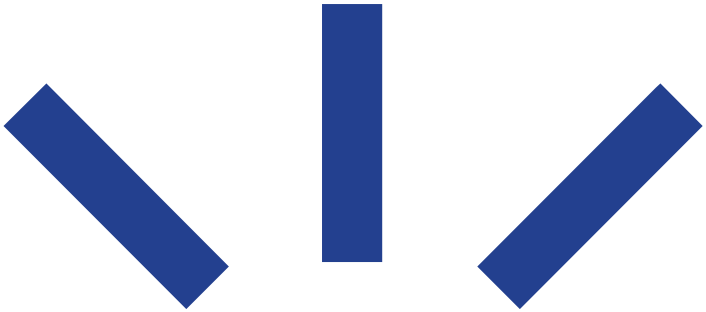
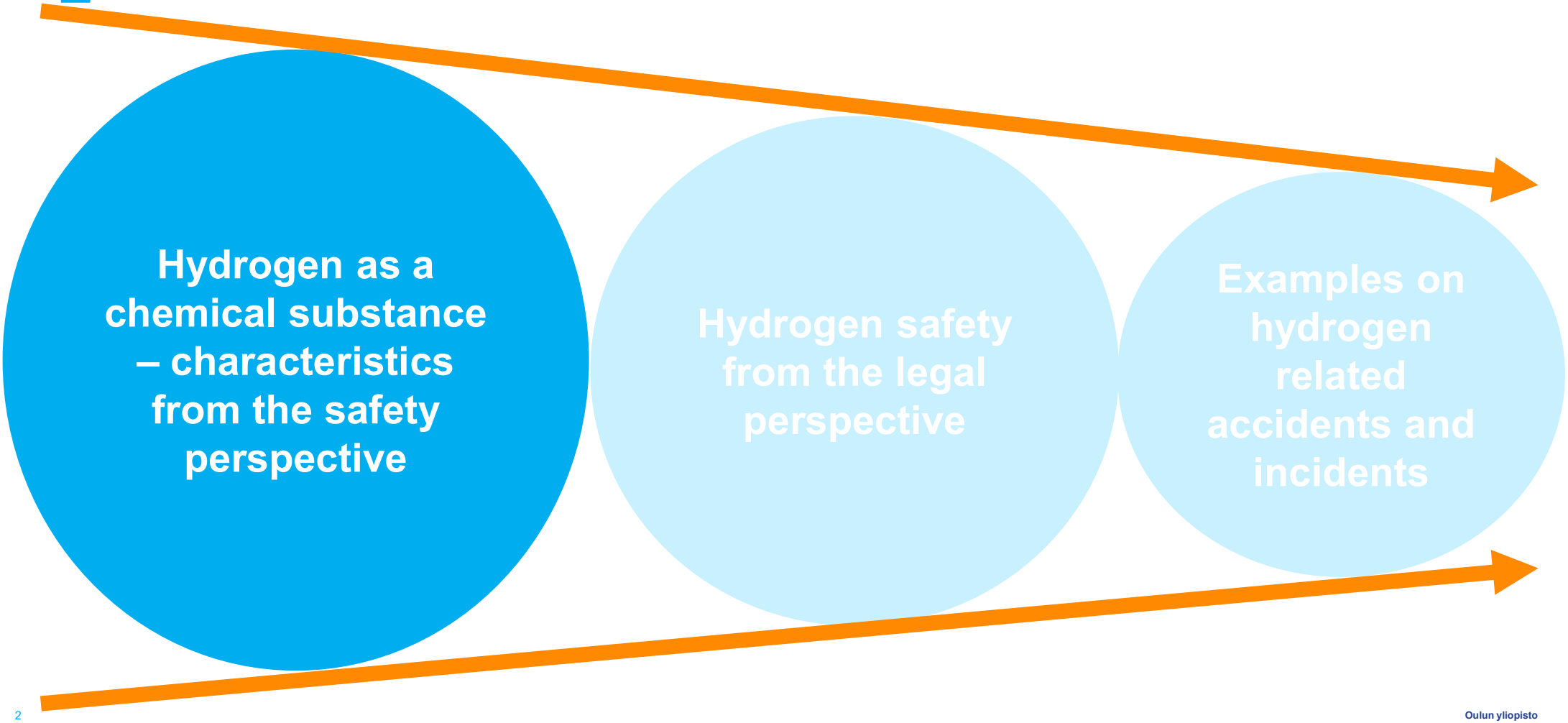


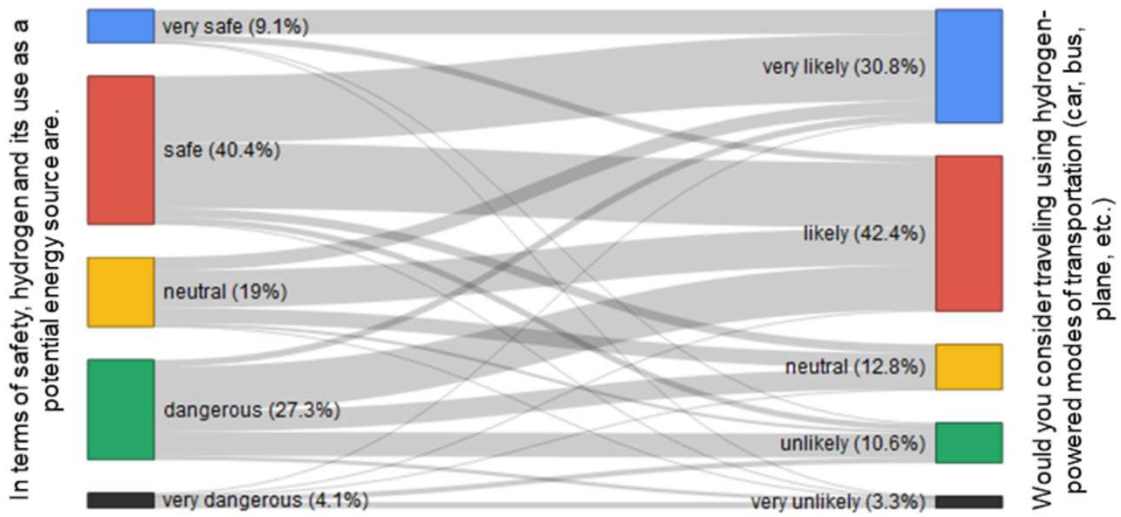
Hydrogen safety – basic issues, laws and standards

Research team leader, Adjunct prof. Arto Reiman
University of Oulu, Industrial Engineering and Management

Structure of this lecture



Hydrogen – safety or not?



- World Economic Forum: https://www.weforum.org/agenda/2019/04/why-don-t-the-public-see-hydrogen-as-a-safe-energy-source/

- Public perception on hydrogen safety is mixed. At least partly this relates to major catastrophes, where hydrogen has been in some part. For instance, the Hindenburg Zeppelin catastrophe in 1937 has been associated to the discussion on hydrogen safety. The causes for the catastrophe are still uncovered, yet it is known that hydrogen was used instead of helium. For an overview of the accident, see for instance: https://www.youtube.com/watch?v=VJy17qZmhjE .
- More recently disasters like the ones related to nuclear power plants (Three Mile Island nuclear plant in 1979 and Fukushima in 2011 and the Challenger Space Shuttle explosion in 1986 have affected the public perception on hydrogen safety.

Use of hydrogen is increasing – how good is our awareness of its' safety?

- Demands for the use of hydrogen have risen. At the same the awareness of the hydrogen safety should be deepened. Engineers, researchers, technology & infrastructure designers, plant operators and maintenance experts and first responders should have the knowledge to deal with hydrogen systems at pressures up to 100 MPa and temperatures down to -253oC (liquefied hydrogen) in open and confined spaces.
- Safety must be considered at all stages of a hydrogen system. From its initial design and continuing to manufacturing, construction, operation, maintenance, and ending with its decommissioning.

Point to consider:

- Where and how hydrogen safety is taught in Finland?
- Who can be considered as experts in hydrogen safety?

- Molkov V (2013) Fundamentals of Hydrogen Safety Engineering I

When discussing hydrogen safety – it is important to understand it as a chemical substance

- Learn more from the Substance Infocard by the European Chemical Agency: https://echa.europa.eu/fi/substance-information/-/substanceinfo/100.014.187
- Vety: https://www.ttl.fi/ova/vety (OVA-ohje in Finnish by FIOH)
- In addition, hydrogen safety is communicated in various chemical safety data sheets by commercial parties.

- In Finland, the Finnish Institute of Occupational Health (FIOH, in Finnish, Työterveyslaitos, TTL) has produced a data sheet on Hydrogen (OVA-ohje) in Finnish. The sheet has been updated in July 2022. Accordingly, hydrogen is:
  - Non-toxic,
  - Colorless, odorless and insipid
  - Extremely flammable

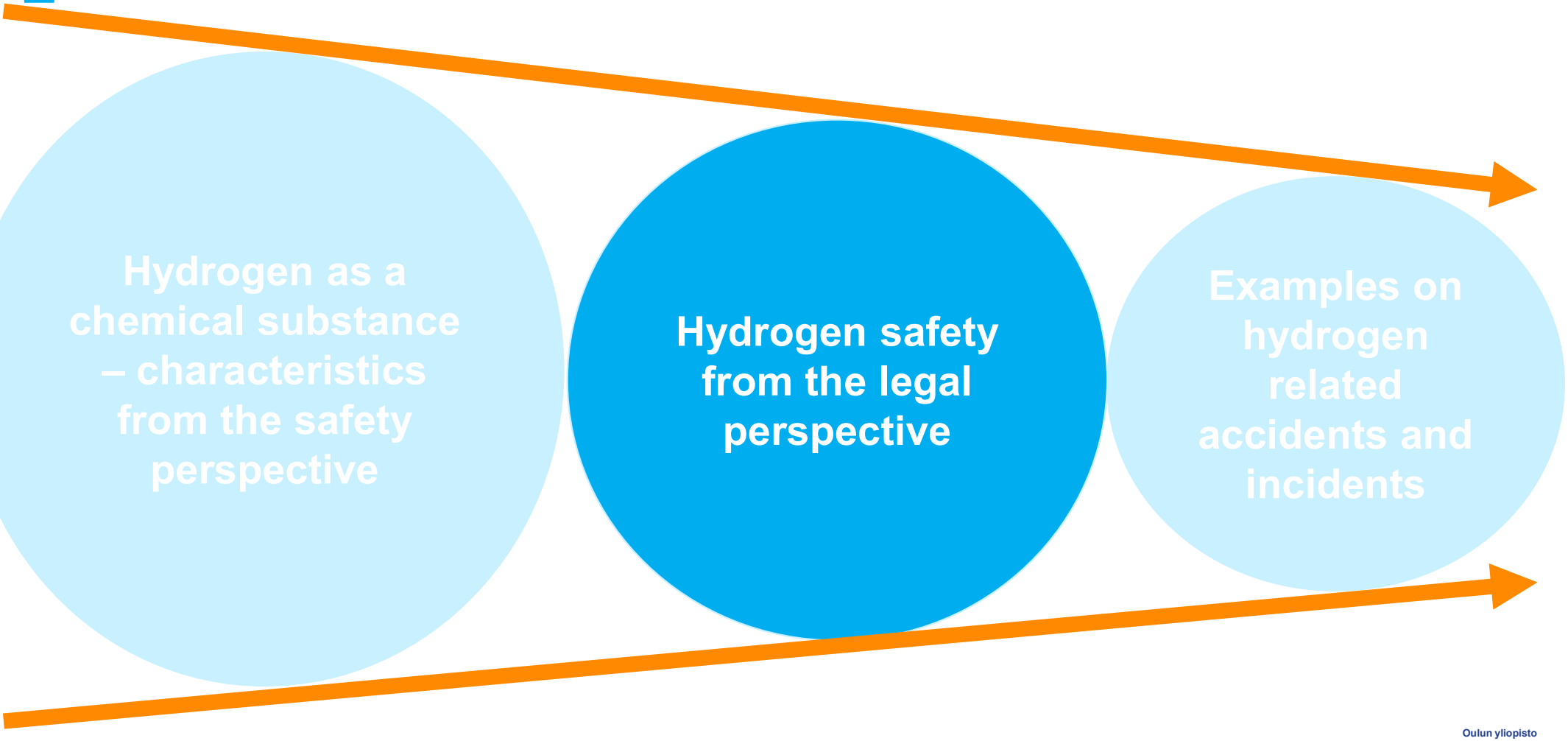
Essential considerations on the health hazards of hydrogen

- Hydrogen is non-toxic. Hydrogen is not expected to cause mutagenicity, teratogenicity, embryotoxicity or reproductive toxicity. However, inhaled hydrogen can result in a flammable mixture within the body.
- Hydrogen is classified as a simple asphyxiant.
- There are no threshold limit values (TLV; in Finnish: HTP-arvot) for hydrogen
- High concentrations of hydrogen in air can cause an oxygen-deficient environment. Individuals breathing air in these environments may experience symptoms like headache, dizziness, drowsiness, unconsciousness, nausea, vomiting, depression of all the senses.
    - When hydrogen is inhaled and above symptoms are observed, the person should be removed to fresh air, give oxygen if breathing difficult, or apply artificial respiration if the person is not breathing.
- Contact with liquid hydrogen can cause serious frostbite burns, hypothermia or tissue damage

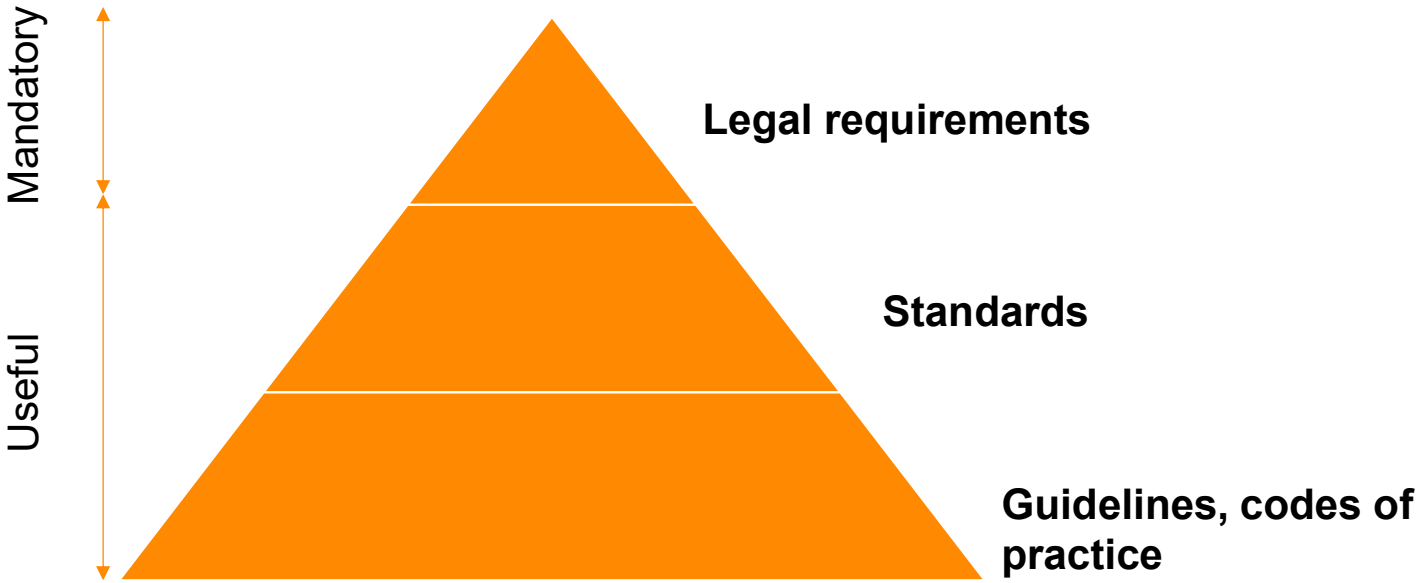
- It is recommended to check the oxygen content before entering an area with possible hydrogen asphyxiation.
- Hydrogen concentrations must be measured with a suitable detector

- OVA-ohje by FIOH: https://www.ttl.fi/ova/vety
- Molkov V (2013) Fundamentals of Hydrogen Safety Engineering I
- Soundarrajan P & Schweighardt F (2009) Hydrogen sensing and detection

Structure of this lecture



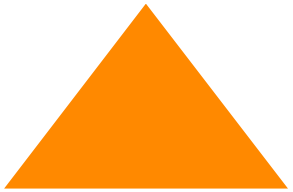
Hydrogen safety from the law and standard perspective



- Regulations are made mainly by political bodies and they are legally binding.
- In Finland, the key regulation in this context relates to EU level directives and related national legislation.
- Standards have been established in consensus. The application of a standards is not obligatory, unless a regulation refers to that standard.

- HySafe: Biennal report on Hydrogen safety: Chapter VI: Legal requirements, standards and other codes.

Essential legal requirements in the EU area



Legal requirements:

- EU Requirements (legally binding)
- EU Directives (legally binding after adoption in EU member states

For preventing damage by explosions in case of unintentional releases of flammable gases:

- ATEX Directive 2014/34/EU on explosive atmospheres
- ATEX Directive 1999/92/EC on safety and health protection of workers potentially at risk from explosive atmospheres

To be considered when designing, installing and operating (hydrogen) high-pressure systems:

- PED Directive 2014/68/EU on pressure equipment
- TPED Directive 2014/68/EU on transportable equipment

To be applied to up-scaled hydrogen production and storage

- Seveso-III-Directive 2012/18/EU on the prevention and control of accidents involving dangerous chemicals

- Moretto P & Quong S (2022) Chapter 7: Legal requirements, technical regulations, codes, and standards for hydrogen safety. https://doi.org/10.1016/B978-0-12-820492-4.00003-8

Essential legal requirements in Finland

- Similarly as in the EU, also in Finland there are no laws specifically dedicated to the safe design, testing, construction, and deployment of fuel cell and hydrogen technologies and systems.
- Concerning large-scale industrial production and utilization of hydrogen, the following legislation is applied:
  - Act on the Safe Handling and Storage of Dangerous Chemicals and Explosives, Chemicals Safety Act 390/2005: Laki vaarallisten kemikaalien ja räjähteiden käsittelyn turvallisuudesta
  - Government Decree on the Monitoring of the Handling and Storage of Dangerous Chemicals 685/2015: Valtioneuvoston asetus vaarallisten kemikaalien käsittelyn ja varastoinnin valvonnasta
  - Occupational Safety and Health Act 738/2002: Työturvallisuuslaki
- Concerning transportation, legislation and regulations on the transport of dangerous goods should be applied. More info from the web pages of Tukes on ”Transport of dangerous goods” and Traficom on VAK – Vaarallisten aineiden kuljetus.

Standards in short

- A good review on standards to be applied in the context of hydrogen production, storage, transportation and use can be found from EU document (2021): SAFETY PLANNING AND MANAGEMENT IN EU HYDROGEN AND FUEL CELLS PROJECTS - GUIDANCE DOCUMENT

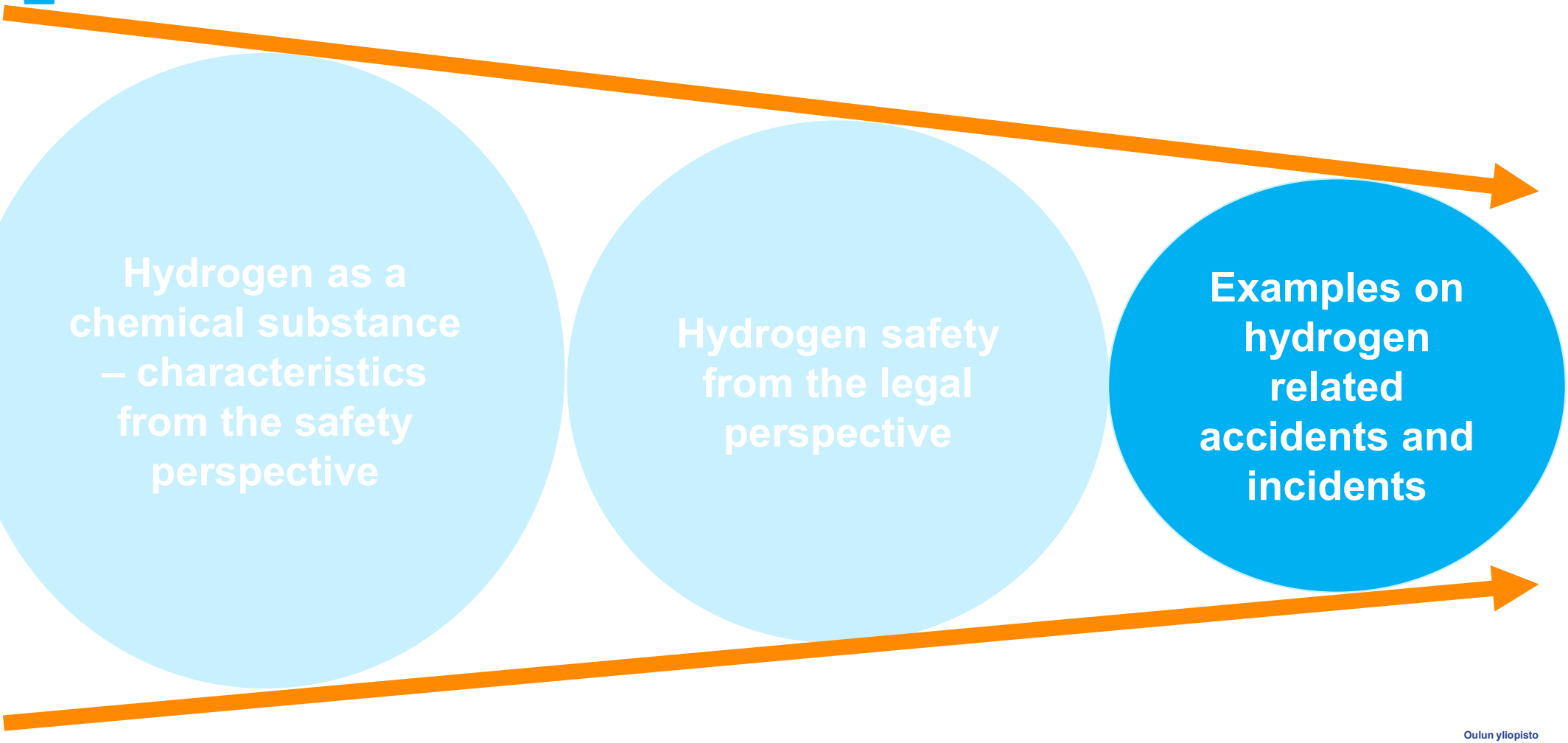
Standards

- **The ISO/TC 1972: Hydrogen technologies**
- **The IEC/TC 1052: Fuel cell technologies**

- ISO/TC 58: Gas cylinders,
- ISO/TC 2202: Cryogenic vessels,
- ISO TC 22/SC 37: Electrically propelled vehicles

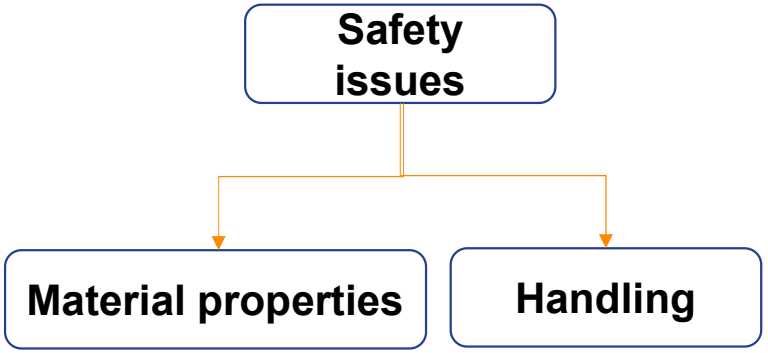
- Moretto P & Quong S (2022) Chapter 7: Legal requirements, technical regulations, codes, and standards for hydrogen safety. https://doi.org/10.1016/B978-0-12-820492-4.00003-8

Structure of this lecture



Safety issues in the application of hydrogen

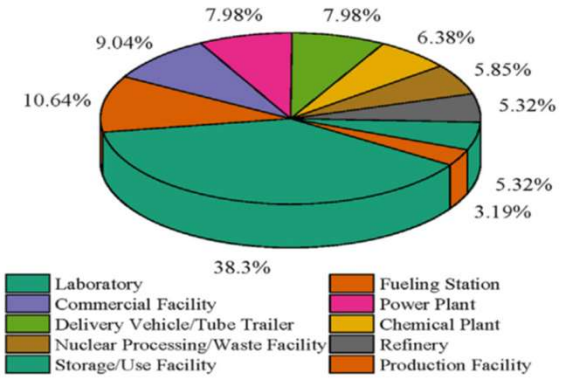
- Hydrogen embrittlement
- Hydrogen permeation
- Changes in properties at low temperatures
- Liner blistering in pressure vessels
- Damage of carbon filters
- Resistance to fire and high temperature



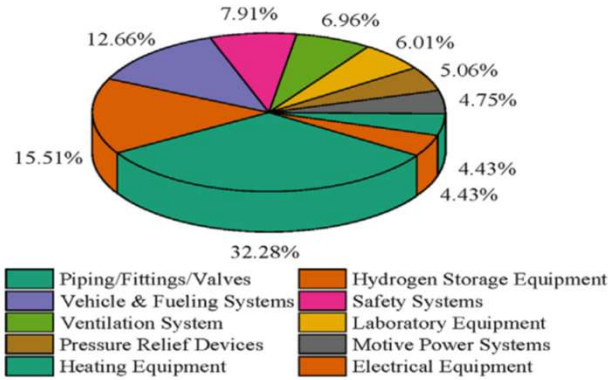
- Gaseous leakage
- Jet fire
- Delayed ignition and explosion
- Thermal radiation
- Temperature variation
- Liquid hydrogen release
- Boiling liquid expanding vapor explosion

- Abohamzeh et al. (2021) Review of hydrogen safety during storage, transmission, and applications processes. J. Loss Prev. Proc. Ind.: https://doi.org/10.1016/j.jlp.2021.104569

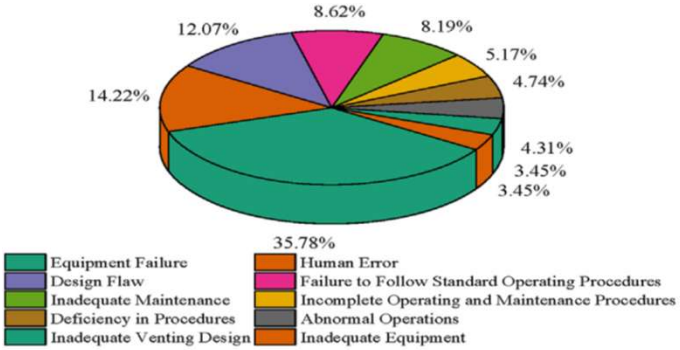
Safety perspectives on hydrogen – some remarks from the U.S. statistics



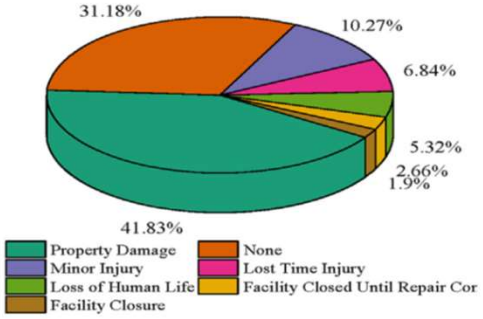
(a) Incident location



(b) Incident equipment



(c) Probable causes



(d) Damage and injuries

Based on an analysis on 120 hydrogen incidents in 1999-2019 from the incident database by the U.S. Department of Energy.

- Yang et al. (2021) Review on hydrogen safety issues: Incident statistics, hydrogen diffusion, and detonation process. Int. J. Hydr. Tech. https://doi.org/10.1016/j.ijhydene.2021.07.005

Safety perspectives on hydrogen – some remarks from the European statistics

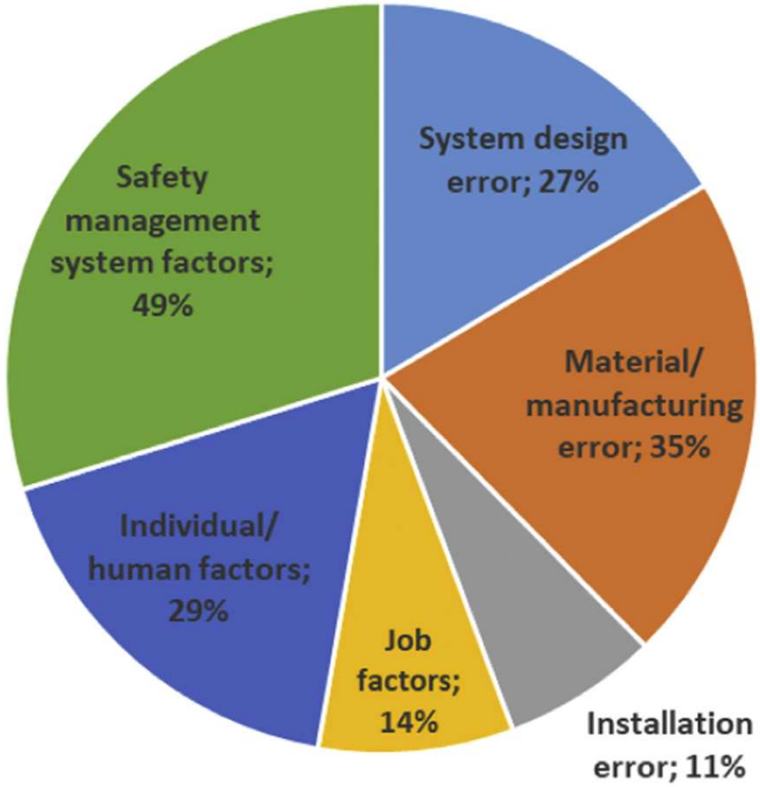
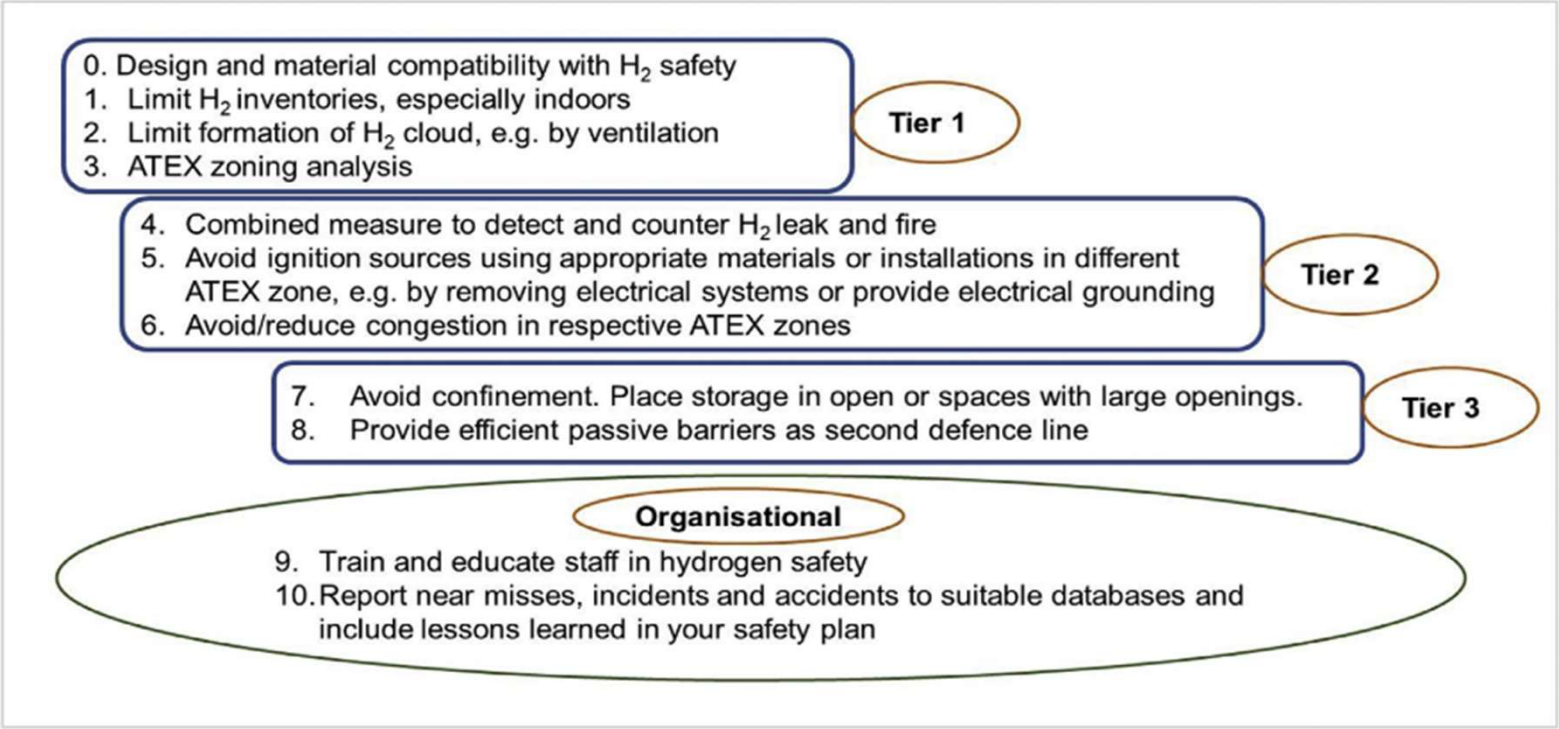


Fig. 5 – Percentages related to the causes of the events considering multiple causes per event.

HIAD 2.0 database contains more than 700 hydrogen related accidents, incidents and near misses in Europe. More info on the database: https://hysafe.info/hiad-2-0-free-access-to-the-renewed-hydrogen-incident-and-accident-database/

- Wen et al. (2022) Statistics, lessons learned and recommendations from analysis of HIAD 2.0 database Int. J. Hydr. Energ. https://doi.org/10.1016/j.ijhydene.2022.03.170

Safety perspectives on hydrogen

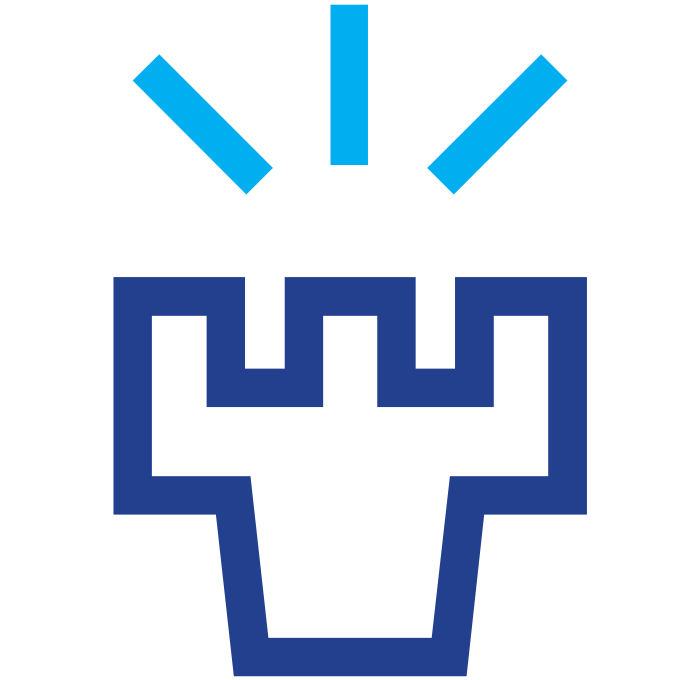


Based on the HIAD material, European Hydrogen Safety Panel produced a set of 10 safety principles to prevent an escalation of prototypical hydrogen accidents.

- Wen et al. (2022) Statistics, lessons learned and recommendations from analysis of HIAD 2.0 database Int. J. Hydr. Energ. https://doi.org/10.1016/j.ijhydene.2022.03.170

Please answer the questions as a homework

	YOUR ANSWER:
Familiarize yourself to Hydrogen as a substance (e.g., from the OVA-ohje by FIOH)	
1. Hydrogen is a toxic substance that should be avoided at all costs.	YES NO
2. Hydrogen is given certain European threshold values that limit time being in contact with hydrogen.	YES NO
3. Hydrogen leakage is easy to detect with organoleptic evaluation measures.	YES NO
Familiarize yourself to hydrogen legislation and standards. A good overview is given in this document by the European Hydrogen Safety Panel:	YES NO
4. There are uniform global regulations dedicated to the safe design, testing, construction, and deployment of fuel cell and hydrogen technologies and systems.	YES NO
5. ATEX directives can be applied to hydrogen even hydrogen is not mentioned in the text.	YES NO
6. Standards are useful instruments for organizations. They are not always mandatory to be applied unless otherwise stated in the regulation.	
Accident, incident and near-miss analyses can provide valuable information for preventive actions. For instance, an analysis on HIAD 2.0 database provides essential information on accident analyses	
7. Accident investigation provides information how to prevent similar kinds of accidents in the future.	YES NO
8. From the safety management perspective, minor events like near-misses seldomly provide valuable information for accident prevention.	YES NO
9. Incidents and accidents related to hydrogen usage are mainly related to industrial contexts	YES NO



UNIVERSITY
OF OULU