the unloading scenario of hydrogen into trucks for delivery

Figure 21: Central Distribution terminal location in Edmonton, Alberta for loading compressed hydrogen gas and liquid hydrogen in tube trailers and liquid trucks respectively

Location of Hydrogen distribution pipeline network

Transportation/Utility Corridor (TUC) to blending station → Distribution network

Total Network area: 1.13 km^2

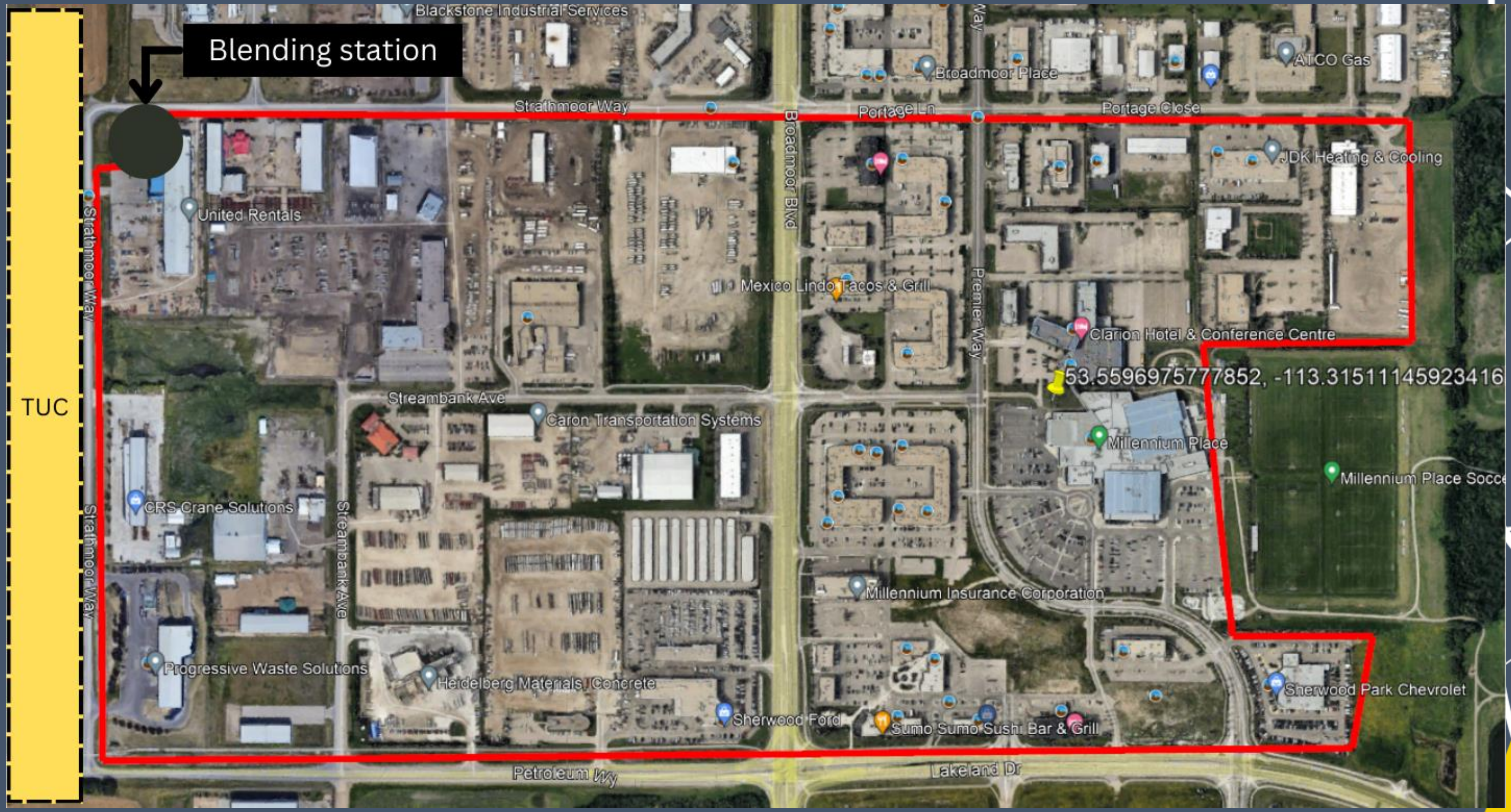

Figure 22: Hydrogen distribution pipeline network location in Edmonton, Alberta

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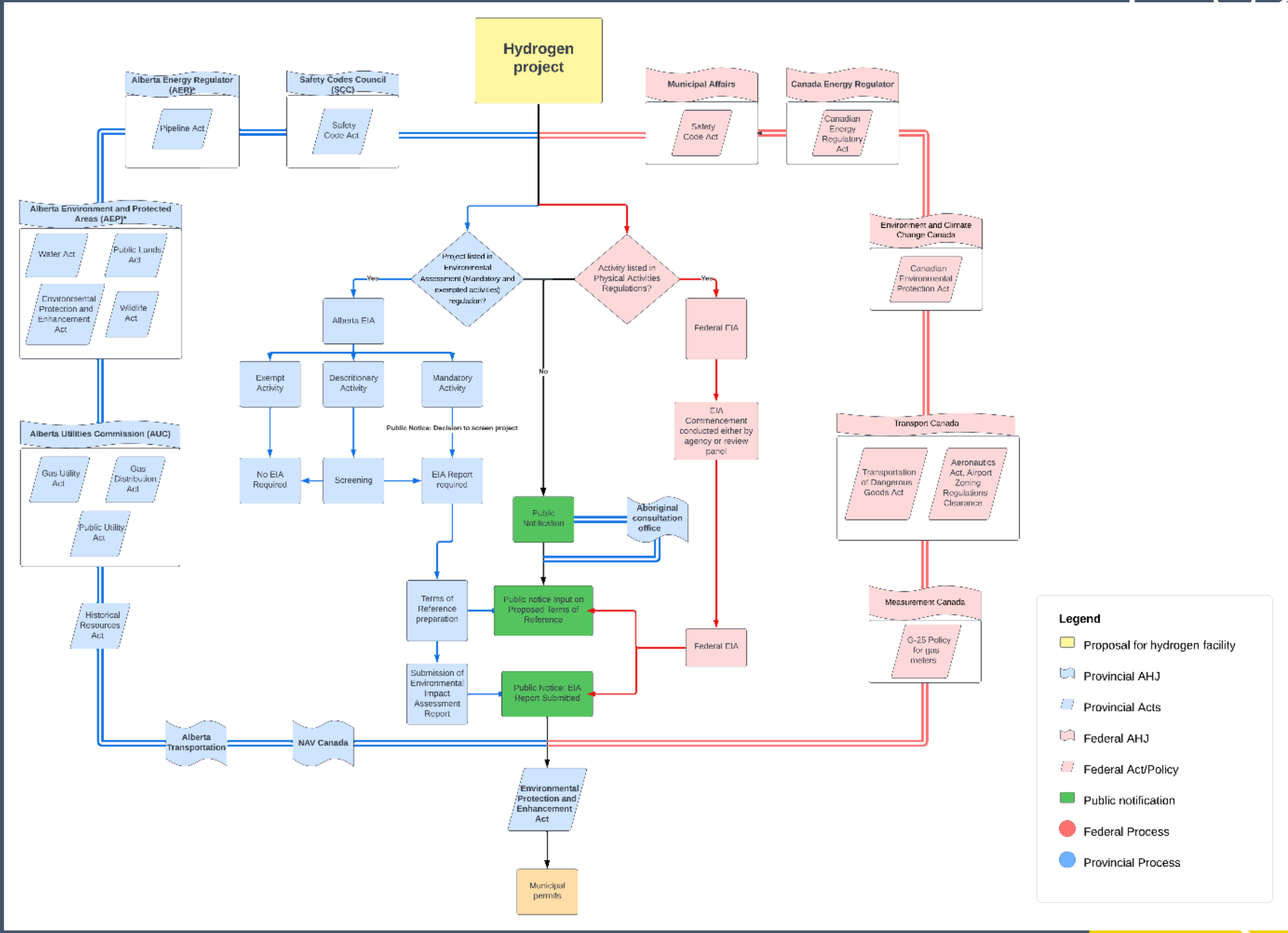
Map authorities having jurisdiction



COMMENTS?
QUESTIONS?

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THANK YOU!

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