Hydrogen safety strategies and risk management in Equinor

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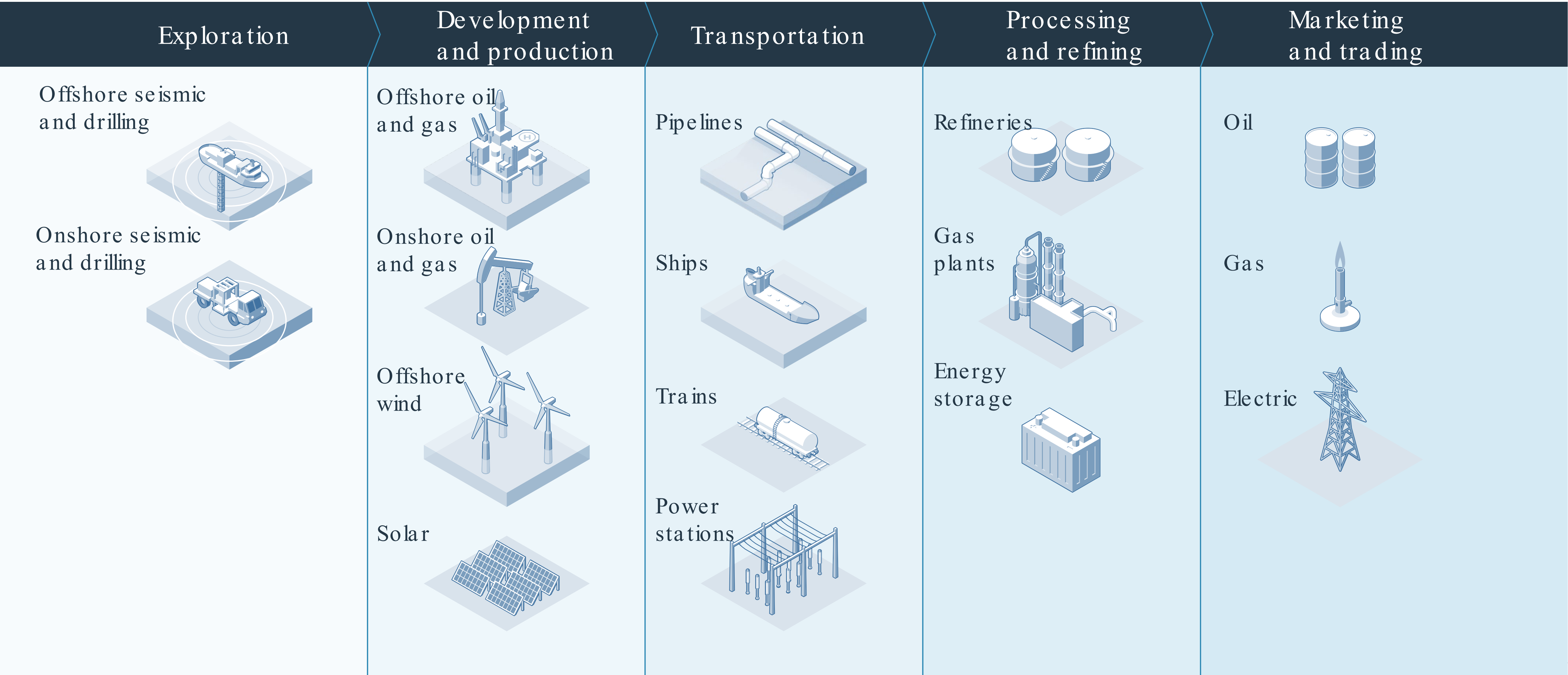
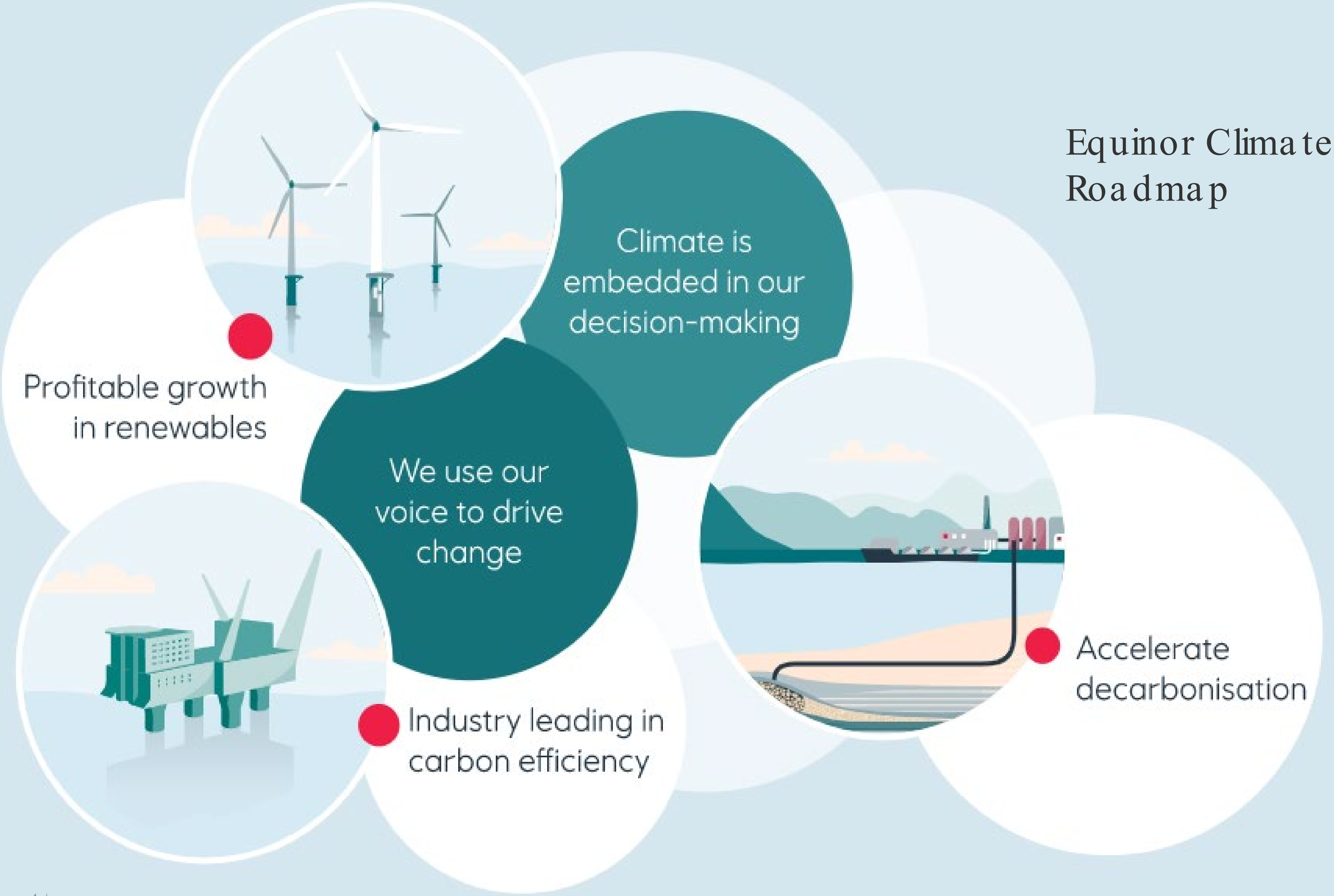
Our value chain



Equinor Climate Roadmap



Shaping the European future of CCS and clean hydrogen

Competitive edge founded on experience, infrastructure and customers.

15-30 MTPA

CO_2 transport and storage capacity by 2035

Equinor share

>25%

CO_2 transport and storage market share in Europe by 2035

3-5 MAJOR INDUSTRIAL CLUSTERS

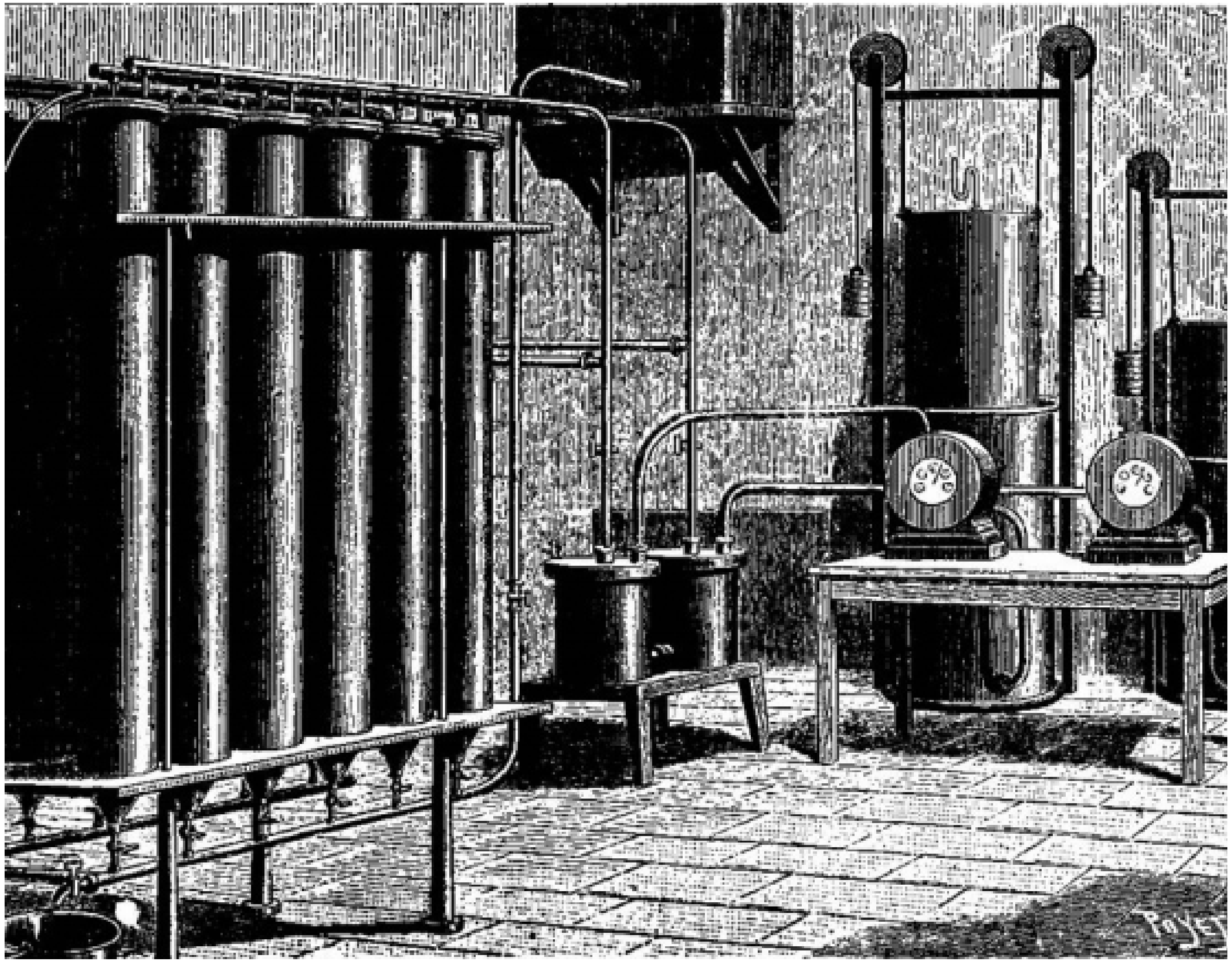
Clean hydrogen projects by 2035

>10%

Clean hydrogen market share in Europe by 2035

Hydrogen utilisation

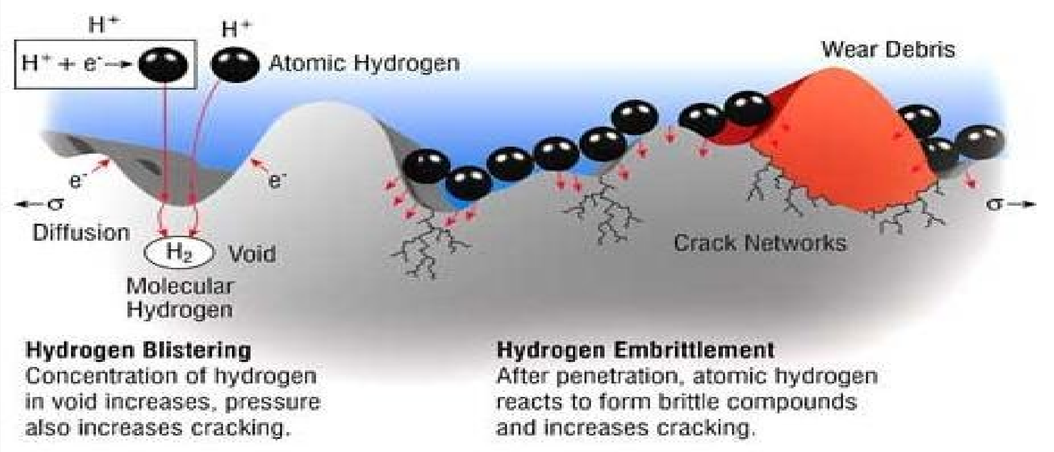
- Known in industry for more than a century
- Many actors are new to hydrogen, but familiar with hydrocarbons like natural gas (NG)
- Hydrogen is different to natural gas. These differences must be reflected in the design and operation of facilities



Industrial electrolysis of water, early 20th century
(https://www.gutenberg.org/files/14990/14990-h/14990-h.htm)

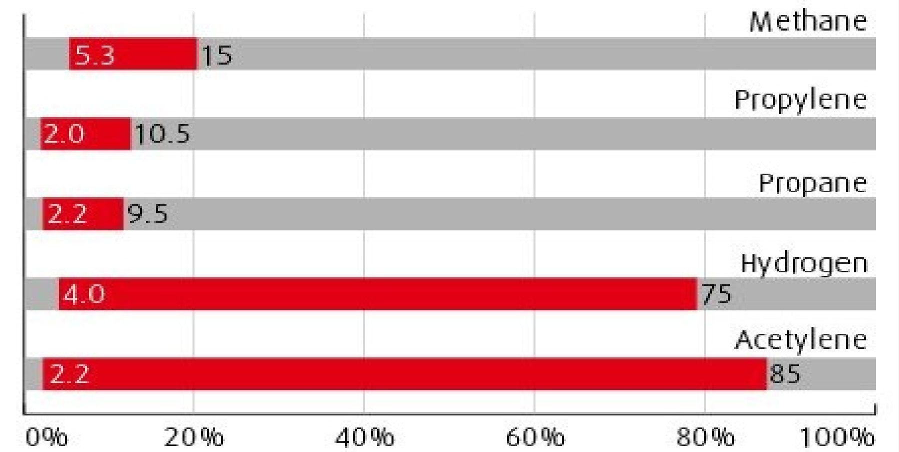
Hydrogen characteristics

Containment (small molecule + failure mechanism)



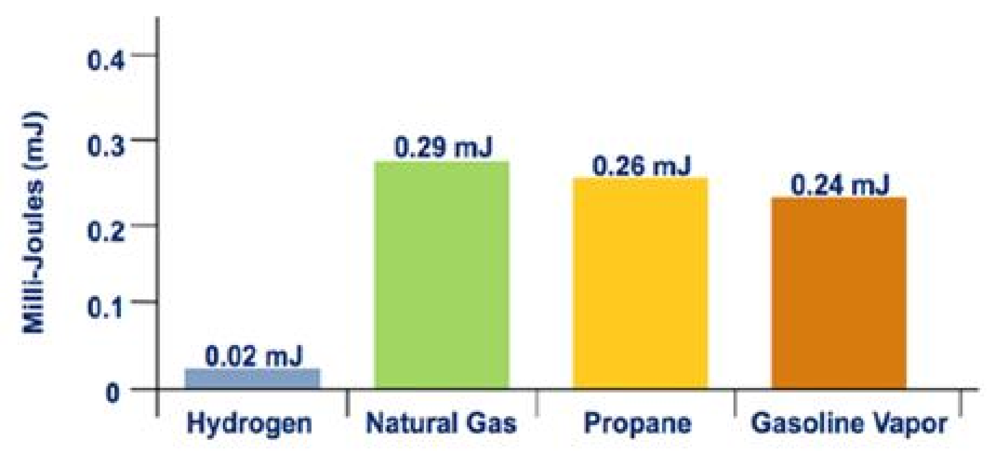
Source: Dini, J.W. (1993) Electrodeposition: The Materials Science of Coatings and Substrates. Noyes Publications

Flammability (flammable concentration in air - wide range)



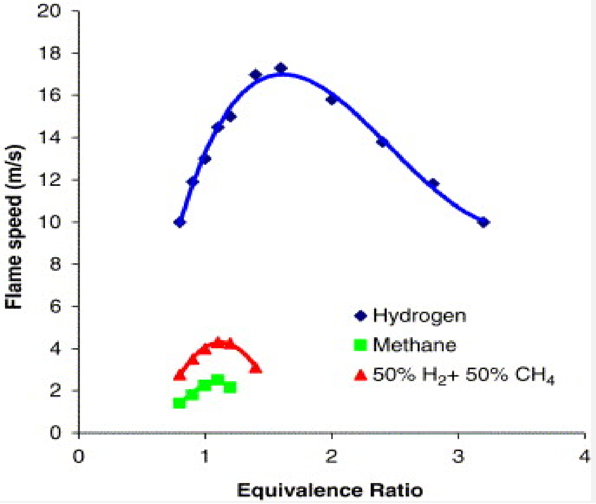
Source: https://www.linde-gas.se/en/safety_health_ren/gas_risks/flammable_gas/index.html

Ignitability (low energies)



Source: https://h2tools.org/bestpractices/hydrogen-compared-other-fuels

Reactivity (fast flame acceleration and DDT)



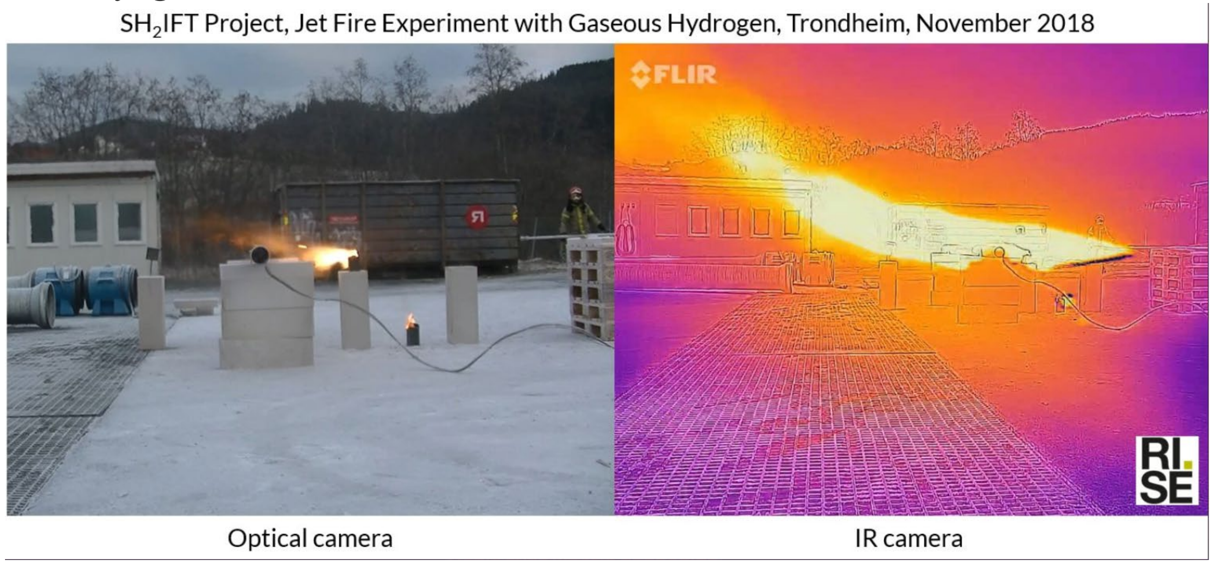
Source: M. Ilbas et.al.: Laminar-burning velocities of hydrogen–air and hydrogen–methane–air mixtures: An experimental study. Int. Journal of Hydrogen Energy, vol. 31, issue 12.

Other hydrogen characteristics

- High buoyancy and high diffusivity of gas
- If released in open air the gas will rise and dilute rapidly, unless determined by a jet
    - Note: Evaporation from liquid hydrogen may behave like a heavy gas

- Hydrogen burns with a light blue flame, practically invisible in daylight

- Very low boiling point (20 K, -253°C.)



https://twitter.com/RISEFR/status/1068457127851761665/photo/1

Two hydrogen accident case studies

Both occurred at Herøya industrial site, Porsgrunn, Norway

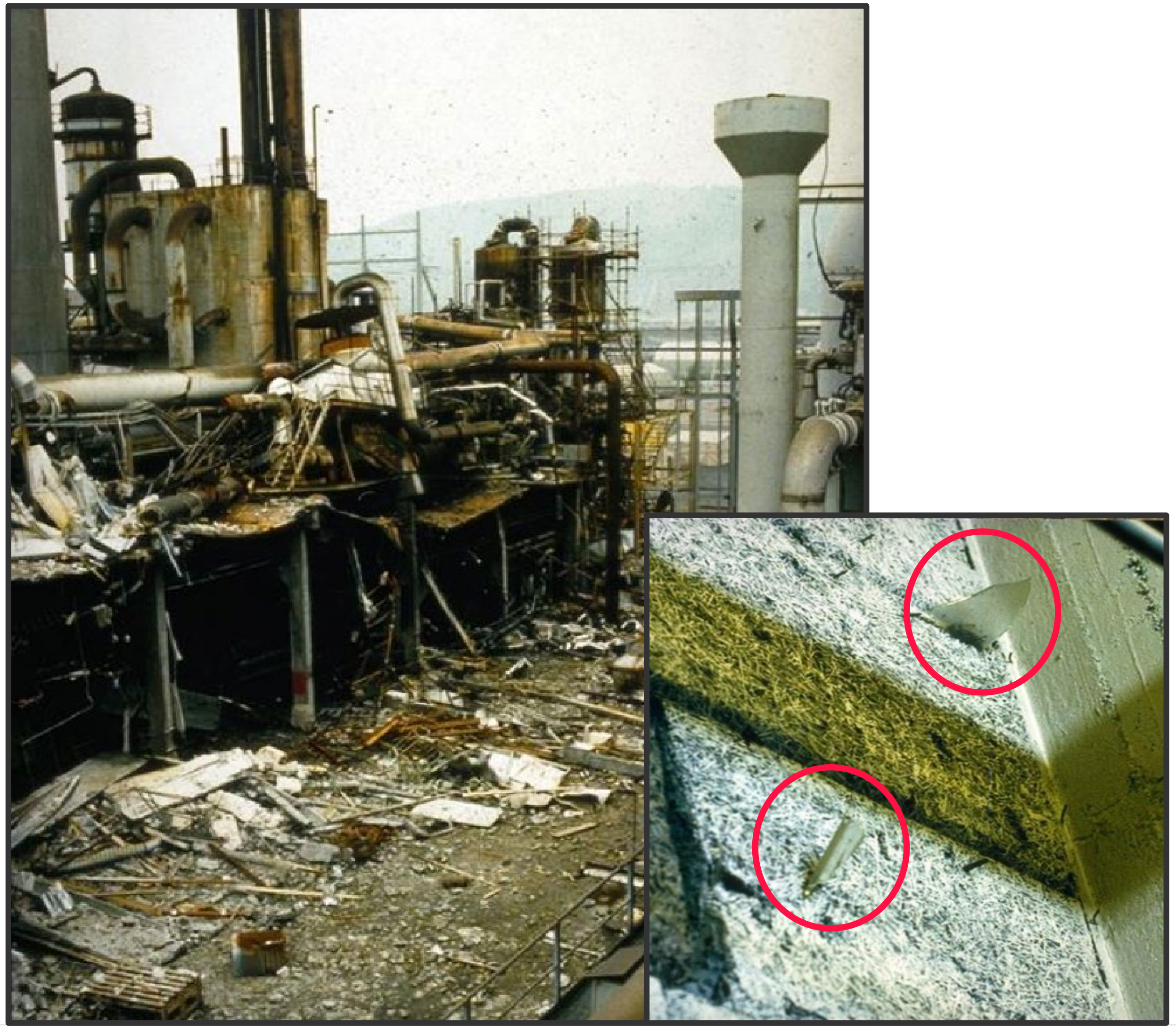
1. Explosion in an ammonia plant, 1985

2. Explosion of a hydrogen-air mixture in a pipeline for CO_2 transportation, 1997

 Google Earth EC (2021), 59°07'11.82"N 9°37'42.88"E

Explosion in ammonia plant, 1985
(presented in ICHS 2005*)

- Two fatalities, extensive damage
- A combination of operational error, technical failures and weakness in the design
- 10-20 kg of hydrogen leaked inside the building
- Most likely that a hot bearing ignited the gas cloud
- 3.5-7 kg of hydrogen involved in the explosion
- From the damage observed, detonation seems most likely
- The explosion caused large number of fragments representing a severe hazard
- Glass windows were broken up to 700 m from the centre of the explosion.
- Within a radius of 100 m all ordinary windows were broken.



*Bjerketvedt, D and Mjaavatten, A (2005), A Hydrogen Explosion in a Process Plant - A Case History, Conference paper, ICHS

Explosion of a hydrogen-air mixture in a pipeline, 1997

(Published in Process safety progress, Vol. 20, Issue 1, 2001*)

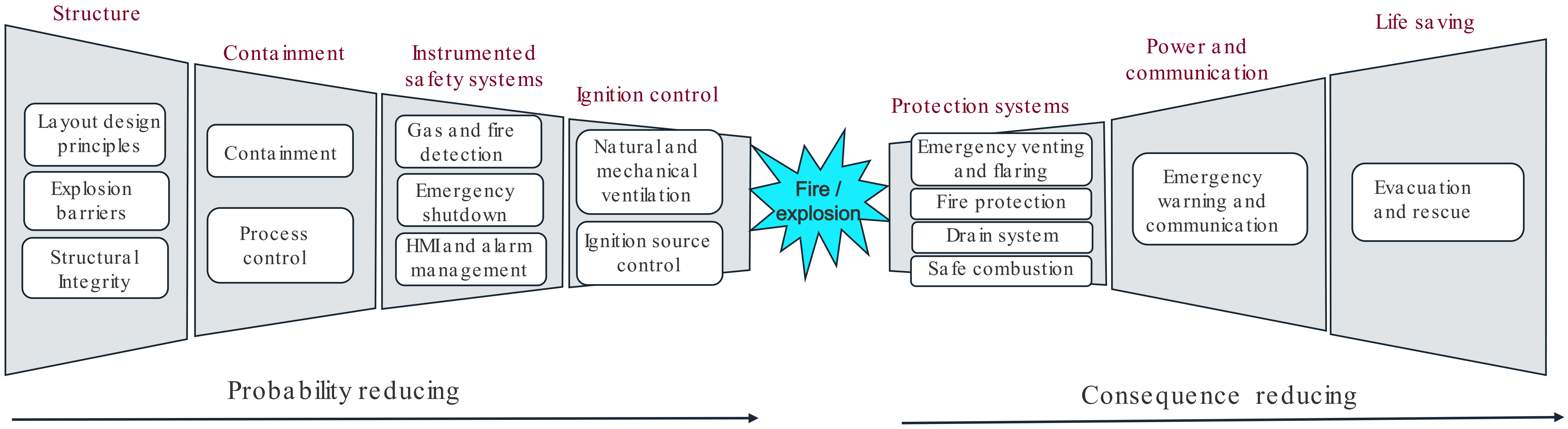
- No injuries (Sunday afternoon), but extensive damage

- A combination of operational error, technical failures and weakness in the design (again)
- CO_2 pipeline had been out of service for six days
- Hydrogen leaked into pipeline
- Ineffective purging, air leaking into pipeline
- Possibly ignited by external hot work
- 10 kg of hydrogen involved in explosion
- 850 meters of the pipeline was totally destroyed
- Combustion front accelerated in pipeline, causing rupture at intervals of 1-20 m

Pande, J.O and Tonheim, J: Ammonia plant NII: Explosion of hydrogen in a pipeline for CO_2. Process safety progress, Vol 20, Issue 1, 2001
Pande, J.O., Stokke, R.G., Tonheim, J., Explosion of hydrogen in a pipeline for CO_2, Loss Prevention Bulletin of IChemE 156(1):11-13, 2000

Safety strategy and its role in safety and risk management

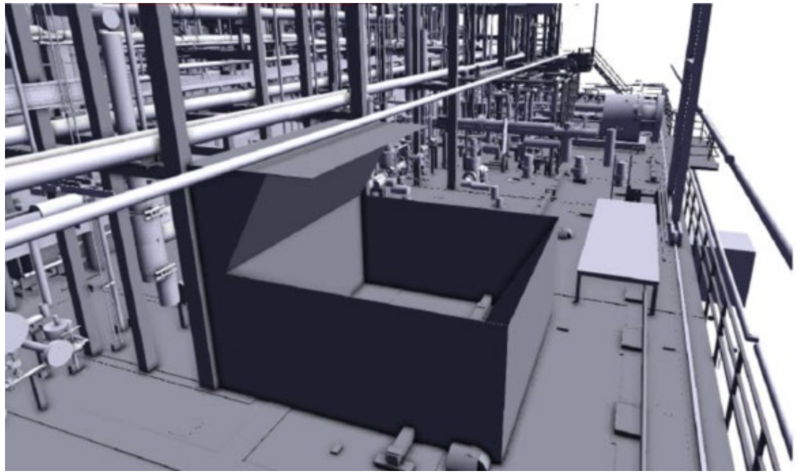
Bow-tie, flammable gas release

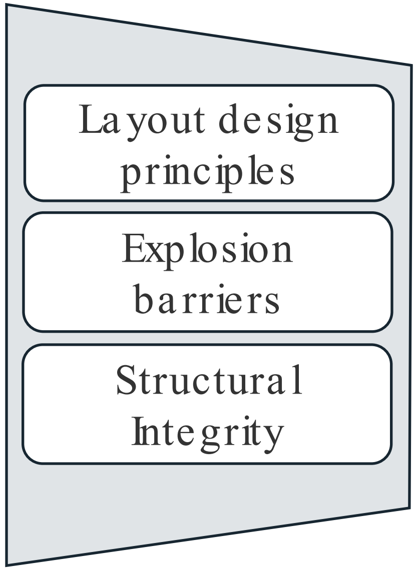


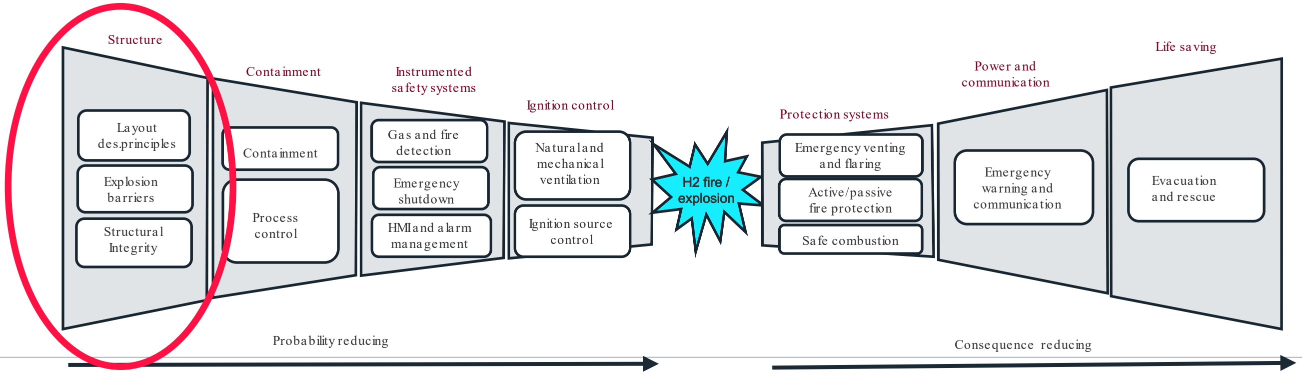
Structural loads

Layout & explosion barriers

- Avoid enclosed and confined areas
- "Open box" design to direct leaks away from confined and congested areas
- H_2 piping on top of buildings/structures, outdoors
- Safe location of vent system outlets
- Restricted flow of hydrogen
- Explosion relief panels
- Design for explosion loads
- Design to avoid detonation



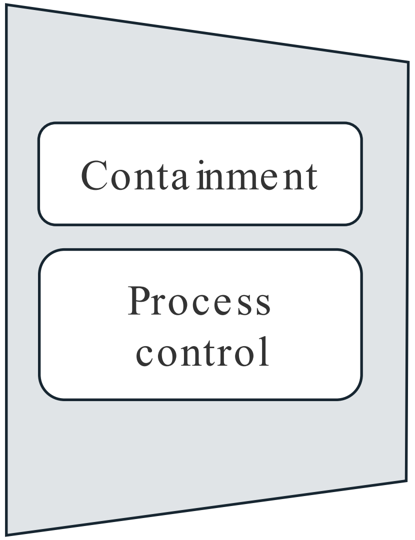




Ensure containment

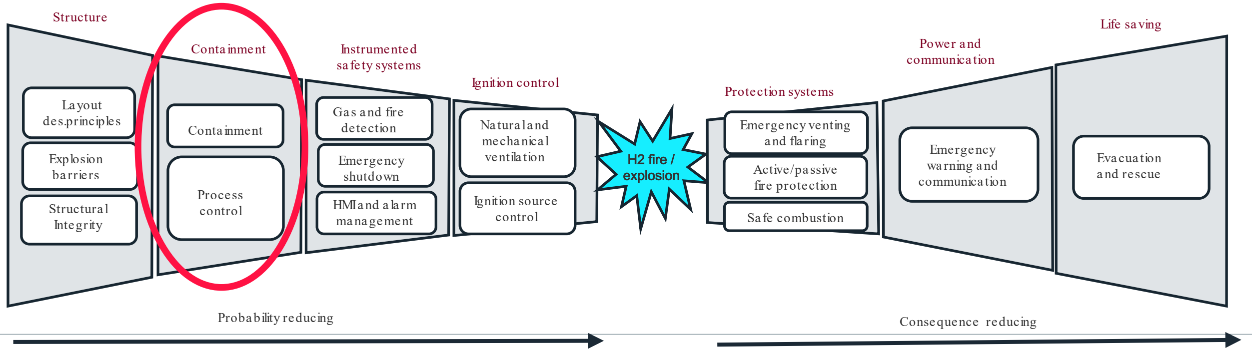
Containment

- H_2-suitable materials of construction
- Fully welded systems
- «Pipe-in-Pipe» solutions
- ESD valves



Process Control

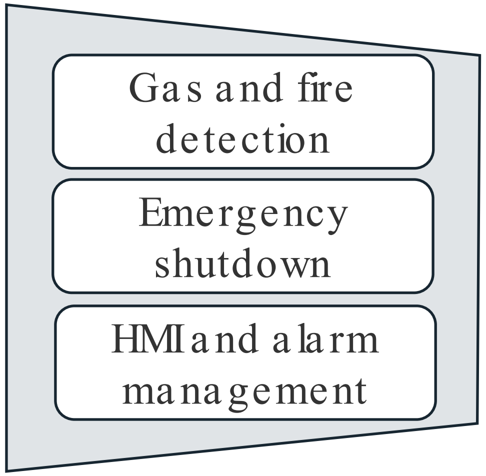
- Pressure, temperature and level control
- Pressure relief systems
- H_2 vent system



Detection and shutdown

Gas and fire detection

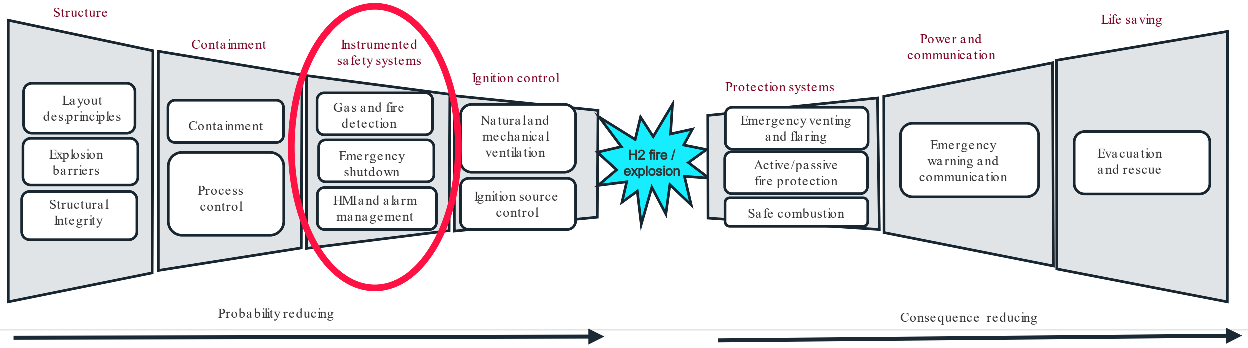
- Specific H_2 gas & flame detectors, sonic detection
- Close to typical leak points
- Early detection in «pipe-in-pipe» in confined areas



Instrumented safety systems

Emergency shutdown

- Valves automatically to safe position in case of an accident/leak



Open

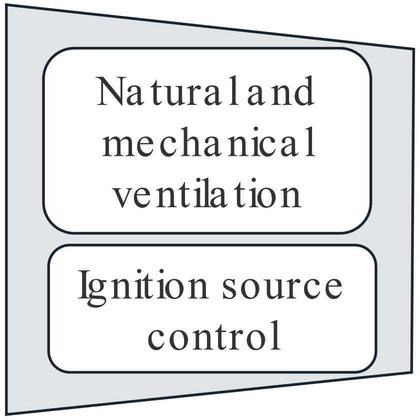
Prevent ignition

Natural and mechanical ventilation

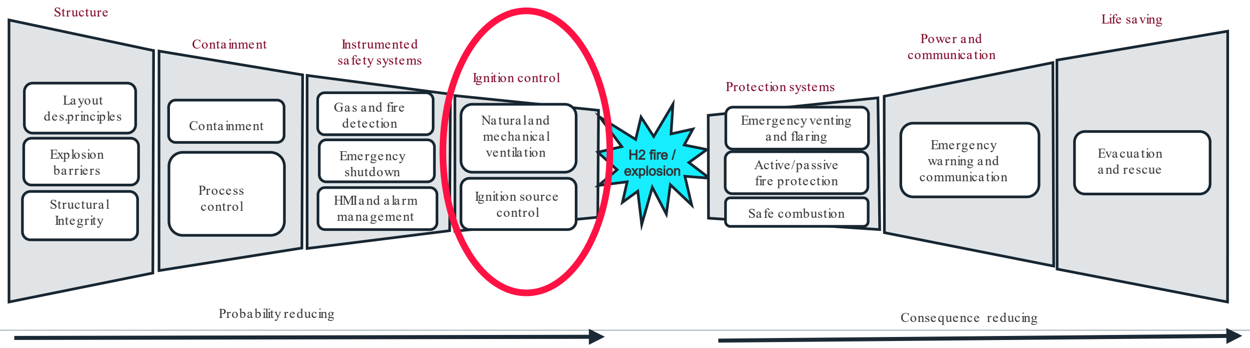
- H_2-containing equipment and potential leak points located in open, naturally ventilated areas, high level
- High ventilation rate in confined areas

Ignition source control

- Equipment Group IIC in H_2 hazardous areas
- Prevent static electricity formation
- Shutdown of ignition sources if confirmed gas detection



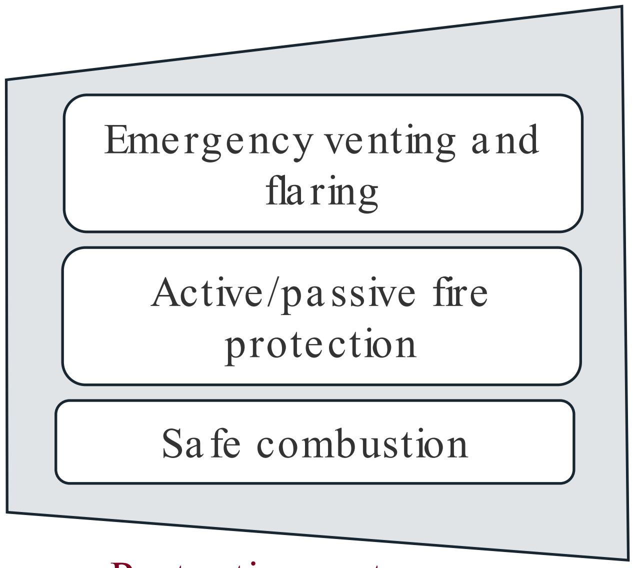
Ignition control



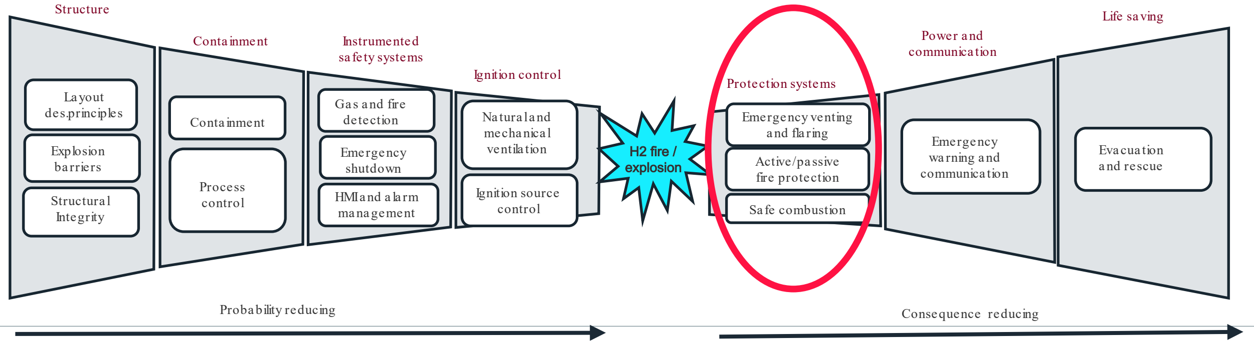
Mitigating consequences

Venting and emergency depressurisation
- Vents to be located and designed for ignited scenarios
- Blowdown to safe location
- N_2 purging & pilot flame in flares

Active and passive fire protection
- Protect structures against heat exposure

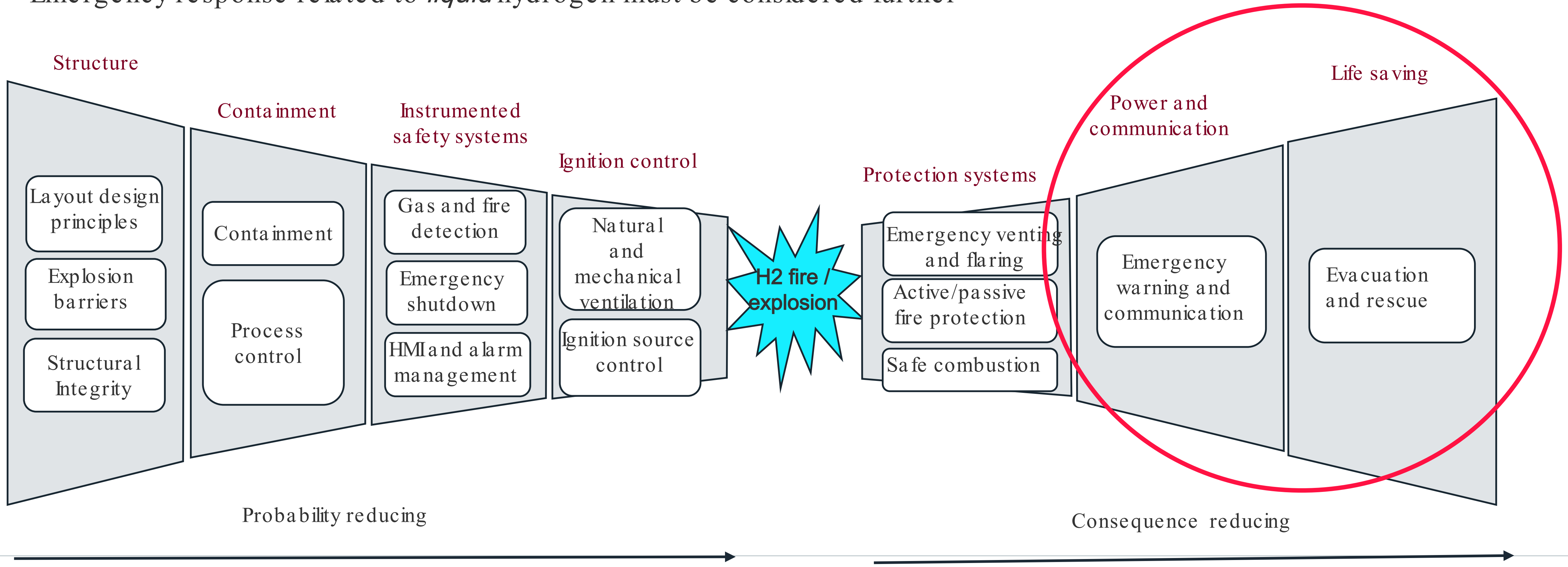


Protection systems



Emergency preparedness and response

- Follow general principles for facilities containing flammable substances
- Emergency response related to *liquid* hydrogen must be considered further



Summing up

- The safety strategy approach used in our oil and gas facilities is valid also for H_2
- Facility design and safety barrier requirements must be adapted to H_2 challenges
- More work needed on safe utilisation of liquid hydrogen
- Safety barriers in design, adapted to the properties and risk characteristics of hydrogen, are being implemented in Equinor hydrogen value chain projects

Thank you!

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