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Developments and Uncertainties in Hydrogen Fuels Risk Assessment

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Hazards31

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Presentation Overview

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Current H_2 Fuelling Landscape

Societal expectations.

Safety Concerns & Historical Events

What is the industry history, and expectations?

Assessing Risk for H_2 Fuelling Technology

Data and uncertainties.

Conclusions / Discussion

Challenges for managing H_2 fuelling risks.

Introduction – Expectations for Hydrogen Fuelling

Expectation from society –

Risk from hydrogen
no worse than gasoline
usage

Obstacles:

- Ease of release
  (small molecule, high pressure source)
- Ease of ignition
  (low ignition energy)
- Severity of ignition event
  (propensity to ignite explosively)

Introduction – Public Perception

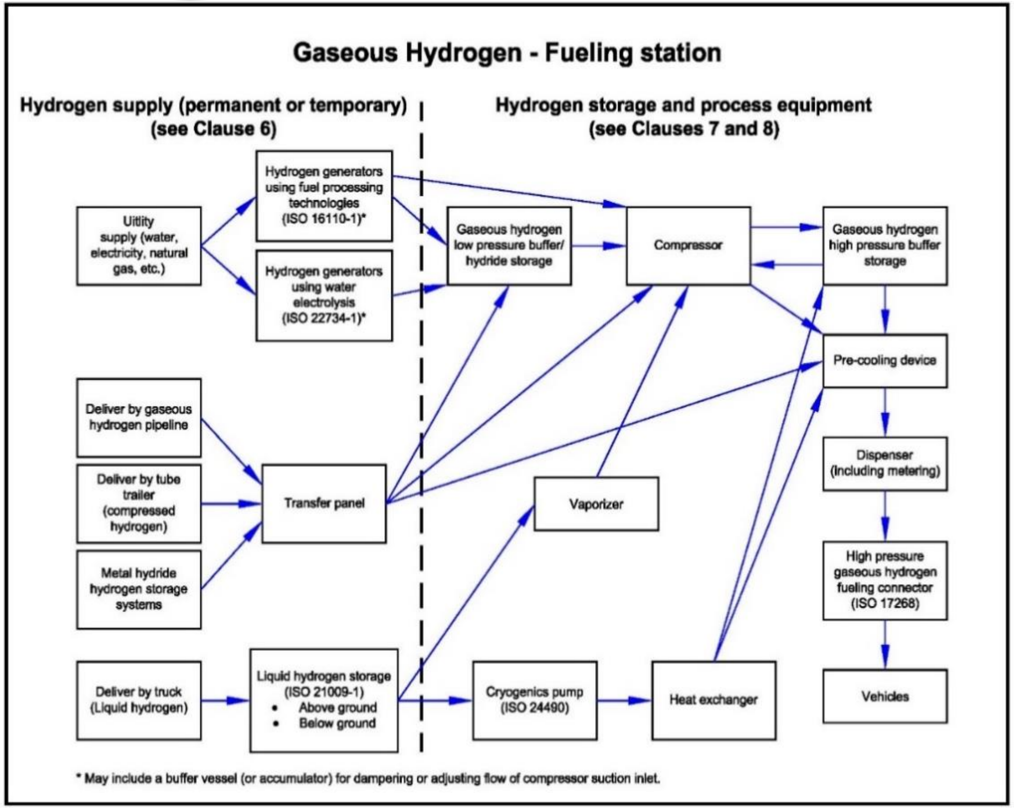
- **Air Products Santa Clara (2019)**
  - *3-4 month shutdown for the only provider in the Bay Area region*
  - *Disruption of distribution resulted in FCEV owners abandoning their vehicles*
- ***Gangwon Technopark (2019)***
  - *Destroyed facility half the size of a soccer field, killing 2 and injuring 6 more*
  - *Public protests, refusal to incorporate in stations, etc. delay rollout of FCEV tech*
- ***Uno-X Norway (2019)***
  - *Leak from improperly installed plug*
  - *Closed 10+ Uno-X stations around Europe due to lack of public trust*

South Koreans Protest Gangneung Storage Tank Explosion

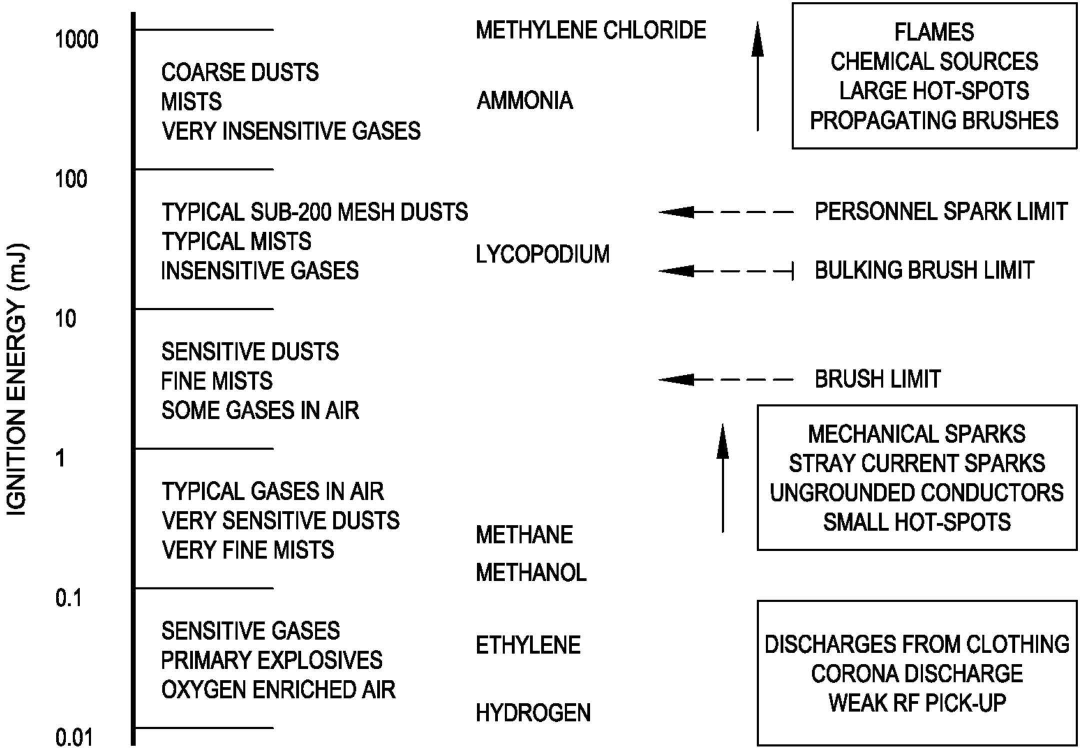
Air Products Santa Clara Valley – Supply Disruption

Evaluation for Different Fuelling Options

From ISO 19880-1:2016



Ignition Energies and Sources



Variability of Opinions on Ignitability of H_2

Release Conditions	T = 38C (100F), P = 7 barg (100 psig), Hole Diam. = 25 mm (1 inch), Release Duration = 100 sec., Weather = typical daytime, Release into Class I Div.1 area					
Estimated Probability*	**Expert 1**	**Expert 2**	**Expert 3**	**Expert 4**	**Expert 5**	**Expert 6**
Immediate Ignition	0	0.1	0.1	0	0.1	0.1
Delayed Ignition	1	0.75	0.01	1	0.9	0.01

* The total ignition probabilities do not add up to 1 in some cases (i.e., there is a probability of non-ignition)

Some Proposed H_2 Ignition Mechanisms

Electrostatic ignition - Ignition due to sparks, brush discharges and corona discharges

Reverse Joule-Thompson effect - Hydrogen is atypical in that its temperature can rise upon depressuring, potentially reaching its autoignition temperature (AIT).

Hot surface ignition - Hydrogen can be ignited by a hot surface, although this requires temperatures substantially higher than the reported AIT.

Diffusion ignition - Ignition of a gas at a temperature well below its AIT has been reported experimentally in a shock tube at high speeds.

Adiabatic compression/turbulence - The equipment geometry at or near the point of release drives compression that results in a shock wave that leads to ignition.

Performance of H_2 Fuelling Facilities

- What is the operating history?
- What is the failure history?

Operating History of H_2 Fuelling Facilities

Data/Assumptions:

- There are about 500 hydrogen refuelling stations in the world.
- The average station has been in operation for 3 years.
- The average station performs 20 fillings per day (7,000 per year).
- There are 30,000 hydrogen automotive vehicles in the world.
- The average vehicle has been on the road for 2 years.
- The average vehicle is refilled 25 times per year.

The operating history is between 1 and 15 million fillings??

Fire/Explosion Incident History at H_2 Fuelling Facilities

- **Norway (2019)**
- **California (2019)**

Norway and the U.S. account for about 10% of worldwide H_2 fuelling facilities.

Do we know if there is full reporting of incidents in the popular press from the other 90% of worldwide H_2 fuelling facilities?

Some Proposed Failure Rates

Failure Mode	RIVM (Timmers 2017)	Sandia (Ehrhart 2021)
Dispenser delivery hose leaks	4E-5/hour	
Dispenser delivery hose breaks and ESD fails	4E-9/hour	
Nozzle pop-off		8.2E-7/filling
Nozzle failure to close		2E-3
Drive-off with hose still attached		5.2E-5/filling
Overpressure during fueling		1.1E-5/filling

Use of standard industrial leak frequencies for hydrogen equipment suggests higher numbers than gasoline fuelling history.

Other Considerations

Are failure rates dominated by usage, or total time in service?

Fuelling hoses remain connected to source, and hoses are replaced at the station after each use so there is ~ no damage potential between uses.

> Does this imply that failure rates for hoses should be time-based (e.g. because of exposure to weather)?

Hoses are subject to repeated pressure cycling, possibly leading to fatigue.

> Does this imply that failure rates for hoses should be ‘per use’ based?

Conclusions

1

Societal expectations.

Society expects H_2 fuelling performance to be no riskier than gasoline fuelling.

2

Industry expectations vs history.

There have been fuelling incidents at the relatively few H_2 fuelling facilities. There are reasons that incidents could be more common at H_2 facilities (e.g. ease of ignition).

3

Uncertainties.

Operating history is small; there is debate over ease of hydrogen ignition.

4

Needs for objective risk assessment.

Agreement on risk assessment inputs that are now perhaps order-of-magnitude estimates.

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Questions? Discussion.

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