Hydrogen safety strategies and risk management in Equinor

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### Our value chain

<table>
<thead>
<tr>
<th>Exploration</th>
<th>Development and production</th>
<th>Transportation</th>
<th>Processing and refining</th>
<th>Marketing and trading</th>
</tr>
</thead>
<tbody>
<tr>
<td>Offshore seismic and drilling</td>
<td>Offshore oil and gas</td>
<td>Pipelines</td>
<td>Refineries</td>
<td>Oil</td>
</tr>
<tr>
<td>Onshore seismic and drilling</td>
<td>Offshore oil and gas</td>
<td>Ships</td>
<td>Gas plants</td>
<td>Gas</td>
</tr>
<tr>
<td>Offshore wind</td>
<td></td>
<td>Trains</td>
<td>Energy storage</td>
<td>Electric</td>
</tr>
<tr>
<td>Solar</td>
<td></td>
<td>Power stations</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Offshore seismic and drilling
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- Offshore oil and gas
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- Solar
- Pipelines
- Ships
- Trains
- Power stations
- Refineries
- Gas plants
- Energy storage
- Oil
- Gas
- Electric
Equinor Climate Roadmap

- Climate is embedded in our decision-making
- Profitable growth in renewables
- We use our voice to drive change
- Industry leading in carbon efficiency
- Accelerate decarbonisation
Shaping the European future of CCS and clean hydrogen

Competitive edge founded on experience, infrastructure and customers.

15-30 MTPA
CO₂ transport and storage capacity by 2035
Equinor share:

>25%
CO₂ 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)

**Flammability** (flammable concentration in air - wide range)

<table>
<thead>
<tr>
<th>Gas</th>
<th>Lower Flammability Limit (LFL)</th>
<th>Upper Flammability Limit (UFL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane</td>
<td>5.3</td>
<td>15</td>
</tr>
<tr>
<td>Propane</td>
<td>2.0</td>
<td>10.5</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>2.2</td>
<td>9.5</td>
</tr>
<tr>
<td>Acetylene</td>
<td>4.0</td>
<td>75</td>
</tr>
<tr>
<td>Acetylene</td>
<td>2.2</td>
<td>85</td>
</tr>
</tbody>
</table>

**Ignitability** (low energies)

**Reactivity** (fast flame acceleration and DDT)

![Graph showing milli-Joules for different fuels](https://h2tools.org/bestpractices/hydrogen-compared-other-fuels)


![Graph showing laminar burning velocities of hydrogen-air and hydrogen-methane-air mixtures](https://miub.ch/BestPractices/hydrogen-compared-other-fuels)


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

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.)
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
Explosion in an 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)
- CO₂ 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

Safety strategy and its role in safety and risk management

- Authority regulations
- Company requirements
- Risk picture
  - Identified hazards, risk analysis
- Safety strategy
- Maintenance plans
  - Verification activities
  - Etc.
Bow-tie, flammable gas release

Structure
- Layout design principles
- Explosion barriers
- Structural integrity

Containment
- Containment
- Process control

Instrumented safety systems
- Gas and fire detection
- Emergency shutdown
- Hazard and alarm management
- Ignition source control

Ignition control
- Natural and mechanical ventilation

Protection systems
- Emergency venting and flaring
- Fire protection
- Drain system
- Safe combustion

Power and communication
- Emergency warning and communication

Life saving
- Evacuation and rescue

Probability reducing

Consequence reducing
Structural loads

**Layout & explosion barriers**
- Avoid enclosed and confined areas
- “Open box” design to direct leaks away from confined and congested areas
- H₂ 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

**Layout design principles**

**Explosion barriers**

**Structural integrity**
Ensure containment

**Containment**
- H₂-suitable materials of construction
- Fully welded systems
- «Pipe-in-Pipe» solutions
- ESD valves

**Process Control**
- Pressure, temperature and level control
- Pressure relief systems
- H₂ vent system
Detection and shutdown

Gas and fire detection
- Specific H₂ gas & flame detectors, sonic detection
- Close to typical leak points
- Early detection in «pipe-in-pipe» in confined areas

Emergency shutdown
- Valves automatically to safe position in case of an accident/leak
Prevent ignition

Natural and mechanical ventilation
- H₂-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 IIIC in H₂ hazardous areas
- Prevent static electricity formation
- Shutdown of ignition sources if confirmed gas detection
Mitigating consequences

**Venting and emergency depressurisation**
- Vents to be located and designed for ignited scenarios
- Blowdown to safe location
- N₂ purging & pilot flame in flares

**Active and passive fire protection**
- Protect structures against heat exposure

**Protection systems**

- Emergency venting and flaring
- Active/passive fire protection
- Safe combustion
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 H₂
- Facility design and safety barrier requirements must be adapted to H₂ 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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