Hydrogen storage

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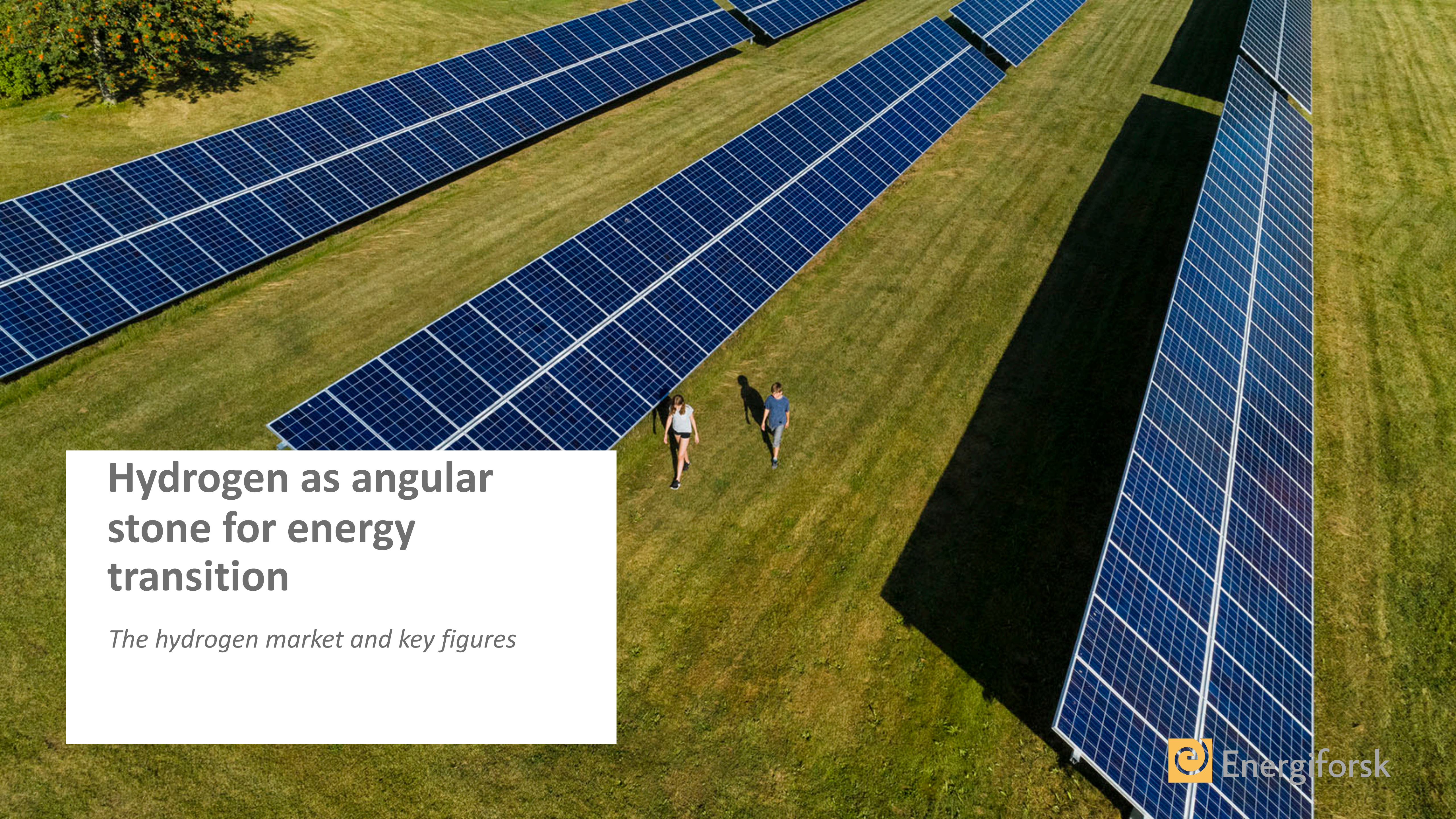
Agenda

- Hydrogen as angular stone for the energy transition
- Hydrogen storage project
- Hydrogen storage
- Looking to the future



Hydrogen as angular stone for energy transition

The hydrogen market and key figures

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Countries with a Hydrogen National Strategy

< 2019

- Australia
- Japan
- South Korea
- Belgium

4

2020

- EU
- France
- Germany
- Netherlands
- Norway
- Portugal
- Spain
- Chile
- Canada
- Finland
- New Zeeland
- USA

12

2021

- Hungary
- UK
- Czech Republic
- Colombia
- Denmark
- India
- Morocco
- Paraguay
- Singapore
- Sweden

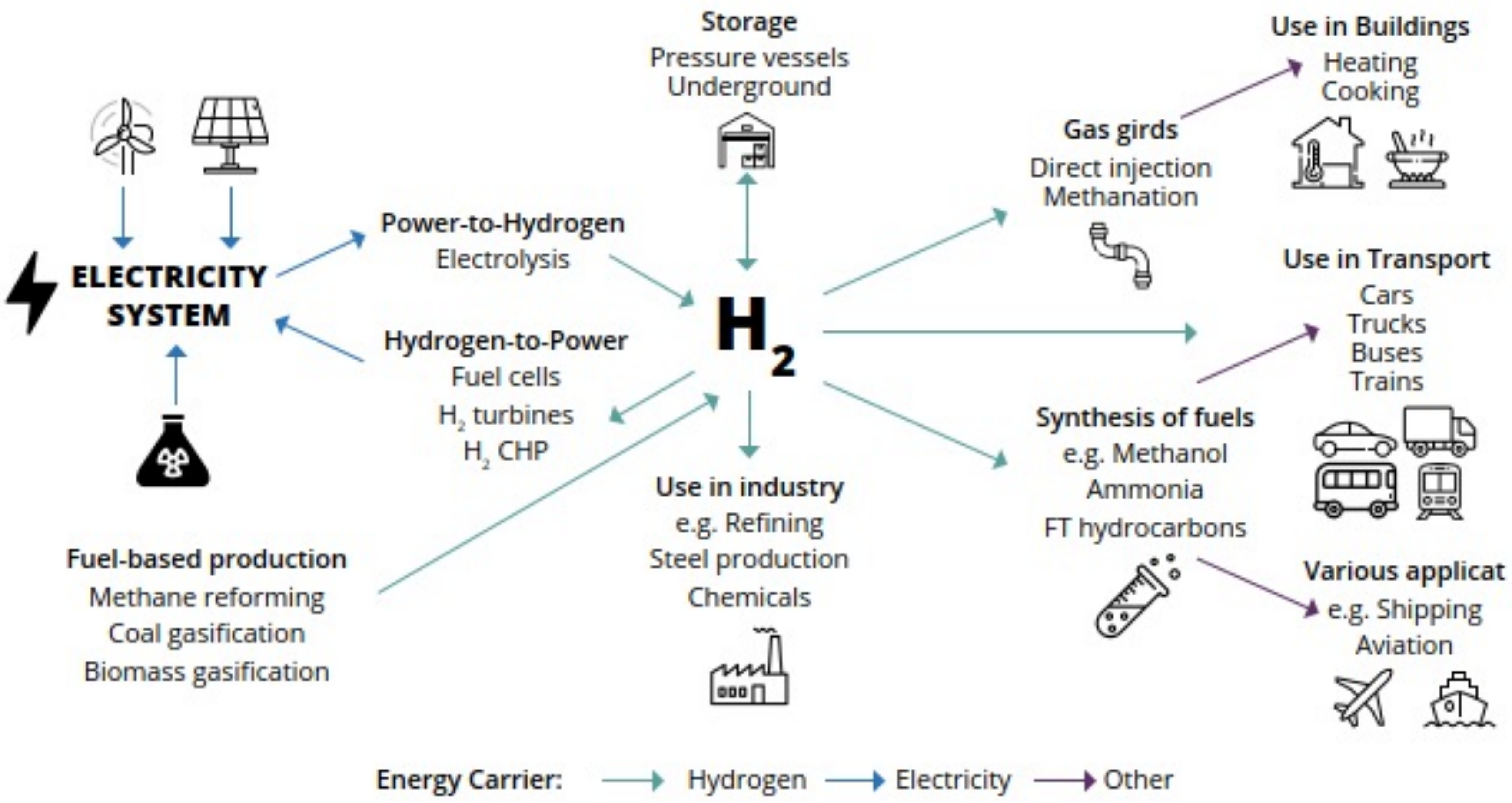
10

2022 (Q1,Q2)

- China
- Saudi Arabia

2

Overview of key hydrogen production and usage pathways



IEA. *Power-to-hydrogen and hydrogen-to-X: System analysis of the techno-economic, legal and regulatory conditions.* 2020

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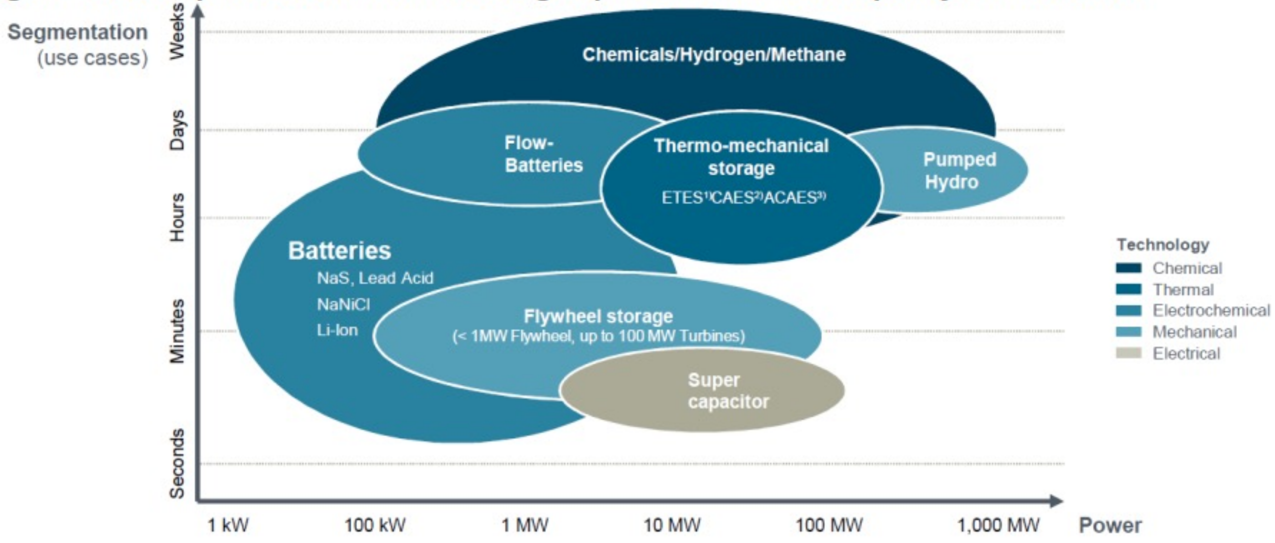
Competitiveness of hydrogen applications versus low-carbon and conventional alternatives

Challenges in implementation

- Hydrogen storage is important for the integration of hydrogen in the energy system
- Renewable energy sources are intermittent and cannot be regulated
- To ensure hydrogen availability when and where is needed it should be stored
- Other energy storage techniques are well established and commercialized
- Hydrogen storage is not new, but has not been done at the scale and spread that is being planned now
- Hydrogen storage for energy but also as raw material

Figure 1: A comparison of different storage options in terms of capacity and duration



1) Electro-Thermal Energy Storage 2) Compressed Air Energy Storage 3) Adiabatic Compressed Air Energy Storage

Source: Siemens (2017)

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Our project

Hydrogen Storage

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Project description

The hydrogen storage project: 4 work packages

- Work Package 1: Hydrogen storage techniques (review)
- Work Package 2:Analysis and evaluation of system efficiency, costs and benefits.
- Work Package 3: Regulations, standards and permitting process.
- Work Package 4: Identify knowledge gaps through dialogue with relevant actors

Boundary for the project is gas to gas, meaning no consideration is to be taken on how the hydrogen is produced.

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Work Package 1

- Description of the stationary storage techniques: Sizes, pressures, temperatures, materials, et.)
- Energy requirements for injection and release
- Dynamic behaviour
- Limitations
- General comparison between different alternatives

The selection of hydrogen storage solution is determined by several factors, such as the application for the stored hydrogen, availability of raw materials (CO_2 for methanol for example), energy system (electricity available, access to heat, geographic position, and so on).

Work Package 2

For a limited number of selected techniques, work package 2 will deliver:

- Analysis and evaluation of the system efficiency
- System costs (CAPEX/OPEX)
- System benefits

The work package will include hydrogen storage techniques that are required for the industry, energy and transport sectors.

The selection of hydrogen storage solution will build on work package 1.

A first approach to associated risks with hydrogen storage will be included, as an introduction to work package 3.

Work Package 3

The focus is on *Regulations, standards and permitting processes* that are required for different hydrogen storage techniques.

Hydrogen is a flammable gas and has been handled in the industry for many years.

The main difference is that hydrogen has not been stored in large volumes until now.

Other relevant differences are for the transport sector where refuelling stations are planned in close proximity to housing areas, this presents a different set of consequences to known risks.

Because of these reasons, permitting and regulations are needed in order to correctly implement the new energy systems with large hydrogen usage.

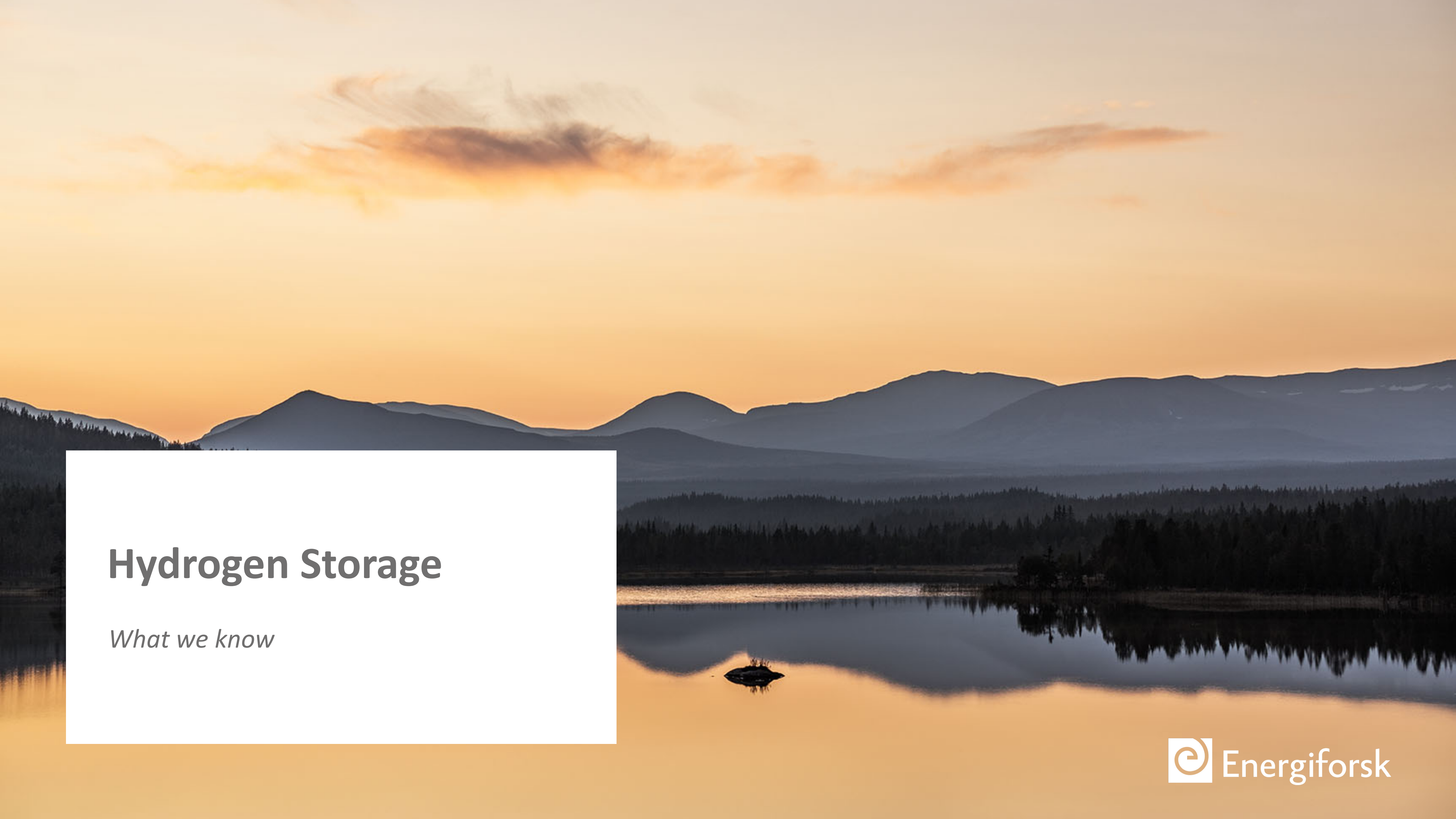
Wrong, or rushed, implementation can lead to accidents of various magnitudes and lost of trust from the stakeholders and their acceptance.

Work Package 4

Dialogue with stakeholders.

In this work package we allow ourselves to search for questions, to look into the less commercialized techniques, and to see what would be necessary to bring those to a competitive level.

For the existing technologies, there are still challenges, and this work package seeks to identify them.



Hydrogen Storage

What we know

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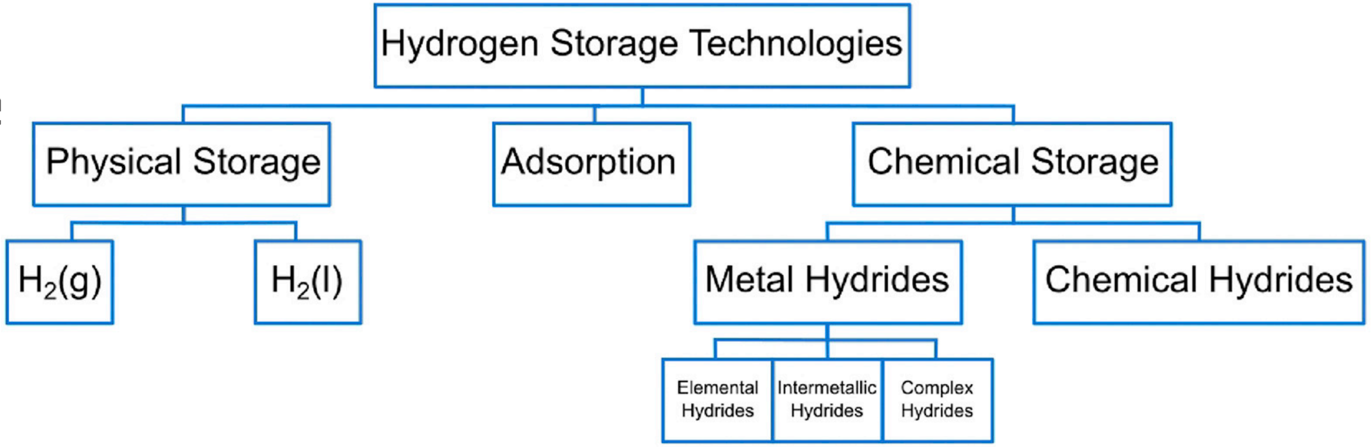
Hydrogen Storage: Techniques

- Different forms of hydrogen storage with different TRL.
- Physical storage is well known (commercial maturity) for small scale.
- Chemical storage is partly well known for specific Chemical Hydrides. Large knowledge gaps for reconversion back to H_2.
- Different applications require different storage solutions.



“Today, liquid hydrogen is the signature fuel of the American space program and is used by other countries in the business of launching satellites.”

https://www.nasa.gov/topics/technology/hydrogen/hydrogen_fuel_of_choice.html

Physical storage

No compression

- $1kg_{H2}$ = 100km
- $1kg_{H2} = 11m^3$

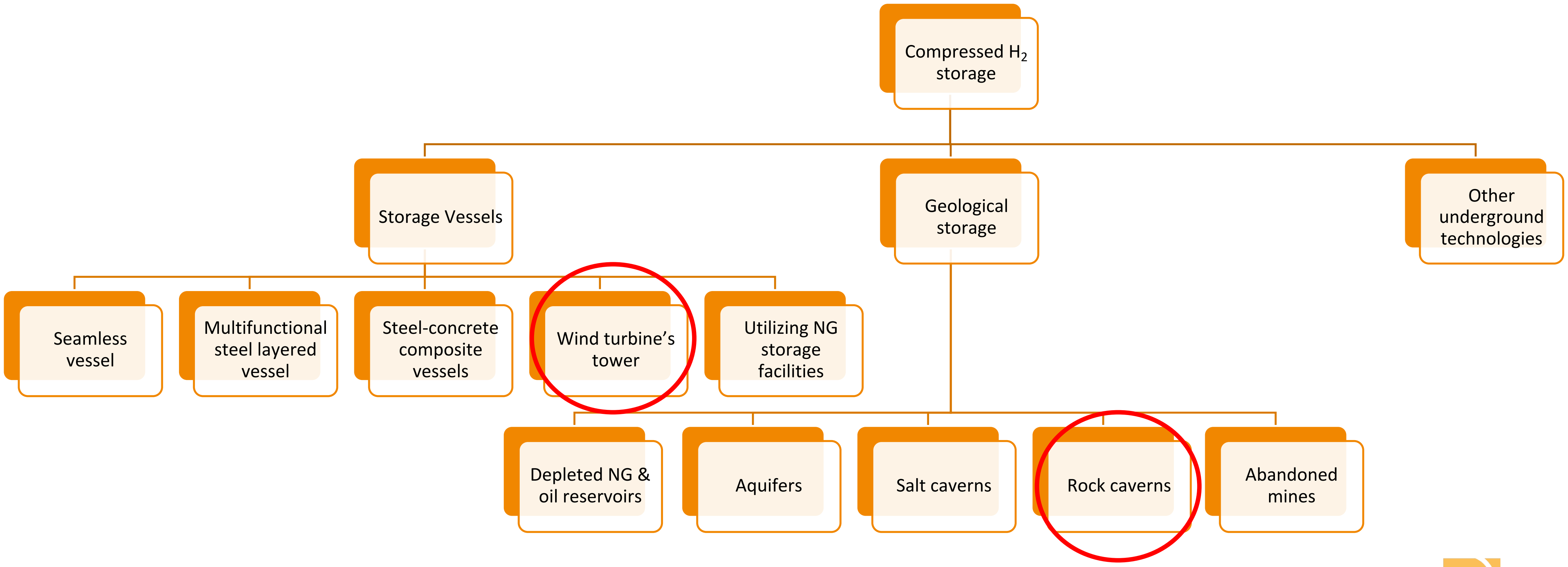
Compressed gas

- 700bar
- 42 kg/m^3
- 5kg= 125L
- 5kg = 500-600 km

Liquid

- T< -252,87°C, 1,013 bar
- 71 kg/m^3
- 5kg = 75L

Physical storage options



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Physical storage options – gas form

- Geological storage offers the lowest cost for large scale storage
- The type of geological storage depends on the geographic location
- The technology maturity for Geological storage of H_2 should be included (Hybrit)

Criteria	Compressed			
	Storage vessels			Geological storage
	Wind turbine tower	Pressure vessels	Underground pipes	
Storage size (GWh)	Up to 0,031 per 82 m tall WT	0,034	2,15	>10-100 Depends on the site nature
Cost	■	■	■	■
Technology maturity For NG	N/A	✓	✓	✓
Technology maturity For H_2	×	✓	Exist but not on large scale	×

DEMO scale Hybrit

Ahmed M. Elberry, Jagruti Thakur, Annukka Santasalo-Aarnio, Martti Larmi. *Large scale compressed hydrogen storage as part of renewable electricity storage systems.* 2021

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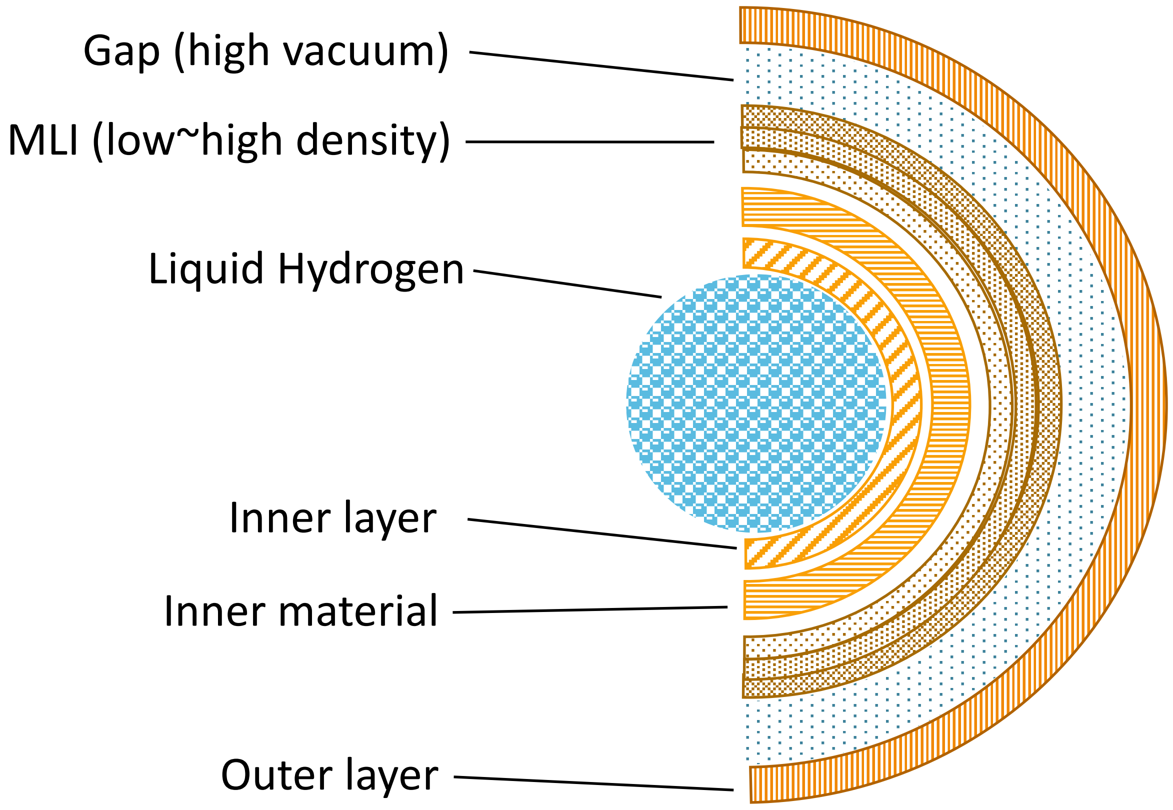
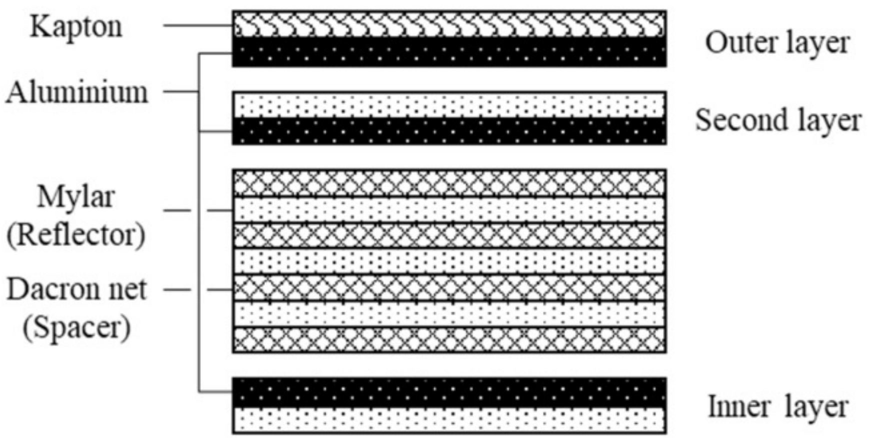
Physical storage options – liquid form

- Figure to the right shows an Insulation concept for liquid hydrogen storage developed for a test bed.
- MLI stands for Multi-Layer insulation and is described in more detail in the figure below





Daehoon Kang, Sungho Yun, Bo-kyong Kim. *Review of the Liquid Hydrogen Storage Tank and Insulation System for the High-Power Locomtive.* 2022

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Chemical storage

Metal Hydrides

H_2 chemically bonded within the metal compound structure

Operating pressure: 10-40 bar

Operating temperature ~20C

Small volumes, 1,5 kgH2 (50kWh) per 100kg metal hydride

Desorption process at 45-65C

Storage over extended periods (months)

Chemical Hydrides

H_2 chemically bonded

Ammonia is widely used and traded. Regulations and standards are already in place

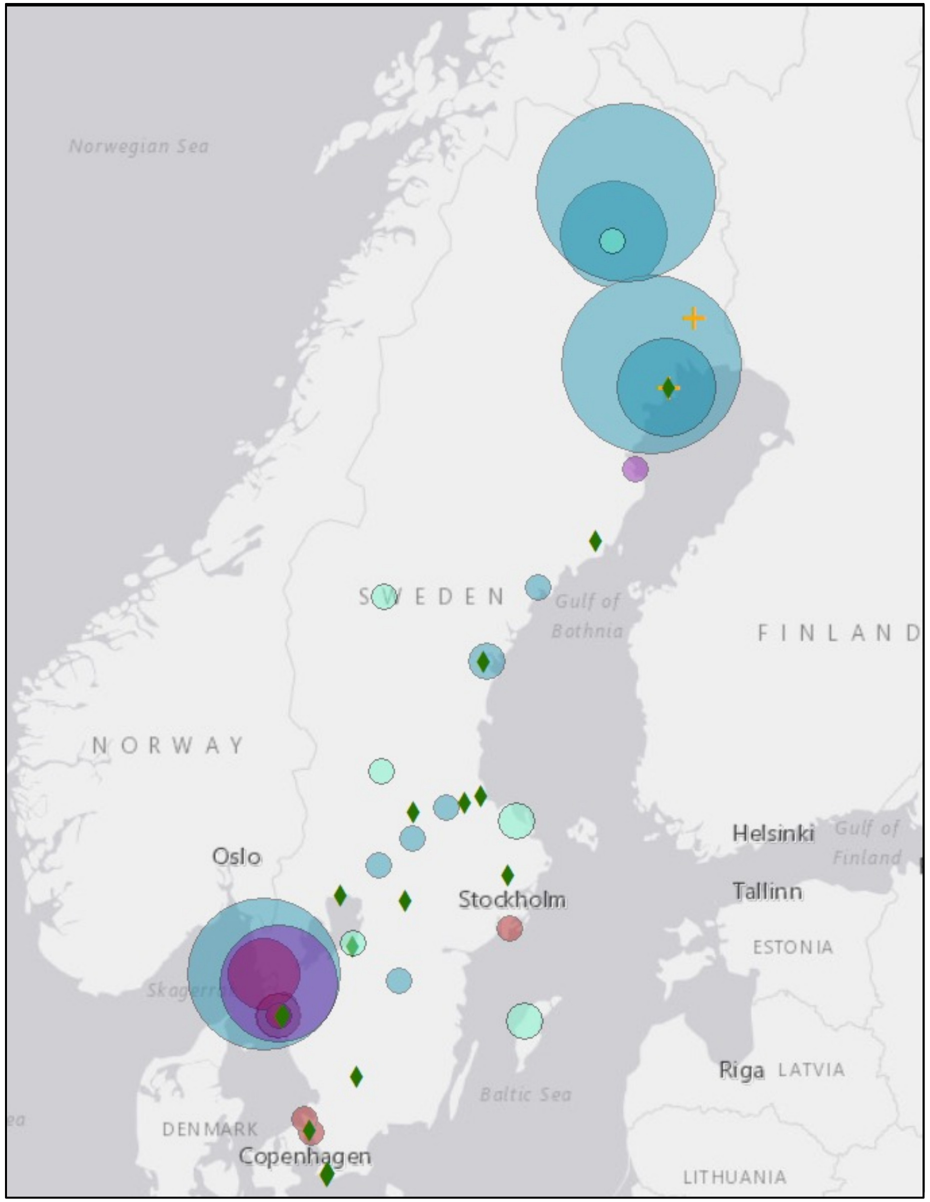
There are high risks associated with ammonia. Consequences of accidents can be vast.

Import of hydrogen to EU is getting ready for increase trade of ammonia


HYDROGEN DEVELOPMENTS IN ROTTERDAM
EXPECTED H2 THROUGHPUT
Grey hydrogen
Blue hydrogen
Green hydrogen
Imported hydrogen
20
15
10
5
0
2020
2030
2040
2050
WEIGHT
20 MTON H2
130 MTON AMMONIA
120 MTON METHANOL
322 MTON LOHC
56 MTON CRUDE OIL
TIMETABLE
Shell 200 MW electrolyser
2024
H2 backbone HyTransPort.RTM; Green ammonia imports start
2024
bp-HyCC 250 MW electrolyser; Uniper 100 MW electrolyser; LOHC import at industry scale; 1000 H2 powered trucks
2025
Pipelines Delta Corridor Chemelot–NRW; 12 H2 powered inland barges; H-vision (blue H2)
2026
LH2 terminal
2027
2 – 2,5 GW electrolysers
4 Mton imports
2030
H2 IMPORT
CCS (PORTHOS)
H2 IMPORT
CO2 PIPELINE
BLUE H2 PRODUCTION (H-VISION)
H2 IMPORT TERMINAL
H2 IMPORT TERMINAL
ADDITIONAL USE OF H2 FOR HEATING (GREENHOUSES, HOMES)
CONNECTION TO NATIONAL H2 GRID
2 GW OFFSHORE WIND
2 GW CONVERSION PARK FOR GREEN H2
ELECTRICITY CABLE
H2 AS TRANSPORT FUEL
H2 FROM BIOMASS
INDUSTRY USES H2 FOR HEATING AND AS FEEDSTOCK
H2 BACKBONE HYTRANSPORT.RTM
TRANSPORT TO NORTH RHINE-WESTPHALIA
DELTA CORRIDOR
TRANSPORT TO CHEMELOT
Port of Rotterdam

Hydrogen projects in Sweden

- Electricity production
- Hydrogen refilling station
- Train, maritime and aviation
- Industry – Existing hydrogen units (grey H_2)
- Industry – New units planned
- Industry – Future potential applications for H_2



Borrowed from KTH, Stefan Grönkvist, Kumail Marnate

*Kartan är ritad med ArcGIS baserat på annonserade vätgasprojekt i Sverige.
*Storleken på cirklarna anger hur mycket vätgas som kan behövas.

Looking to the future

Gap knowledge analysis

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Relevant topics to be studied in the future

- One of the projects' purposes is to identify knowledge gaps in the storage technologies
- Hydrogen conversion and contamination, recoverability of hydrogen
- Materials for hydrogen storage
- Surface facilities such as compressors
- Storage integrity
- Storage performance for lower TRL techniques
- Economics and system integration
- Infrastructure for the future energy system

Transforming society together

SWECO