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)
• Air Products Santa Clara (2019)
  o 3-4 month shutdown for the only provider in the Bay Area region
  o Disruption of distribution resulted in FCEV owners abandoning their vehicles

• Gangwon Technopark (2019)
  o Destroyed facility half the size of a soccer field, killing 2 and injuring 6 more
  o Public protests, refusal to incorporate in stations, etc. delay rollout of FCEV tech

• Uno-X Norway (2019)
  o Leak from improperly installed plug
  o Closed 10+ Uno-X stations around Europe due to lack of public trust
Evaluation for Different Fuelling Options

From ISO 19880-1:2016
Ignition Energies and Sources

- **1000**
  - COARSE DUSTS
  - MISTS
  - VERY INSENSITIVE GASES
- **100**
  - TYPICAL SUB-200 MESH DUSTS
  - TYPICAL MISTS
  - INSENSITIVE GASES
- **10**
  - SENSITIVE DUSTS
  - FINE MISTS
  - SOME GASES IN AIR
- **1**
  - TYPICAL GASES IN AIR
  - VERY SENSITIVE DUSTS
  - VERY FINE MISTS
- **0.1**
  - SENSITIVE GASES
  - PRIMARY EXPLOSIVES
  - OXYGEN ENRICHED AIR
- **0.01**
  - METHYLENE CHLORIDE
  - AMMONIA
  - FLAMES
  - CHEMICAL SOURCES
  - LARGE HOT-SPOTS
  - PROPAGATING BRUSHES
  - PERSONNEL SPARK LIMIT
  - BULKING BRUSH LIMIT
  - BRUSH LIMIT
  - MECHANICAL SPARKS
  - STRAY CURRENT SPARKS
  - UNGROUNDED CONDUCTORS
  - SMALL HOT-SPOTS
  - DISCHARGES FROM CLOTHING
  - CORONA DISCHARGE
  - WEAK RF PICK-UP
### Variability of Opinions on Ignitability of H₂

<table>
<thead>
<tr>
<th>Release Conditions</th>
<th>T = 38C (100F), P = 7 barg (100 psig), Hole Diam. = 25 mm (1 inch), Release Duration = 100 sec., Weather = typical daytime, Release into Class 1 Div.1 area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Immediate Ignition</td>
<td>0</td>
</tr>
<tr>
<td>Delayed Ignition</td>
<td>1</td>
</tr>
</tbody>
</table>

* 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 H₂ 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\textsubscript{2} Fuelling Facilities

- Norway (2019)
- California (2019)

Norway and the U.S. account for about 10\% of worldwide H\textsubscript{2} fuelling facilities.

Do we know if there is full reporting of incidents in the popular press from the other 90\% of worldwide H\textsubscript{2} fuelling facilities?
Some Proposed Failure Rates

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

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.
Questions? Discussion.

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