



Norwegian Hydrogen

Stavanger - Human Factors in Control

We will be a key contributor to the green shift through our development and operation of a robust and effective infrastructure for green hydrogen, aimed primarily towards heavy road transport and maritime customer segments.





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FLAKK GROUP



TAFJORD

HOFSETH



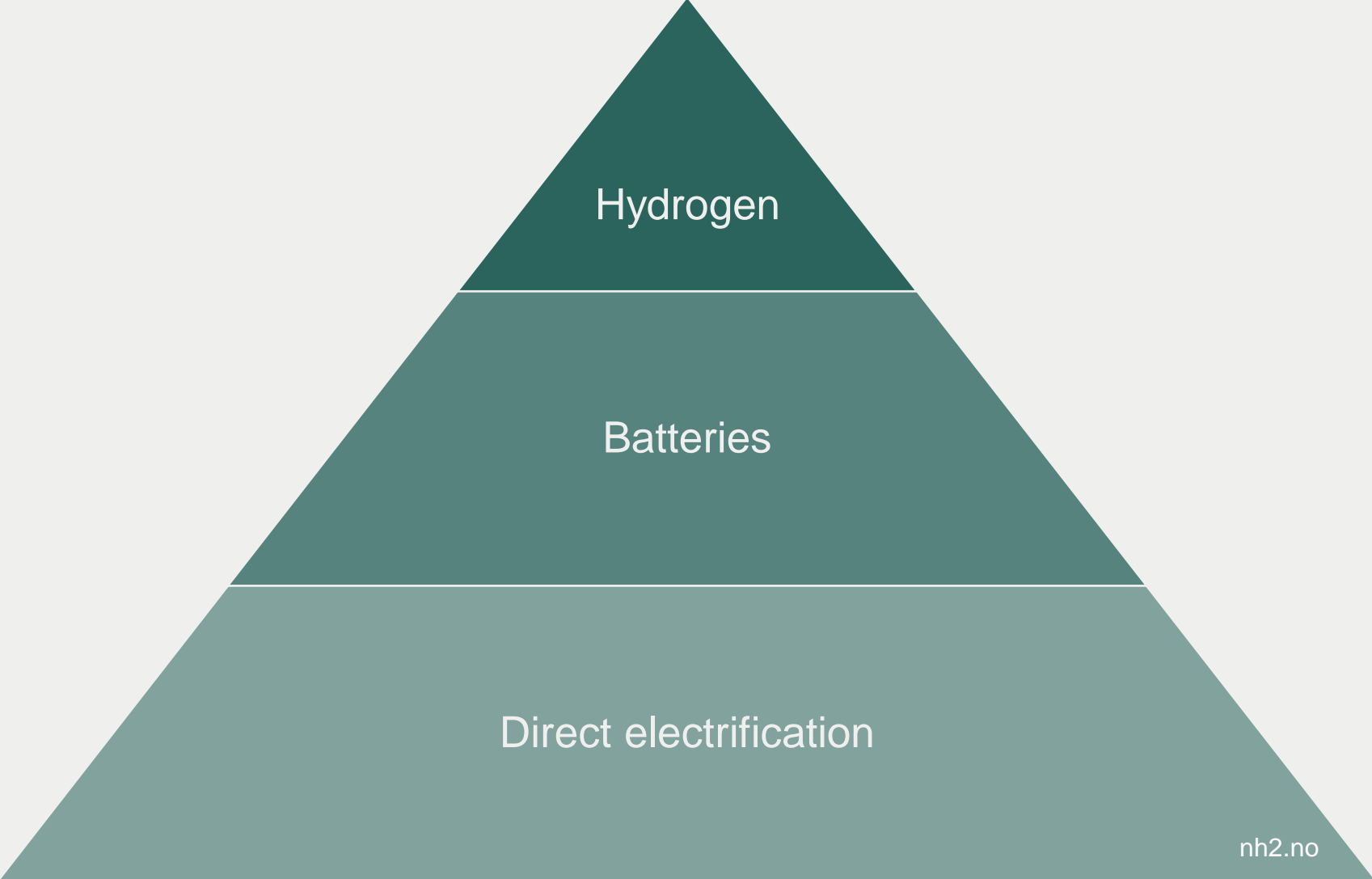
HEXAGON
PURUS





The 1.5 °C target requires major transformation of global energy systems

The electrification pyramid





**Robust and effective infrastructure
for green hydrogen**

Norwegian Hydrogens areas of business

Complete value chain for green hydrogen

Production



Distribution



Customers





ENABLING ZERO EMISSIONS



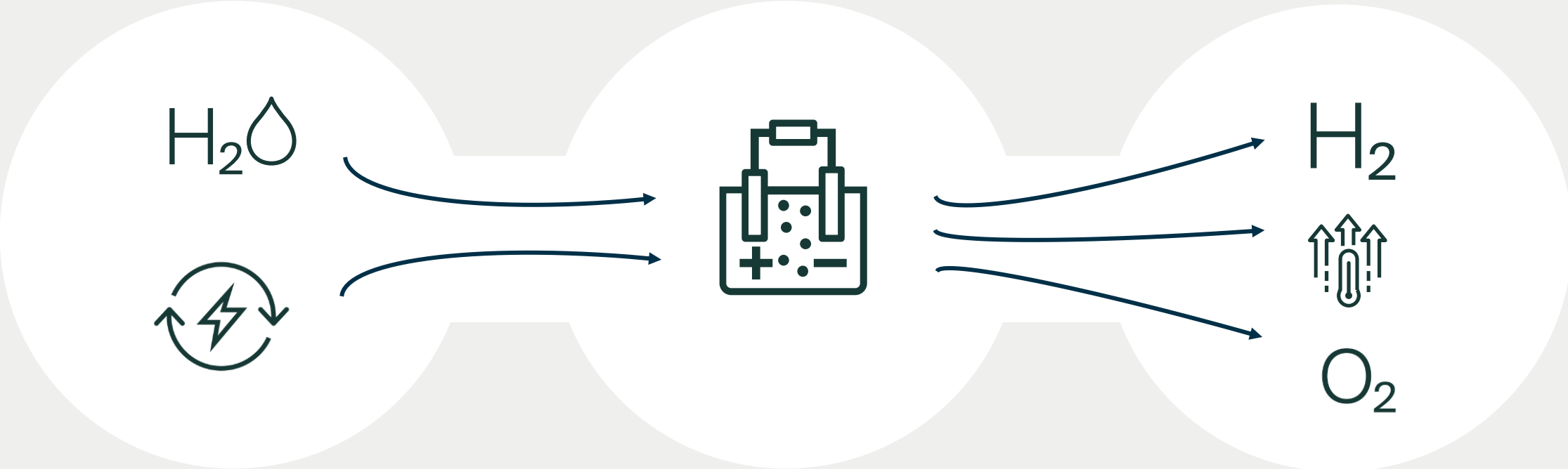
H₂

PRODUCTION OF GREEN HYDROGEN

WATER + ELECTRICITY

ELECTROLYSIS

HYDROGEN + HEAT + OXYGEN







Rjukan, 1927 – 1970-tallet



Glomfjord, 1953 – 1991

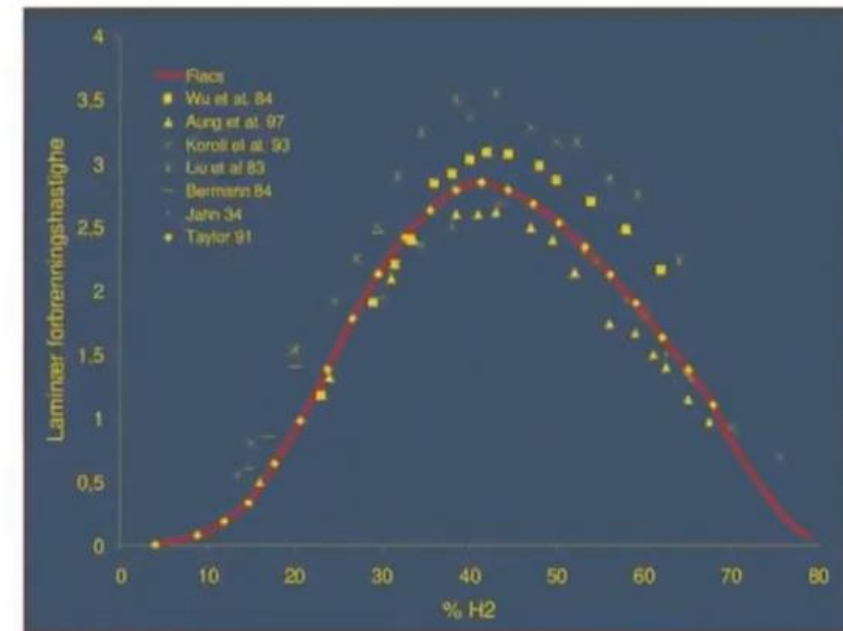


Collaboration with Varanger Kraft Hydrogen AS



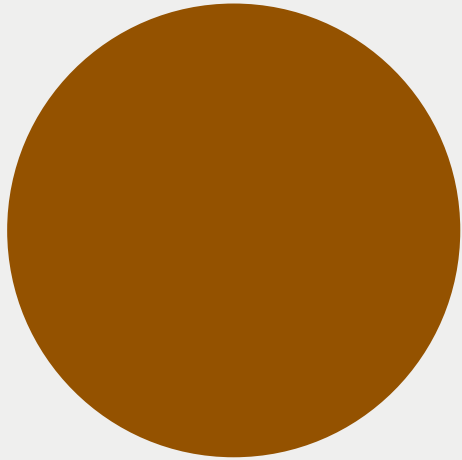
Hydrogen in brief

- Extremely buoyant:
 - ✓ 14 times lighter than air
 - ✓ Rises 6 times faster than natural gas
- Wide flammability range: 4 -75 %
- Very small molecules – leaks easily
- Laminar burning velocity about 3 m/s, which is 6 times faster than hydrocarbon gases
- Low ignition energy: 0.02 mJ which is about 10% of the ignition energy for hydrocarbon gases
- Negative Joule-Thompson effect and tendency for auto-ignition of leakages from high pressure



GRØNT HYDROGEN ER DET UTSLIPPSFRIE ALTERNATIVET

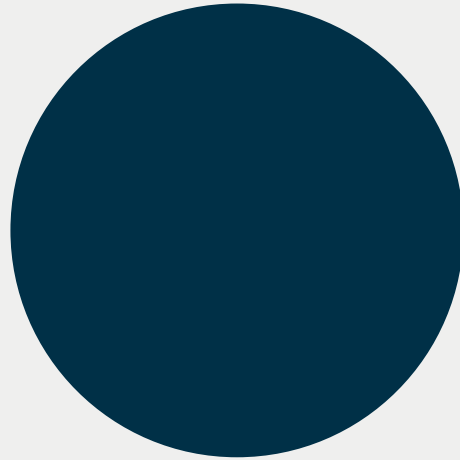
5(0) shades of hydrogen



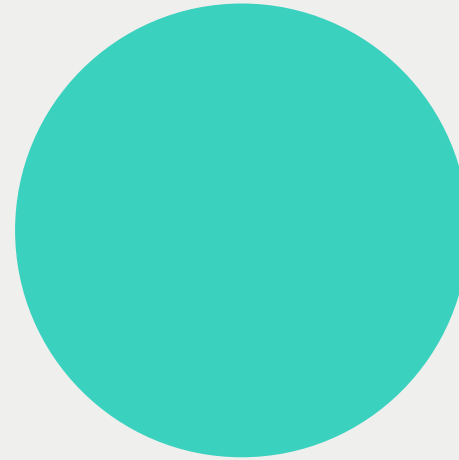
Brunt



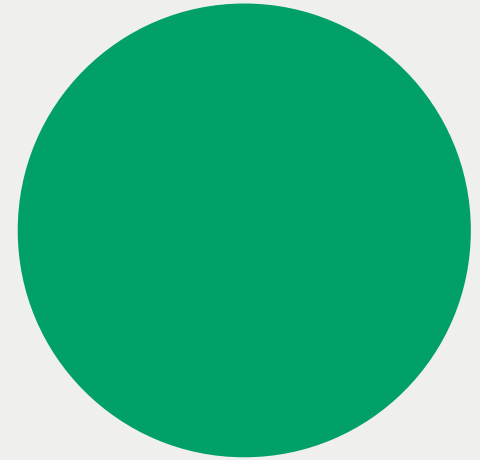
Grått



Blått



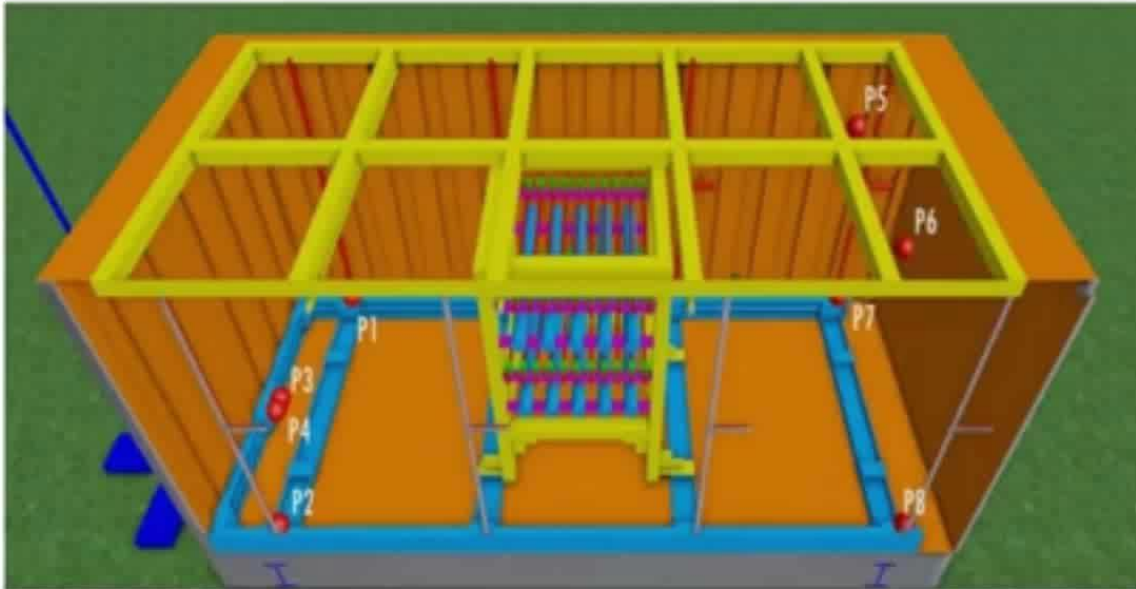
Turkist



Grønt

Fossilt	Bio	Hydrogen / derivat	Electrification	Syntetisk
HFO	Bio-metanol	Hydrogen komprimert	Battery	PTX/P2X Power-to-X
MGO	Flytende biogass	Hydrogen flytende		
MDO	Komprimert biogass	Ammoniakk		
LNG	Biobutanol	LOHC		
LPG	Biodiesel (FAME) Biodiesel (RME)	Metallhydrid		
CNG	HVO	e-metanol		
Etan				
Metanol				
Bensin				
Diesel				
Metan				

Test setup



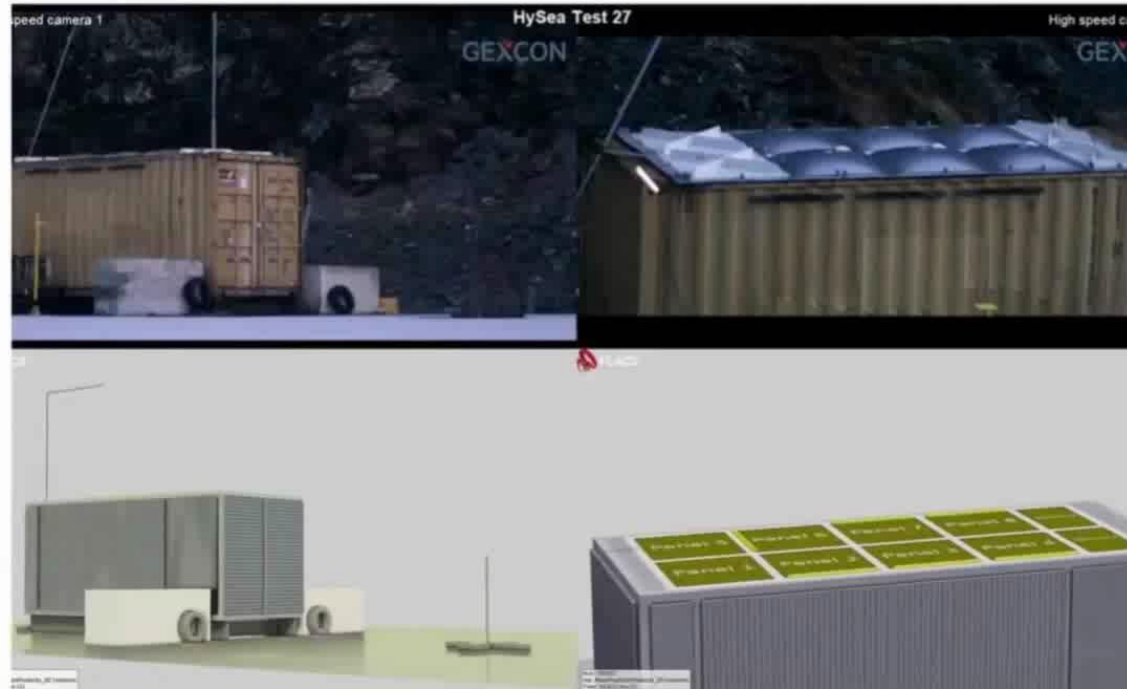
20ft ISO containers

Various dummy equipment configurations to mimic vehicle fueling compressor stations
Framework in ceiling to accommodate explosion vent devices



Implementation in Prediction tool

FLACS Hydrogen



Simulation vs. live test

HySEA Test no. 27

21 vol% H₂

Mechanical vent devices

0.1 bar overpressure





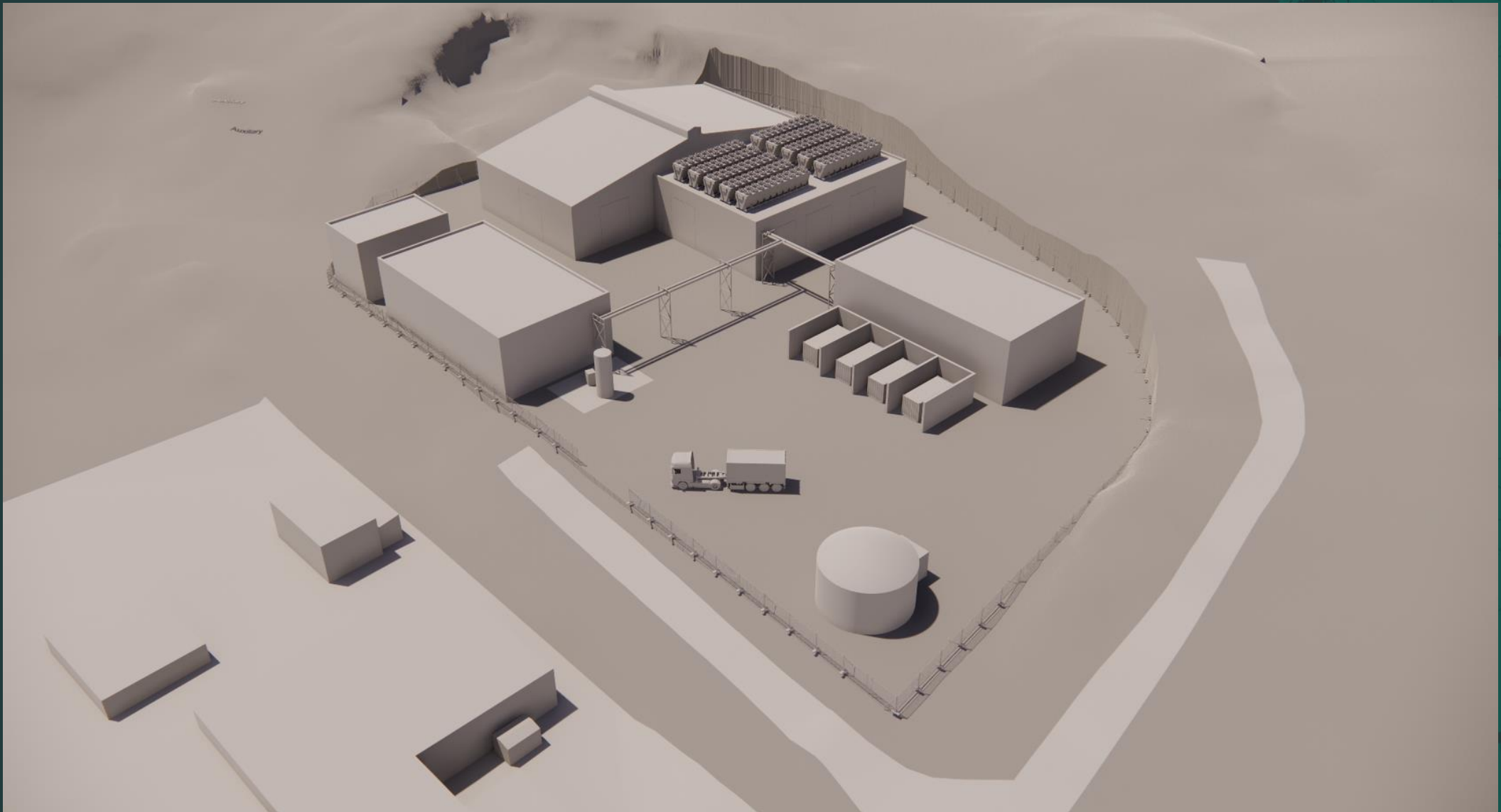
Norwegian Hydrogen

Norwegian Hydrogen

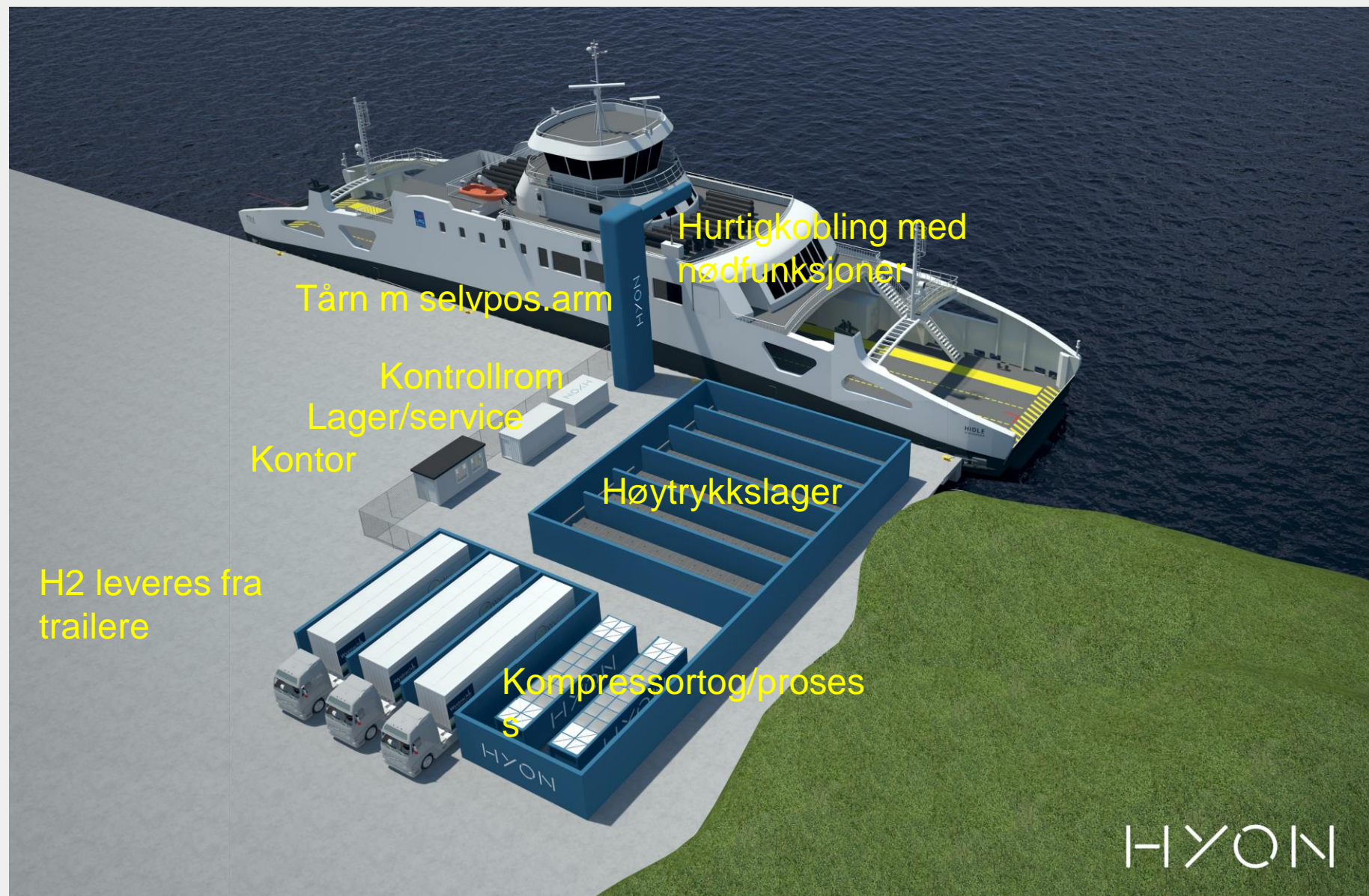
ENABLING ZERO EMISSIONS

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Typisk anlegg for høykapasitets hydrogenfylling



2 Acts, Regulations and Standards

The hydrogen production plant and belonging facilities shall be designed, fabricated, and tested in accordance with statutory requirements and the latest editions of the standards below.

2.1 CE certification and declaration of compliance

All system packages and equipment supply are subject to EU Directive for the respective type of equipment, machinery, pressure equipment, electrical equipment and shall have declaration of Compliance. All deliveries from manufactures shall comply to the EU directive and CE marked accordingly.

2.2 Authority hierarchy

The plant shall be designed and constructed in accordance with the authority hierarchy as referred to in Figure 2-1 and in the table below with latest edition.

- Act
- Directive
- Regulation
- Guideline
- Standard, norm (CEN, ISO, API, ASME etc.)
- Specification, industry standard



Figure 2-1: Authority hierarchy.

2.3 Governing documents and standards

The plant shall be designed and constructed in accordance with the authority hierarchy as referred to in the tables below with latest edition.

Table 2-1: Relevant acts.

Laws		
Organization	Doc. Id. / Code	Title
Ministry of Local Government and Regional Development	LOV-2008-06-27-71	Planning and Building Act (<i>Plan- og bygningsloven</i>)
Ministry of Justice and Public Security	LOV-2002-06-14-20	Fire and explosion protection Act (<i>Brann- og eksplosjonsvernloven</i>)
Ministry of Labour	LOV-2005-06-17-62	Working Environment Act (<i>«Arbeidsmiljøloven» - Lov om arbeidsmiljø, arbeidstid og stillingsvern mv.</i>)
Ministry of Climate and Environment	LOV-1981-03-13-6	Pollution Act (<i>«Forurensningsloven» - Lov om vern mot forurensninger og om avfall</i>)
Ministry of Justice and Public Security	LOV-1929-05-24-4	Electrical installations and equipment Act (<i>El-tilsynsloven</i>)

Table 2-2: Relevant directives

Directives		
Organization	Doc. Id. / Code	Title
European Commission	2014/68/EU	Pressure Equipment Directive (PED)
European Commission	2014/34/EU	Equipment and Protective systems intended for use in potentially explosive atmospheres (ATEX)
European Commission	2006/42/EU	Machinery Directive
European Commission	2014/30/EU	Electromagnetic Compatibility (EMC) Directive
European Commission	2014/32/EU	Measuring instruments directive (MID)
European Commission	2014/35/EU	Low voltage directive (LVD)
European Commission	2012/18/EU	Seveso Directive

Table 2-3: Relevant regulations

Regulations		
Organization	Doc. Id. / Code	Title
Directorate for Safety and Civil Protection	FOR-2016-06-03-569	Regulation of preventing and limit consequences of major accidents (<i>Storulykkeforskriften</i>)
Directorate for Safety and Civil Protection	FOR-2009-06-08-602	Regulation of handling hazardous substances (<i>Forskrift om håndtering av farlig stoff</i>)
Directorate for Safety and Civil Protection	FOR-2017-10-10-1631	Regulation of pressurized equipment (<i>Forskrift om trykkpåkjent utstyr</i>)
Directorate for Safety and Civil Protection	FOR-2017-11-29-1849	Regulation of equipment in explosive atmospheres (<i>Forskrift om utstyr og sikkerhetssystem til bruk i eksplosjonsfarlig område</i>)
Ministry of Climate and the Environment	FOR-2004-06-01-931	Pollution regulation (<i>Forskrift om begrenning om forurensning. Forurensningsforskriften.</i>)
Ministry of Climate and the Environment	FOR-2004-12-23-1851	Regulation on climate quotas. (<i>Forskrift om kvotepålagt og handel med kvoter for utslipp av klimagasser. Klimakvoteforskriften.</i>)
Ministry of Justice and Public Security	FOR-2015-12-17-1710	Regulations on fire prevention measures and supervision (<i>Forskrift om brannforebygging</i>)
Ministry of Local Government and Modernisation	FOR-2017-06-19-840	Technical regulations to the Planning and Building Act (<i>Forskrift om tekniske krav til byggverk. Byggeteknisk forskrift</i>)
Ministry of Local Government and Modernisation	FOR-2010-03-26-488	(<i>Byggesaksforskriften - Forskrift om byggesak</i>)
Ministry of Local Government and Modernisation	FOR-2017-06-19-840	TEK 17. (<i>Forskrift om tekniske krav til byggverk. Byggeteknisk forskrift</i>)
Ministry of Labour and Social Affairs	FOR-2009-08-03-1028	Construction Client Regulations (<i>Byggherreforskriften - Forskrift om sikkerhet, helse og arbeidsmiljø på bygge- eller anleggsplasser</i>)

Ministry of Labour and Social Affairs	FOR-1996-12-06-1127	Regulations relating to Systematic Health, Environmental and Safety Activities of Enterprises (<i>Internkontrollforskriften - Forskrift om systematisk helse-, miljø- og sikkerhetsarbeid i virksomheter</i>)
Ministry of Labour and Social Affairs	FOR-2009-05-20-544	Machinery regulations (<i>Forskrift om maskiner</i>)
Ministry of Justice and Public Security	FOR-1998-11-06-1060	Regulations regarding electrical low voltage installations (<i>Forskrift om elektriske lavspenningsanlegg, FEL</i>)
Ministry of Justice and Public Security	FOR-2005-12-20-1626	Regulations on electrical distribution systems (<i>Forskrift om elektriske forsyningsanlegg, FEF</i>)

Table 2-4: Mechanical and process related standards

Standards – mechanical and process related.		
Organization	Doc. Id. / Code	Title
European Standards	EN 13445	Pressure vessels & heat exchangers for gas and lye cooling
International Organization for Standardization	ISO 12100	Safety of machinery - General principles for design - Risk assessment and risk reduction
"	ISO 10434 (API 600)	Bolted Bonnet Steel Gate Valves for Petroleum and Natural Gas Industries
"	ISO 14313	Petroleum and Natural Gas Industries - Pipeline Transportation Systems - Pipeline Valves
"	ISO 15761	Steel Gate, Globe and Check Valves for Sizes DN 100 and Smaller, for the Petroleum and Natural Gas Industries
"	ISO 17292	Metal ball valves for petroleum, petrochemical and allied industries
"	ISO 8573	Compressed air — Contaminant measurement

Table 2-5: Civil related standards

Standards – Civil		
Organization	Doc. Id. / Code	Title
European Standards	EN 1990	Basis of structural design
"	EN 1991-1-1	Eurocode 1: Actions on structures, Part 1-1: General actions, Densities, self-weight, imposed loads for buildings
"	EN 1991-1-3	Eurocode 1: Actions on structures, Part 1-3: General actions, Snow actions
"	EN 1991-1-4	Eurocode 1: Actions on structures, Part 1-4: General actions, Wind actions
"	EN 1991-1-5	Eurocode 1: Actions on structures, Part 1-5: General actions, Thermal actions
"	EN 1991-1-7	Eurocode 1: Actions on structures, Part 1-7: General actions, Accidental loads

"	EN 1992-1-1	Eurocode 2: Design of concrete structures, Part 1-1: General rules and rules for buildings
"	EN 1993-1-1	Eurocode 3: Design of steel structures, Part 1-1: General rules and rules for buildings
"	EN 1993-1-3	Eurocode 3: Design of steel structures, Part 1-3: Supplementary rules for cold-formed members and sheeting
"	EN 1993-1-8	Eurocode 3: Design of steel structures, Part 1-8: Design of joints
"	EN 1993-1-10	Eurocode 3: Design of steel structures, Part 1-10: Material toughness and through-thickness properties
"	EN 1993-5	Eurocode 3: Design of steel structures, Part 5: Piling
"	EN 1997-1	Eurocode 7: Geotechnical design, Part 1: General rules
"	EN 1997-2	Eurocode 7: Geotechnical design, Part 2: Ground investigation and testing
"	EN 1998-1	Eurocode 8: Design of structures for earthquake resistance, Part 1: General rules, seismic actions and rules for buildings
"	EN 1998-5	Eurocode 8: Design of structures for earthquake resistance, Part 5: Foundations, retaining structures and geotechnical aspects
"	EN 206	Concrete - Specification, performance, production and conformity
"	EN 13670	Execution of concrete structures

Table 2-6: Technical safety related standards

Standards – Technical Safety		
Organization	Doc. Id. / Code	Title
International Organization for Standardization	ISO 4126	Safety devices for protection against excessive pressure
"	ISO/TR 15916	Basic considerations for the safety of hydrogen systems
"	ISO 31000:2018	Risk management guideline
"	IEC 31010:209	Risk management, risk assessment techniques
European Standards	EN 60079-10-1	Explosive atmospheres – Part 10-1: classification of areas – Explosive atmospheres

Table 2-7: Instrumentation related standards

Standards - Instrumentation		
Organization	Doc. Id. / Code	Title
European Standards	EN 50173	Information technology - Generic cabling systems
"	EN 50174	Information technology - Cabling installation

*	EN 50310	Telecommunications bonding networks for buildings and other structures
*	EN ISO 13849	Safety of machinery – Safety-related parts of control systems
International Electrotechnical Commission	IEC 60079-20-1	Material characteristics for gas and vapour classification
*	IEC 60079	Standard series for equipment and instrumentation in hazardous areas.
*	IEC 61508	Functional Safety of Electrical / Electronic / Programmable Electronic Safety-Related Systems
*	IEC 61511	Functional Safety – Safety Instrumented Systems for the Process Industry Sector
*	IEC 60079-20-1	Material characteristics for gas and vapour classification
*	IEC 60079	Standard series for equipment and instrumentation in hazardous areas.
*	IEC 61508	Functional Safety of Electrical / Electronic / Programmable Electronic Safety-Related Systems
International Society of Automation	ISA 5.1	Instrumentation Symbols and Identification
*	ISA 20	Specifications Forms for Process Measurement and Control Instruments, Primary Elements and Control Valves
*	ISA 50.1	Compatibility of Analog Signals for Electronic Industrial Process Instruments
*	ISA 51.1	Process Instrumentation Terminology

Table 2-8: Electrical related standards.

Standards - Electrical		
Organization	Doc. Id. / Code	Title
Norsk Elektroteknisk Komite	NEK 420A	Electrical installations in potential explosive atmospheres based on EN/IEC 60079-14, 17, 19 and IEC/IEEE 60089-30-2
*	NEK 420B	Classification of areas in potential explosive atmospheres based on EN/IEC 60079-10-1 and EN/IEC 60079-10-2
Norsk Standard	NS 3960	Fire detection and fire alarm systems Design, installation, operation and maintenance
Norsk Elektroteknisk Komite	NEK EN 62271	High-voltage switchgear and control gear
*	NEK EN 61439	Low-voltage switchgear and control gear assemblies
*	NEK 320	Protection against lightning. Risk management, planning and installation.
*	NEK 400	Electrical low voltage installations based on IEC 60364 and CEN/LEC HD 60364

*	NEK 440	Power installations exceeding 1 kV based on NEK EN 61936 and NEK EN 50522
*	NEK EN 50160:2010	Voltage characteristics of electricity supplied by public electricity networks
International Electrotechnical Commission	IEC 61158	Industrial communication networks – Fieldbus specifications
*	IEC 61784	Industrial communication networks – Profiles
*	IEC 61508	Functional safety of electrical/electronic/programmable electronic safety-related systems
*	IEC 61511	Functional safety - Safety instrumented systems for the process industry sector
European Norm	EN 62040-1-1	Uninterruptible power systems (UPS) - Part 1-1: General and safety requirements for UPS used in operator access areas.

Table 2-9: Hydrogen related standards

ISO Standards - Hydrogen specific		
Organization	Doc. Id. / Code	Title
International Organization for Standardization	ISO/TR 15916:2015	Basic considerations for the safety of hydrogen systems
*	ISO 22734:2019	Hydrogen generators using water electrolysis — Industrial, commercial, and residential applications
*	ISO 26142:2010	Hydrogen detection apparatus — Stationary applications
*	ISO 19880	Gaseous hydrogen all parts
*	ISO 22734-1: 2008	Hydrogen generators using water electrolysis process — Part 1: Industrial and commercial applications
*	ISO 14687-2:2012	Hydrogen fuel — Product specification — Part 2: Proton exchange membrane (PEM) fuel cell applications for road vehicles
*	ISO 14687:2019	Hydrogen fuel quality — Product specification
*	ISO 19880-1:2020	Gaseous hydrogen — Fuelling stations — Part 1: General requirements
*	ISO 19880-3:2018	Gaseous hydrogen — Fuelling stations — Part 3: Valves
*	ISO 19880-5:2019	Gaseous hydrogen — Fuelling stations — Part 5: Dispenser hoses and hose assemblies
*	ISO 19880-8:2019	Gaseous hydrogen — Fuelling stations — Part 8: Fuel quality control
*	ISO 19882:2018	Gaseous hydrogen — Thermally activated pressure relief devices for compressed hydrogen vehicle fuel containers

QRS
Quantative Risk Analysis
Typically made by Gexcon

Table of Contents

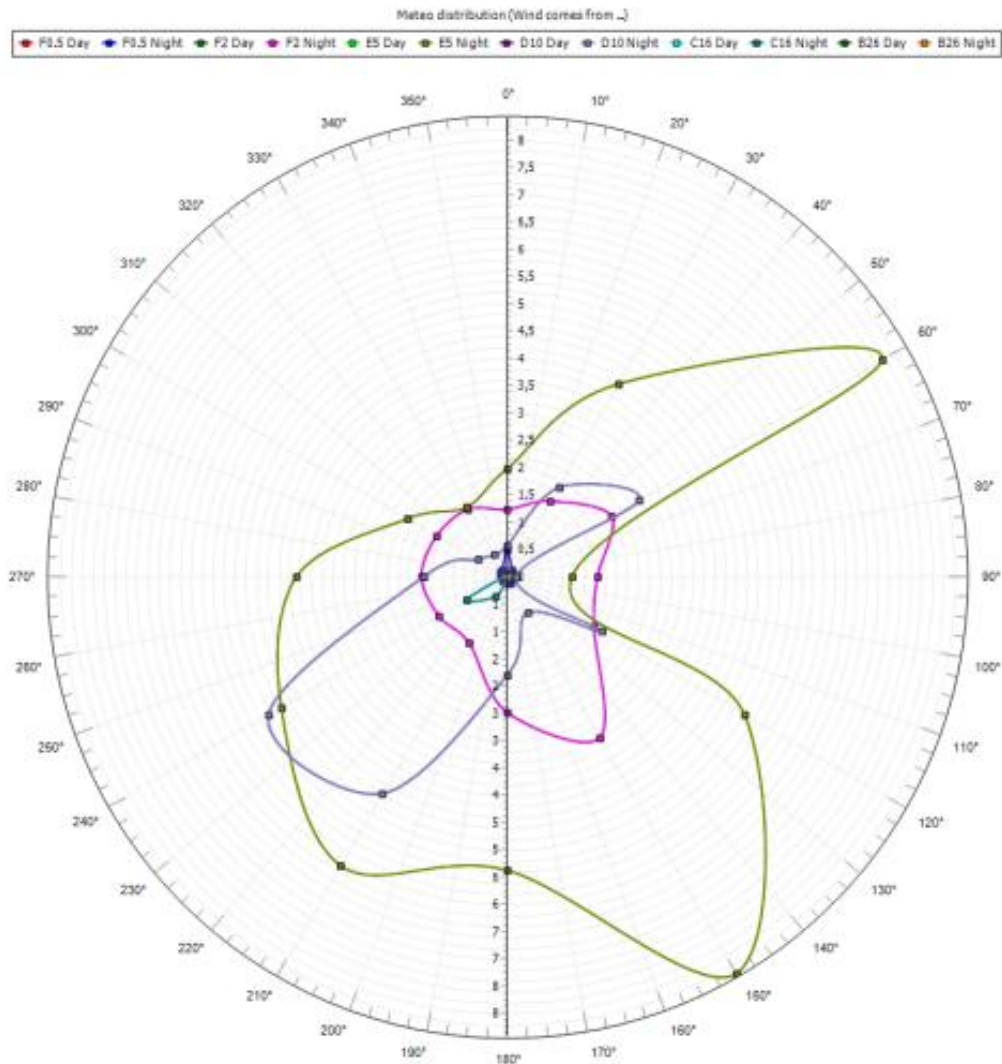
Disclaimer	3
1 Introduction	5
1.1 Riskcurves.....	5
1.2 Abbreviations and definitions	5
2 Project Description	6
2.1 Plant Characteristics	6
2.2 Weather data.....	7
3 Regulatory Requirements	9
4 Assumptions	10
5 Risk analysis	11
5.1 Process segmentation.....	11
5.2 Frequency Assessment.....	11
5.3 Release rates	12
5.4 Ignition probabilities	13
5.5 Ignited events.....	14
5.6 Modelling of ignited events in Riskcurves	15
5.7 Vulnerability.....	15
6 Results	17
6.1 Risk distribution - hazards.....	17
6.2 Bunkering location at Flatholmen.....	19
7 Conclusions	20
7.1 Discussion.....	20
8 References	21
Appendix A Assumption Register	22
A 1 Hydrogen Plant	22
A 2 Analytical Assumptions	22
Appendix B Leakage frequency assessments	23

Wind data for the area is based on local meteorological statistics. The closest weather station having appropriate statistics is at Vigra Airport. The average speed/direction for each hour of the period from 1 January 2010 through 31 December 2020 has been downloaded from Norsk Klimaservicesenter at seklima.met.no. Data older than 1 January 2010 is not available. The data is presented in Table 2.1

Table 2.1 *Distribution of wind observations from 2010 to 2020 for Vigra*

Wind speed (m/s)		Wind direction (deg)												
Range	Repr.	0	30	60	90	120	150	180	210	240	270	300	330	SUM
0 - 1	0,5	0,5 %	0,1 %	0,1 %	0,1 %	0,1 %	0,1 %	0,1 %	0,1 %	0,1 %	0,1 %	0,2 %	0,1 %	1,9 %
1 - 3	2	1,2 %	1,6 %	2,2 %	1,6 %	1,8 %	3,4 %	2,5 %	1,4 %	1,5 %	1,6 %	1,5 %	1,4 %	21,8 %
3 - 7	5	2,0 %	4,1 %	8,0 %	1,2 %	5,0 %	8,4 %	5,4 %	6,1 %	4,8 %	3,9 %	2,1 %	1,5 %	52,4 %
7 - 13	10	0,6 %	1,9 %	2,8 %	0,2 %	2,0 %	0,8 %	1,8 %	4,6 %	5,1 %	1,5 %	0,6 %	0,5 %	22,3 %
13 - 19	16	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,4 %	0,9 %	0,1 %	0,0 %	0,0 %	1,5 %
> 19	26	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,1 %	0,0 %	0,0 %	0,0 %	0,1 %
SUM		4,3 %	7,8 %	13,1 %	3,1 %	9,0 %	12,7 %	9,8 %	12,6 %	12,3 %	7,2 %	4,4 %	3,6 %	100,0 %

The wind rose applied for the risk analysis is shown in Figure 2.2.



Representative release rates need to be calculated

Process section	Pressur [bar]	Temperature [°C]	Segment Volume [m ³]	Representative Leakage Range [kg/s]		
				5 mm	50 mm	100 mm
Electrolyser	25	70	3			
Compressor	400	50	0,5			
Storage container	350	10	25			

Norwegian major incident regulation regarding Hydrogen

COLUMN 1		COLUMN 2	COLUMN 3
		Limit amount (kg)	
		Duty to notify according to §6	Complete safety documentation according to §9
Hazardous substance	CAS Number		
Hydrogen	1333-74-0	5 000	50 000

Figure 3.1 Extract from DSB regulations (2016)

Regardless of which category applies, the company will need to apply for consent to the DSB (The Norwegian Directorate for Civil Protection) before activities can legally start on the facility. Threshold amounts for Hydrogen storage are given in Figure 3.1 above.

The major incident regulations define influence zones that dictate what kind of activities and exposure time for humans are acceptable in the area around a facility. These influence zones are defined as follows in the table below.

Table 3.1 Influence zones according to the major incident regulation

Zone	3 rd party risk threshold	Description
Inner	1×10^{-5}	This is usually the facility site itself. In addition, it can include areas used for agricultural purposes. Only short-term human presence is acceptable, such as people passing through on already established hiking trails.
Middle	1×10^{-6}	Public roads, railroads, docks and similar. Permanent places of work, such as industry or offices, is also acceptable in this zone. However, there shall be no hotels or residential buildings. Scattered residences may be accepted in some cases.
Outer	1×10^{-7}	Residential areas and areas with access for the general public may be inside the outer zone, including shops. Buildings with high occupancy such as schools, day care centres and hospitals, shall be located outside the outer zone.

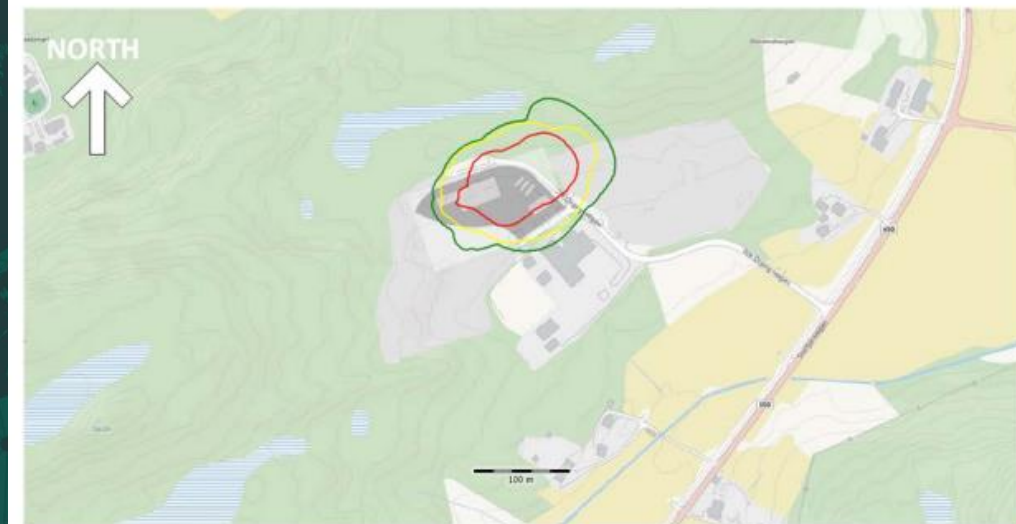


Figure 6.3 Frequency contours for lethality due to occurrence of flammable concentrations: 10^{-5} (red), 10^{-6} (yellow), 10^{-7} (green)

The Kjørbo Incident June 10th 2019



 budstikka.no/nyheter/kjorbo-anlegget-ble-aldri-behandlet-politisk/204285/

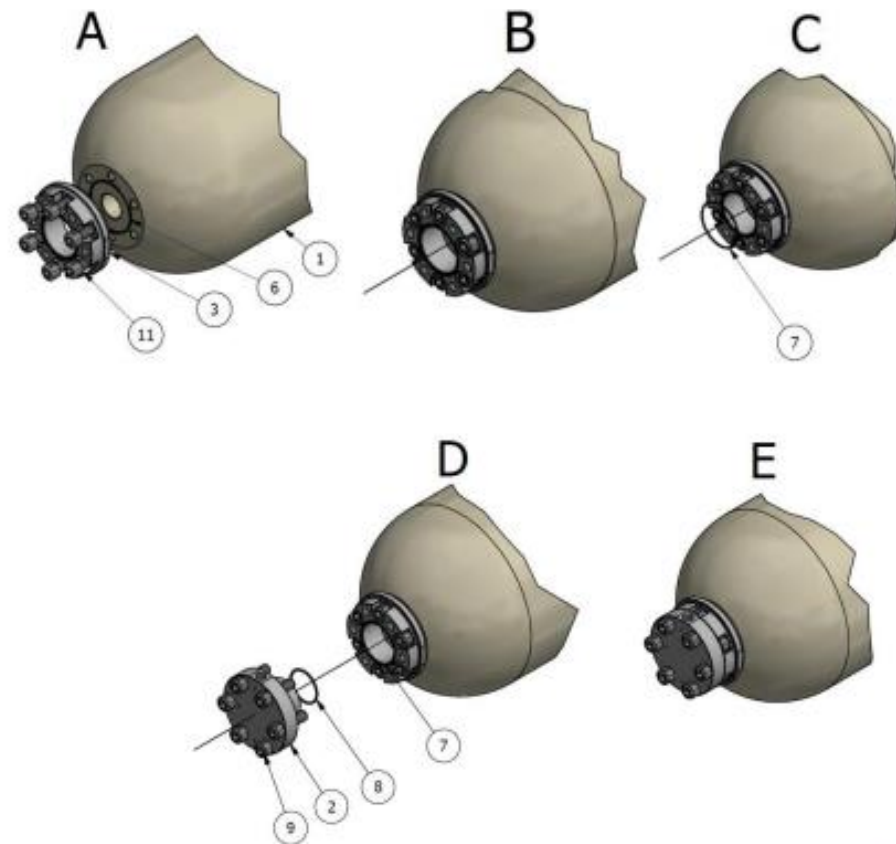
Root cause

Non-core Nel technology

- Assembly error in high-pressure storage unit
- Unit consists of steel tanks and other components by third parties, some of which are designed by Nel



Kjørbo incident



Root cause - failure mechanisms of plug assembly

Non-core Nel technology

1. Starting condition

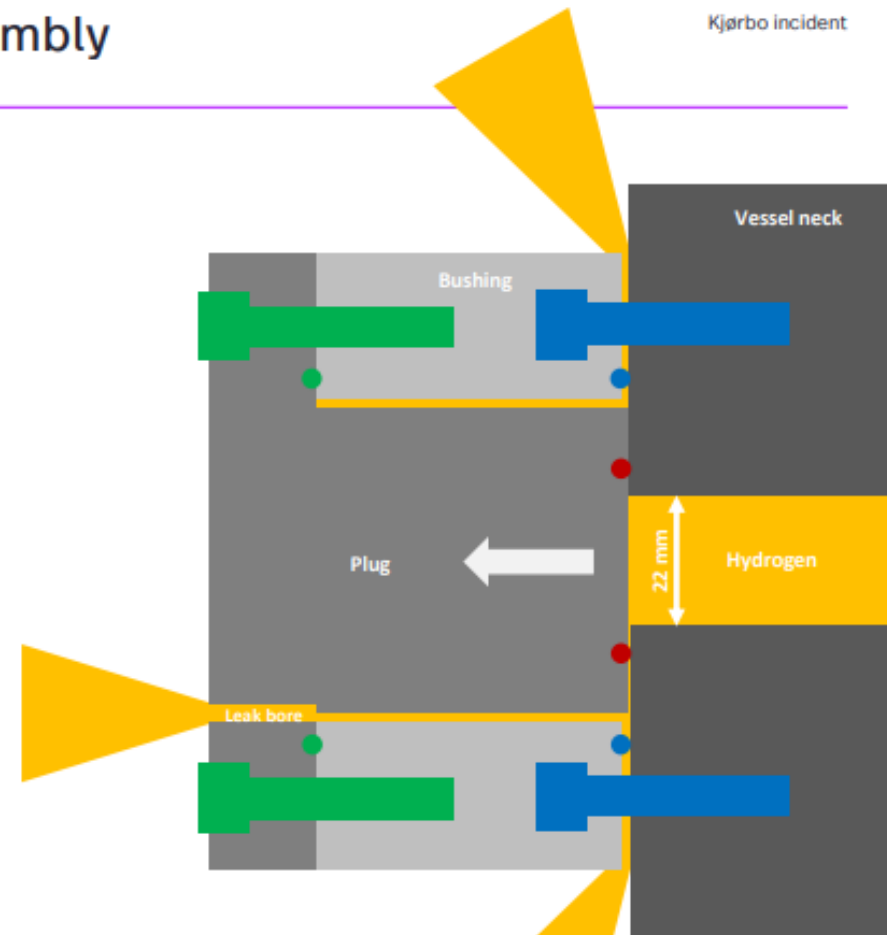
- Green bolts torqued properly
- Blue bolts not torqued properly

2. Red sealing fails

- Starting with small leak on red sealing area
- Small leak wears red sealing out and escalates
- Large leak exceeding capacity of leak bore, causing pressure increases inside blue sealing area

3. Bushing with Plug lifts and the blue seal fails

- Insufficient pre-tension of bolts leads to lift of the plug and blue sealings fail immediately
- Spread of Hydrogen leaks out in uncontrolled way



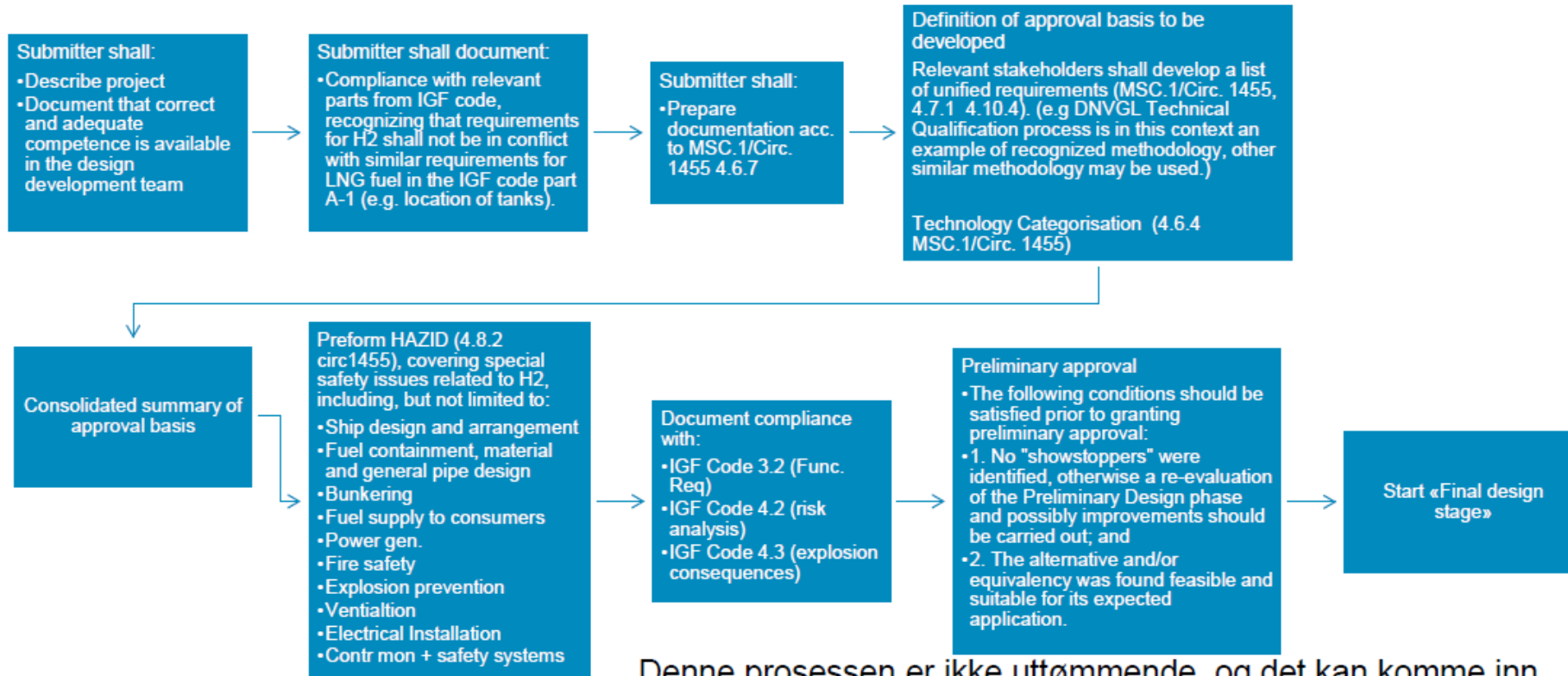
Nel has initiated an inspection and an integrity verification program for the high-pressure storage units with similar plugs. The company would give green light to operators in July or first half of July for other countries. While Europe and Norway, they have to update components to correct the individuated root cause structure. Experts have proposed and operated an update and check of the sites and replacement of all common elements present in. It could be summarized in 4 main points (Relations, 2019):

1. Verified plug solution
 - Inspect all high-pressure storage units in Europe
 - Check/re-torque all plugs
2. Updated routines for assembly of high-pressure storage units
 - Introduce new safety system/routines (aerospace standard)
 - Torque verification, double witness and documentation/markings
3. Improved leak detection
 - Software update to increase leak detection frequency
 - Consider additional detection hardware/modifications
4. Ignition control measures (site dependent)
 - Smooth surface/no gravel around high-pressure storage unit
 - Additional ventilation in compound & higher extent of EX-equipment



HHH - HELLESYLT HYDROGEN HUB





Denne prosessen er ikke uttømmende, og det kan komme inn ytterligere punkter underveis.



Thank you



Kåre Nerem

Technical Director

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