Hydrogen – Aspects of safety

Wind Finland 2023

Kiwa Inspecta

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4.10.2023

Trust
Quality
Progress

Hydrogen

- **Lightest element, at. weight 1 g/mol density 90 g/m³; transparent, no odour**
- **Smallest atom (& molecule, H_2) and common: 75% of the mass of universe**
- **Reactive, on earth rarely free**

→ **low density**, diluted in open space, more slowly in closed environment

→ **leaks** at joints / contact surfaces and even through walls easier than most gases

→ **ignites** at 4-75% concentration, 1/10 of min. Ignition energy of gasoline (0,02 mJ), burns with 2045°C flame to water

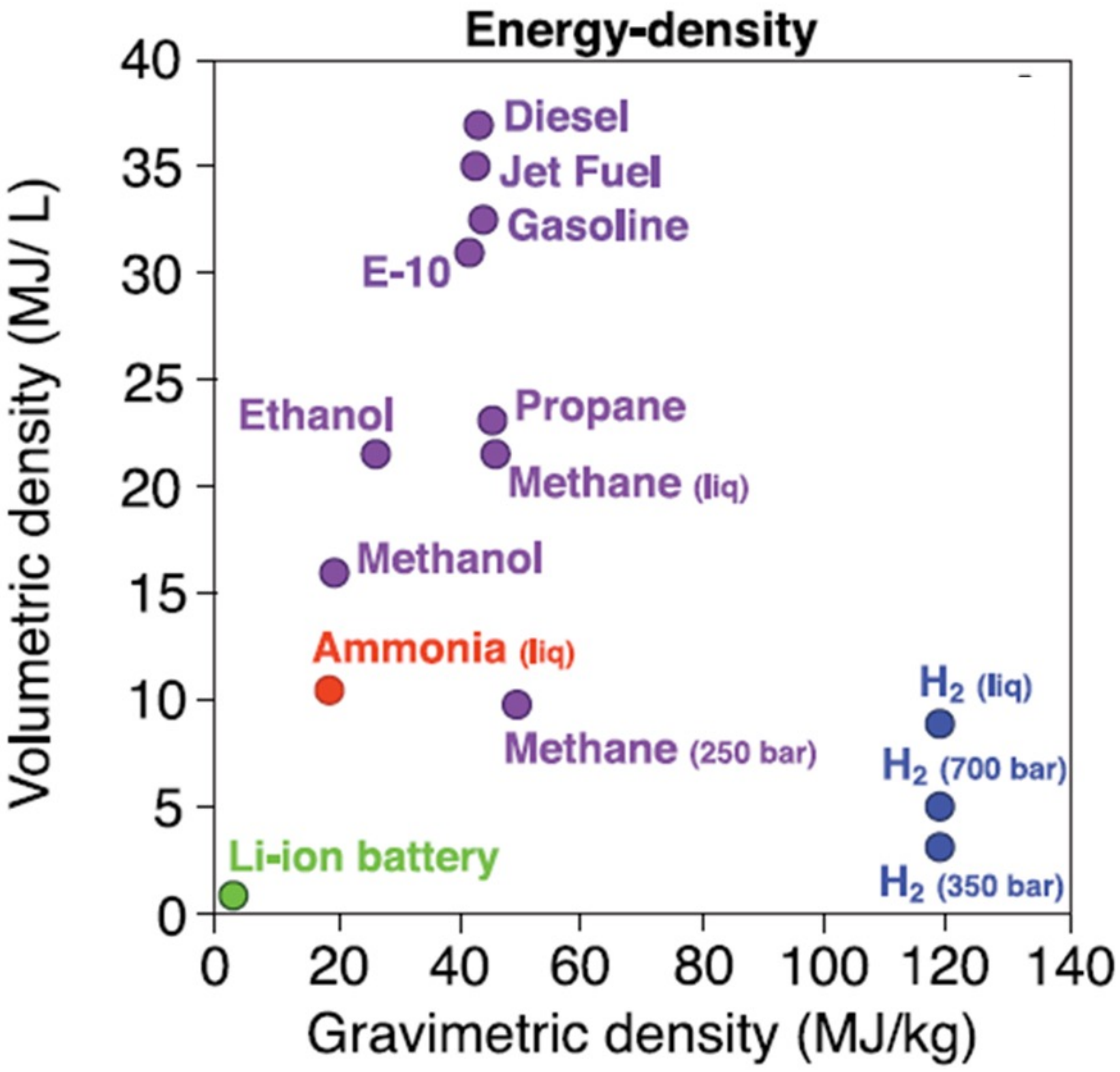
→ **weakens and embrittles** structural materials

Hydrogen as energy carrier

- **Great energy density on a mass basis resulting in minimal weight considerations - lightweight**

- **Poor energy density on volumetric basis requiring increased space requirements**
  - high pressures and low temperatures

- **Safety**: all flammable/explosive, H_2 easily ignited



Davies et al. Science 2018

Hydrogen – regulatory framework and support

- **EU directives, national regulation**
  - EU level requirements: safety, fair playing field for stakeholders, e.g. REII, SEVESO III, ATEX
  - national legislation – safety, legal framework
  - national licencing and supervisory authorisation on safety of hazardous structures and materials/chemicals

- **Standards and guidelines**
  - international (ISO/IEC, EN, other) standards related to hydrogen
  - national, regional, industry/company-specific standards, rules, guidelines, recommendations
  - H_2 transition promotes updating

For example: ISO 31010 Risk assessment

prEN 13480-11, ASME B31.12 Piping design

prEN 13445-15 Pressure vessels

EN 16668 Industrial valves

EN 1591-1 Flange tightness (EN 13445-3 Annex G)

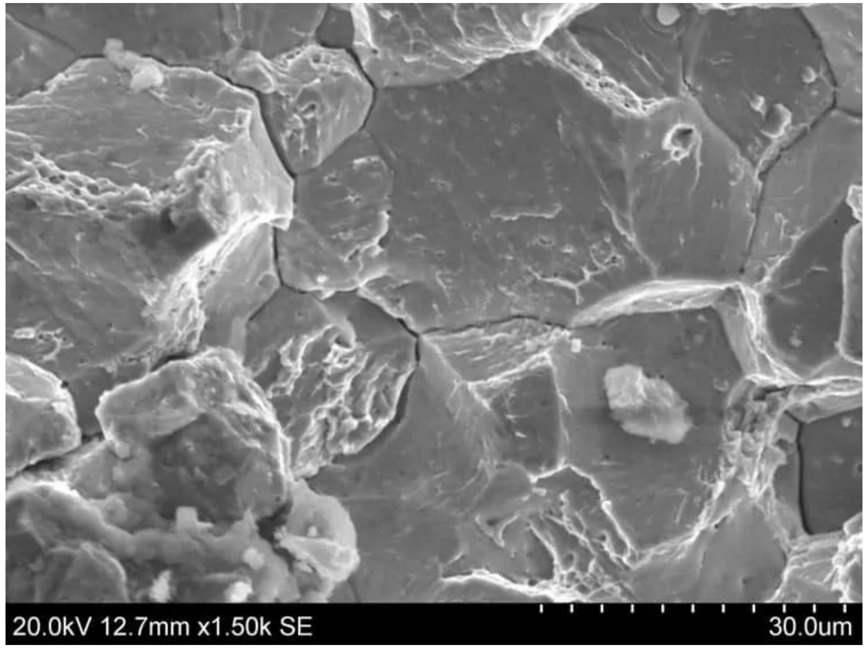
EN 13555 Seal performance

Hydrogen embrittlement and cracking of steel

- Hydrogen has a negative effect on the properties of materials, known as **hydrogen embrittlement (HE)**

- Exposure to hydrogen can make some metal vessels or pipelines brittle and increase the risk of cracking, especially where there are pressure variations

- Exposure can lead early, unpredicted failures



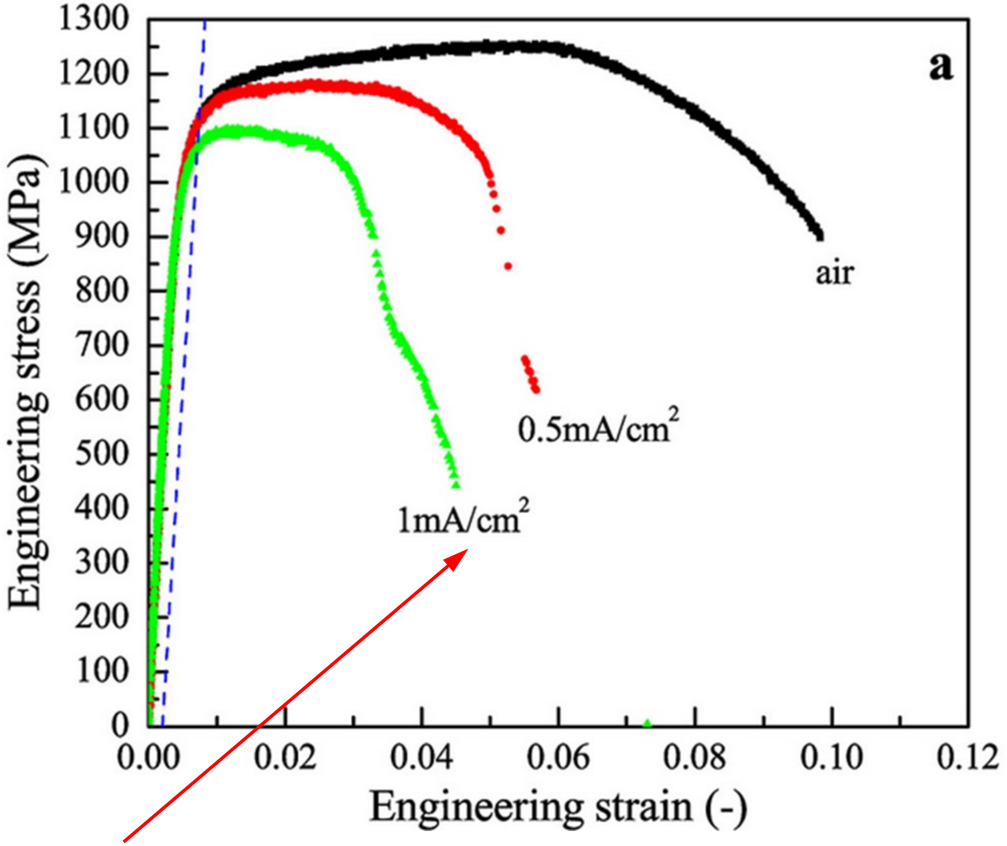
https://uscorrosion.com/index.php/hydrogen-embrittlement-failure-analysis

Hydrogen embrittlement (HE) and cracking of steel

- **Factors promoting embrittlement/cracking**
  - ferritic microstructure, high strength (hardness)
  - high pressure, ingress of atomic hydrogen
  - fluctuating loading (fatigue)
  - construction details are important; manipulations like welding and bending lead to higher strength/hardness → increased HE sensitivity

- **Protective factors**
  - austenitic microstructure
  - hydrogen trapping by microstructural features
  - temperature > 300°C → no HE
  - ferritic Rm < 700 MPa, hardness < 240 HV → decreased riks of HE (cycling is still weakening)

0,22C-2Cr-1,2Ni-0,5Mo-0,22V, QT 920+560°C



Low ductility with hydrogen in steel

Cheng et al. MSEA 2022

Hydrogen – materials selection

Best materials for hydrogen service:
- mostly austenitic steels, e.g. 304, 347, 316L, some Ni alloys

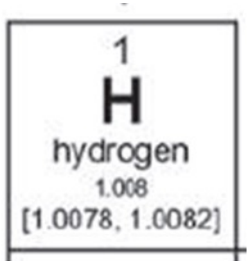
Acceptable: cost-effective ferritic C-, CMn- and Cr-Mo-steels
- limited by allowable strength/hardness, or case-specific acceptance

To be avoided in hydrogen environments:
- stainless ferritic, martensitic and duplex steels, cast irons
- Al and its alloys in moist/wet environments, other than oxygen-free Cu
- Ni, Pb, Sn and their alloys; polymers (plastics, with few exceptions)

Hydrogen: challenges in operation

- **Industrial production and use**
  - organised, centralised, recorded
  - controlled with planned service & maintenance
- **Local and distributed production and use**
  - expanded exposure to risk
  - variability, including extremes of application
  - potentially reduced control and monitoring
  → need to manage case-specific risks
  → planning, automation, new solutions to compensate for the exposure

Hydrogen – challenges in transport, storage



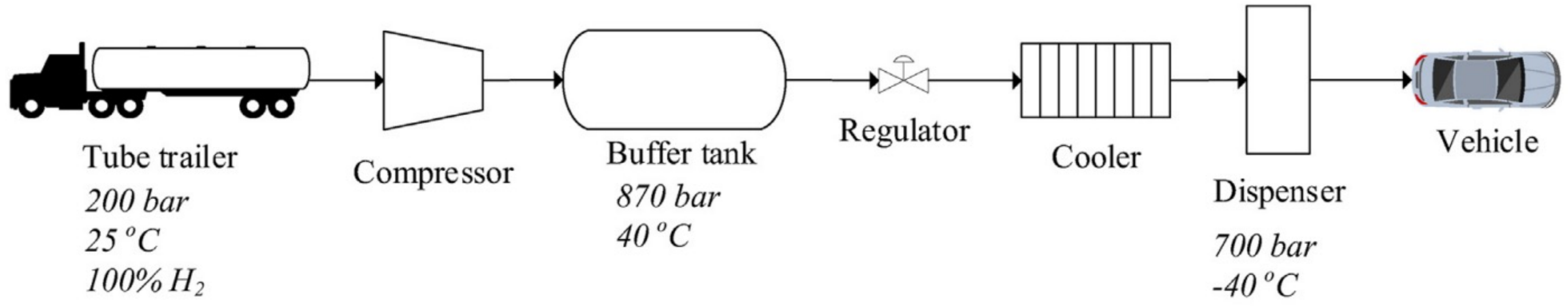
- **Tube trailers**
  - in buildings and tunnels: risk of accidents, leaks if insufficiently diluted/ventilated
- **Shipping, pipework, storage vessels**
  - loading and discharge at harbours
  - connections, valves, leak control
  - heat transfer for liquified H_2 vessels

- **Issues of safety (incl. operation):**
  - hazard/risk assessment for facilities
  - ventilation, leak & flame detection
  - functional condition of equipment
  - minimizing risk exposure of personnel
  - instructions, checklists for maintenance and operation, training
  - completing and signing off work phases
  - … https://tukes.fi

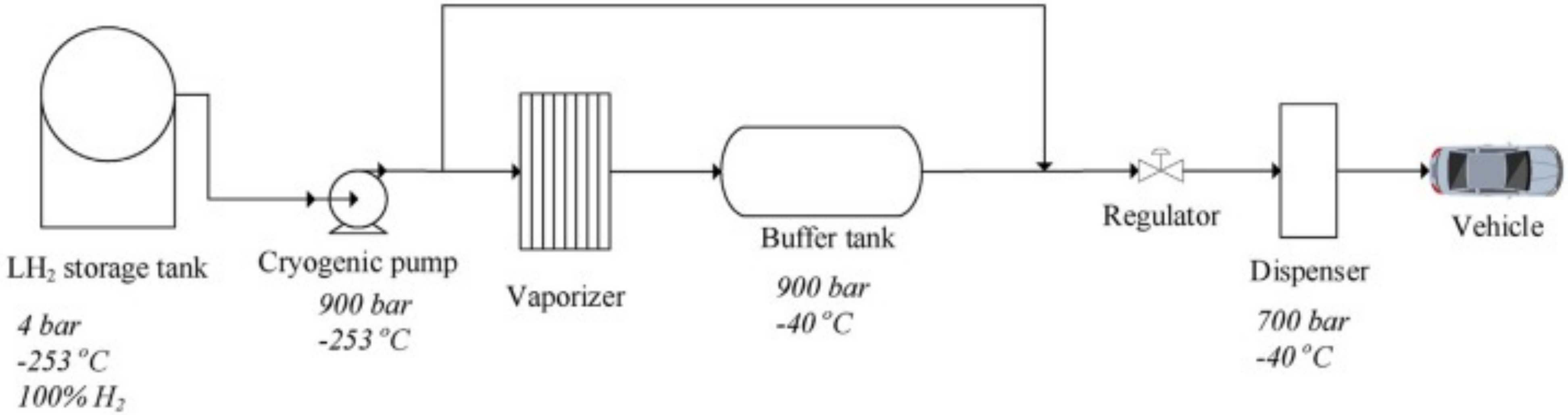
Example: risks of H_2 refueling stations

Yoo et al. Int J Hydrogen Energy 2021

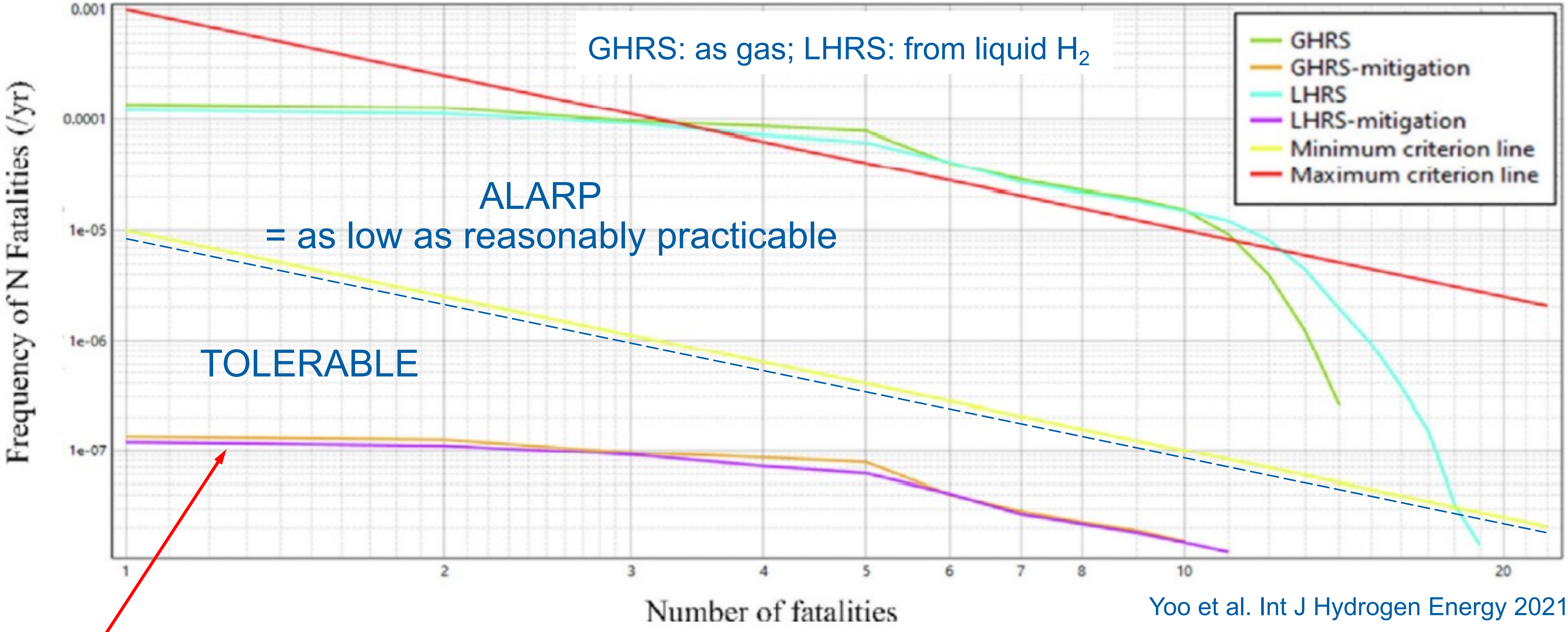
- **H_2 as gaseous fuel for fuel cell cars**
  GHRS
  (gaseous H_2 refueling station)



- **LH_2 to gas tank and to fuel cell cars**
  LHRS
  (liquid H_2 refueling station)



Risks of H_2 refueling stations without and with added mitigation measures



Yoo et al. Int J Hydrogen Energy 2021

Added measures: safety release, leak detection, automatic and manual emergency stop
→ the assessed risk was reduced by three orders of magnitude to a tolerable level

Summary – opportunities and gaps

- **Low carbon H_2**
  - rapid expansion of wind, solar, grid connections
- **Gaps and bottlenecks**
  - EN standards for piping, pressure vessels
  - no underground caverns for CO_2 or hydrogen storage
  - limited experience on H_2 in non-industrial applications
  → for smaller installations where people can access, it will not be possible to provide the same awareness as in chemical industries
  → **A safe design of the installation is of primary importance**
- **Factors of uncertainty and drivers**
  - changes of physical and political climate, cost
  - developments in systems and technology for safe and cost-effective production, handling and use of hydrogen

