SEANERGY

the Sustainability EducationAl programme for greeNER fuels and enerGY on ports

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

Module #2 Energy transition in ports:

SEANERGY

Part 2:
Holistic review of hydrogen in ports and supply chain

Course coordinator:

Dirk Fischer

Name of the organization(s), country:

Argo-Anleg GmbH (Germany)

Email: d.fischer@argo-anleg.de

ARGO ANLEG
Advanced Hydrogen Technologies

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

Learning objectives of the course

SEANERGY

On completion of this course, the participants will be able to:

- **Evaluate the hydrogen supply chain**: Develop a deeper understanding of the hydrogen supply chain, including production, storage, and transportation logistics.
- **Identify hydrogen application options**: Recognize and assess various options for integrating hydrogen applications within ports.

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

Table of Content

SEANERGY

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

Table of Content

SEANERGY

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.1 Introduction to hydrogen as a green energy source

SEANERGY

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.1 Introduction to hydrogen as a green energy source

SEANERGY

Introduction: **„From the big picture to the local point of view…"**

The local industries within EU do not have enough "oil and gas" today. Historically such recources have been shipped by vessels or in higher volumes by gas grids.

Offtakers have been reached ever since by pipelines, rail, inland ships or trucks (trimodality) , over decades.

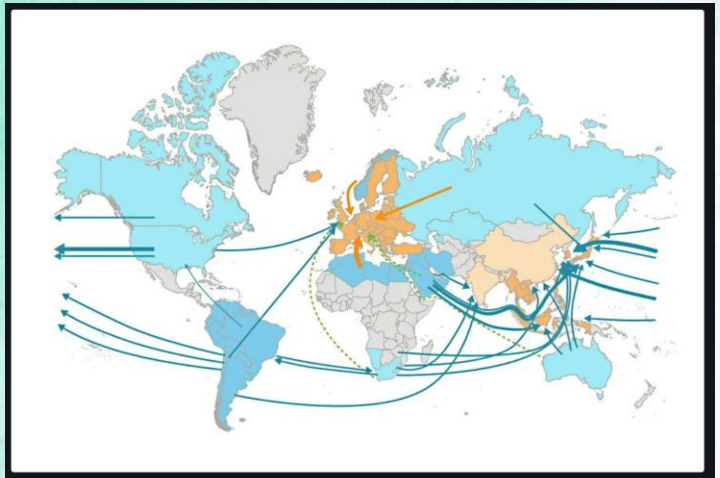
This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.1 Introduction to hydrogen as a green energy source

More than 60% of all clean hydrogen will be transported over long distances by 2050: Hydrogen Council

Pure H2 will be traded via pipeline, with derivatives such as ammonia moving by ship, says new report

Source: https://www.hydrogeninsight.com/



Map from the Hydrogen Council report showing the expected major international flows of hydrogen and derivatives by mid-century. **(Image: Hydrogen Council/McKinsey)**

"...**Europe** has set itself the **goal** of becoming the **first climate-neutral continent by 2050**."

Source: www.equinor.de

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.1 Introduction to hydrogen as a green energy source

SEANERGY

Excecutive summary:

Make industrial ports the nerve centres for scaling up the use of clean hydrogen. Today, much of the refining and chemicals production that uses hydrogen based on fossil fuels is already concentrated in coastal industrial zones around the world, ….

Encouraging these plants to shift to cleaner hydrogen production would drive down overall costs.

These large sources of hydrogen supply can also fuel ships and trucks serving the ports and power other nearby industrial facilities like steel plants.

Source: Global Hydrogen Review 2021 [The Future of Hydrogen (iea.blob.core.windows.net)]

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.1 Introduction to hydrogen as a green energy source

SEANERGY

- Benefits of hydrogen for the port and maritime sector

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.1 Introduction to hydrogen as a green energy source

- Benefits of hydrogen for the port and maritime sector

The IEA's "The Future of Hydrogen" identifies ports and coastal industrial hubs (where much of the refining and chemical production that currently uses hydrogen is concentrated) as opportune places to support the near-term scale-up of lowcarbon hydrogen production and use.
The shift from fossil-based to low-carbon hydrogen by industries in these clusters would boost hydrogen fuel demand by ships and trucks serving the ports as well as by nearby industrial facilities (e.g. steel plants), which would drive down costs.

Source: www.iea.org

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.1 Introduction to hydrogen as a green energy source

SEANERGY

- Benefits of hydrogen for the port and maritime sector

A basic infrastruture is already given thanks to the current oil& gas as well coal (fossil fuel recources). The future transition allows to use this structures as a basis but H2 itself is a "new fuel" to be handled parently in much higher volumes as energy demands increase.

No worries, this can be managed as an approach of this masterplan.

The future demand of the EU economy requires in the next decades high volumes of H2 or Amonia which shall enter the EU via ports as interface and "door to the industries".

Source: www.clean-hydrogen.europa.eu/

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.1 Introduction to hydrogen as a green energy source

SEANERGY

- Benefits of hydrogen for the port and maritime sector

Quote:

Bart Biebuyck, Executive Director of the Clean Hydrogen Partnership, **said:**
"... **With ports and industrial coastal areas expected to account for 42% of the annual hydrogen demand across the EU we need to work together for the development of a 'European Hydrogen Ports Roadmap' that can unlock the ports areas' full decarbonisation potential".**

Source: www.clean-hydrogen.europa.eu/

"**Nearly half of all European hydrogen demand will be used in port areas by 2050**: EU-backed report"

Source: www.hydrogeninsight.com/

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.1 Introduction to hydrogen as a green energy source

SEANERGY

- Benefits of hydrogen for the port and maritime sector

"**Up to 42%** (22 Mt, or 730 TWh) **of total hydrogen demand in the EU in 2050 could be located in port areas….**
Overall, by 2050, in the most ambitious market-driven demand scenarios, annual hydrogen demand across the EU is expected to increase significantly, up to about 53 Mt (or 1,764 TWh), with 42% (22 Mt, or 730 TWh) of this demand being in port areas.

Source: www.clean-hydrogen.europa.eu/

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.1 Introduction to hydrogen as a green energy source

- Current adoption and future potential

SEANERGY

Almost 90% of the global transport of goods are handled by sea- & inland ports.
Vessels to carry goods, tug boats, ferries, as well along costlines, maintenance vessels, transfer boats to rigs or windpower farms (on-shore) are in operation and use fossil based Diesel as standard fuel. This fuel and technology can be substituted by H2 processed in FC/ICE.

For long distances like crossing the Atlantic ocean etc. Methanol shall be an alternative to current fuels.

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.1 Introduction to hydrogen as a green energy source

SEANERGY

- Current adoption and future potential

Ports infrastructure (intra-logistic such as fork lifts, reach stacker, trucks…) **as well its local demands** (depending on sizes) alone are **already** an industrial zone whith **high energy demand**.

The **production sites** such as chemical production, power plants, Gensets for grid peaks, buildings all **may use H2 as a carrier** to be converted into electricity or been burned.

Ammonia cracked local as well H2 been produced on site in so called hubs or just transfered to the "hinterland" or into other countries without the capability to have any sea access gives plenty opportunities.

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.1 Introduction to hydrogen as a green energy source

SEANERGY

- Current adoption and future potential

In all scenarios, the largest hydrogen demand cluster (Belgium, Netherlands, Denmark, and North of Germany) is expected to heavily rely on green and blue hydrogen import (between 40% and 80% of total hydrogen consumption),
mainly coming from North Africa (Morocco, Egypt, Algeria), the Middle East (Oman, Saudi Arabia, Qatar) and even further (e.g., such as Australia).

Some intra-European hydrogen exports and imports can also be expected (e.g. from Spain to France).

Source: www.clean-hydrogen.europa.eu/

This both **maintains and promotes employment**, too!

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.1 Introduction to hydrogen as a green energy source

- Current adoption and future potential

SEANERGY

Example(s) - Coastline and Seaports: **(UK)**

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.1 Introduction to hydrogen as a green energy source

- Current adoption and future potential

SEANERGY

„H2H“ Saltend (UK)
Saltend is part of “Zero Carbon Humber”, **a joint project between Equinor and 11 other companies.** Together they laid out a project plan for the decarbonization of the **UK's largest and most carbon-intensive industrial region.**
in the UK.

Source: www.equinor.de/wasserstoff/h2-projekte-in-europa

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.1 Introduction to hydrogen as a green energy source

- Current adoption and future potential

The planned reforming plant with a capacity of 600MW with CO2 storage will be the world's largest planned plant of its kind for converting natural gas into low-CO2 hydrogen.
This industrial customers located in the park will be able to switch completely to hydrogen The local gas-fired power plant can also add 30% hydrogen. CO2 emissions from the Saltend Chemicals Park can thus be reduced by almost reduced by almost 900,000 tons per year and the target of net zero emissions by net-zero emissions by 2040.

An **estimated 43,000 new jobs will be created** by the switch to hydrogen across the UK.

Source: www.equinor.de/wasserstoff/h2-projekte-in-europa

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.1 Introduction to hydrogen as a green energy source

SEANERGY

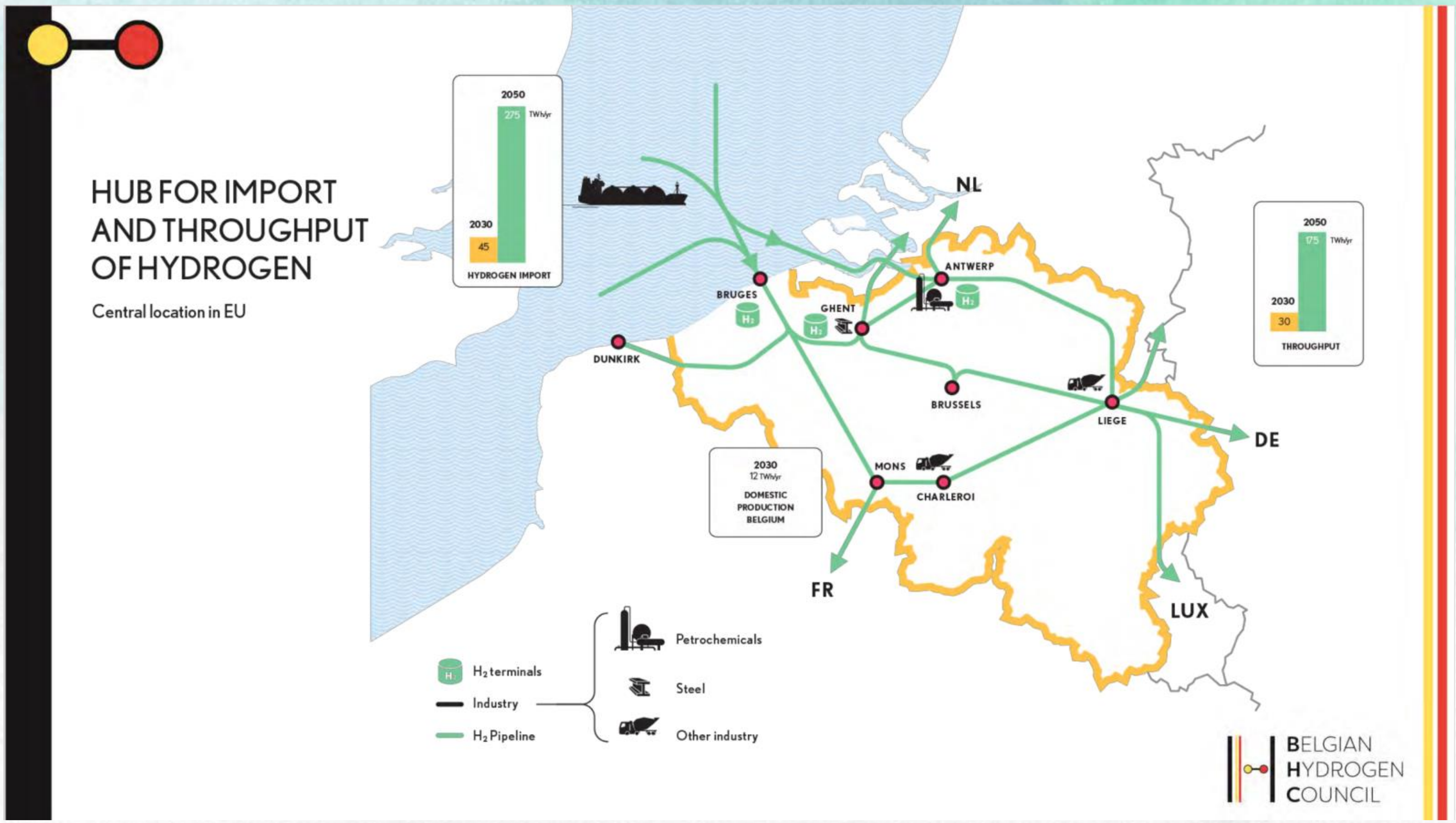
- Current adoption and future potential

Example(s) - Coastline and Seaports: **Belgium**

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.1 Introduction to hydrogen as a green energy source

- Current adoption and future potential



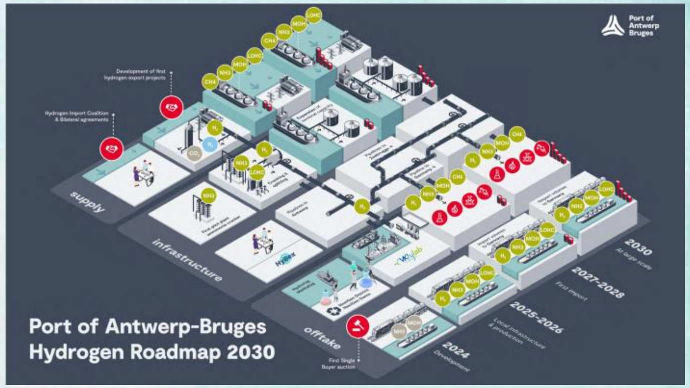
Source: Belgian Hydrogen Council Belgium as an H2 import hub for NWEurope, Antwerp 4. Juni 2024

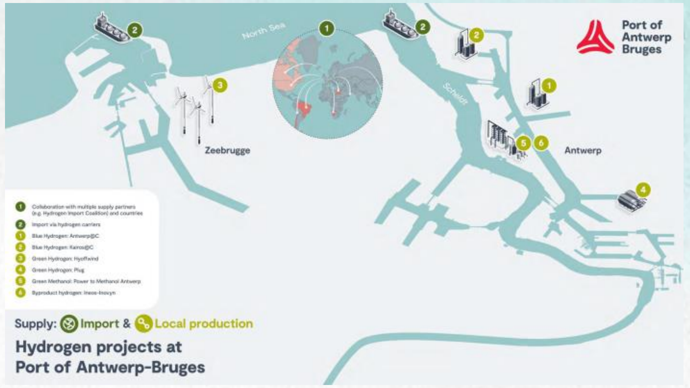
This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.1 Introduction to hydrogen as a green energy source

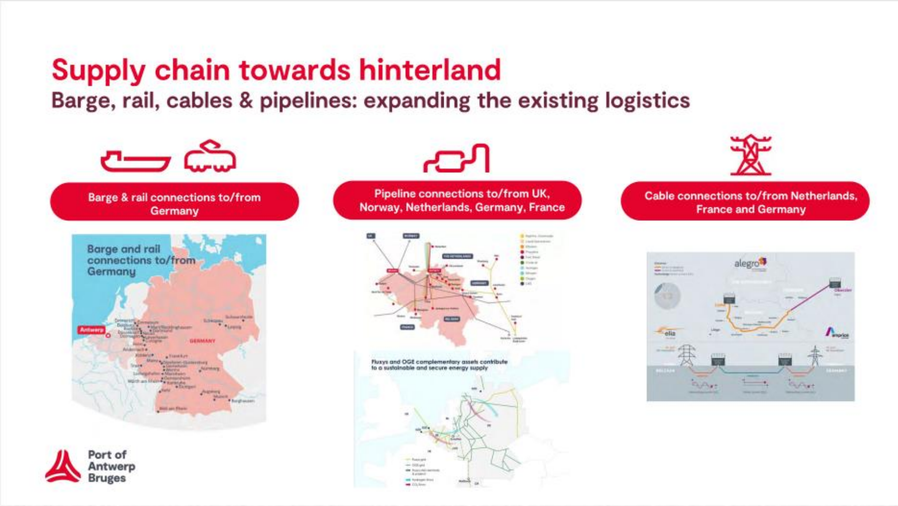
- Current adoption and future potential

SEANERGY





<u>Supply-Chain Approach:</u> from Coastline and Seaports to the hinterland



Source: Patrick Van Cauwenberghe, Port of Antwerp-Bruges 2024

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.1 Introduction to hydrogen as a green energy source

SEANERGY

- Current adoption and future potential

Example(s) - Coastline and Seaports: **Germany**

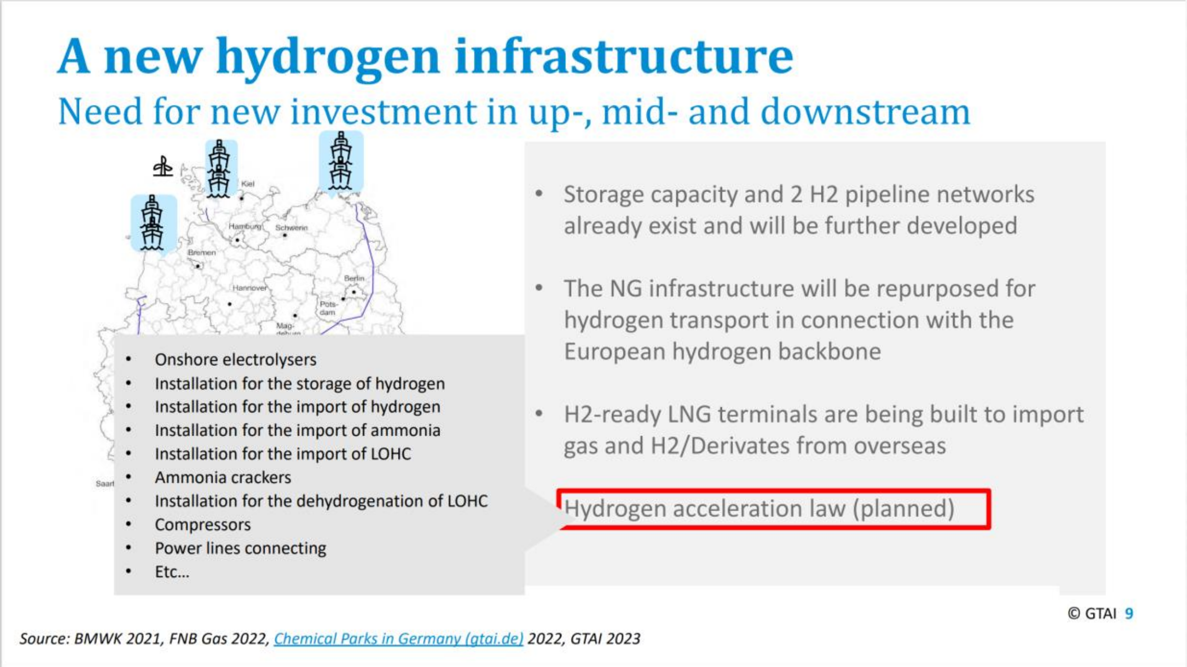
This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.1 Introduction to hydrogen as a green energy source

SEANERGY

- Current adoption and future potential

Source: THILO KRUPP, GERMAN PORTS AND THE HYDROGEN ECONOMY WITH A FOCUS ON BREMEN , May 2024



Source: An overview of the Hydrogen sector in Germany, Raphaël Goldstein, Co-Leader Hydrogen project group, Germany Trade & Invest (GTAI) 08/2024

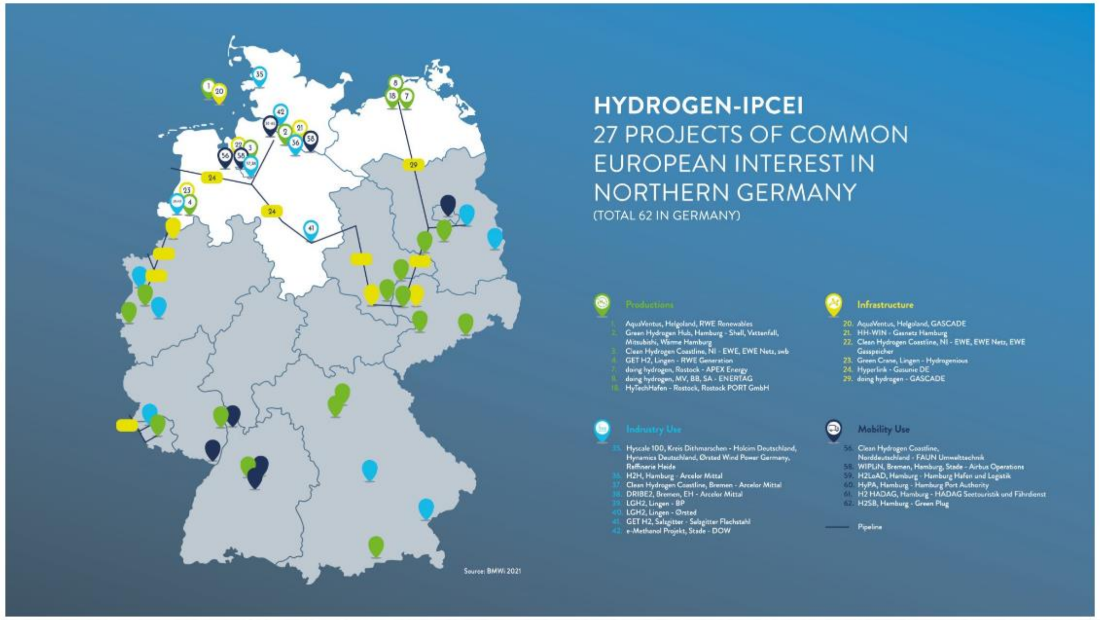
This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.1 Introduction to hydrogen as a green energy source

SEANERGY

- Current adoption and future potential

The Federal Republic of Germany will be investing 9 billion euros in the development of a hydrogen economy in the coming years.



HY-5
The Green Hydrogen Initiative of Northern Germany

Source: www.hy-5.org/en/

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.1 Introduction to hydrogen as a green energy source

SEANERGY

- Current adoption and future potential

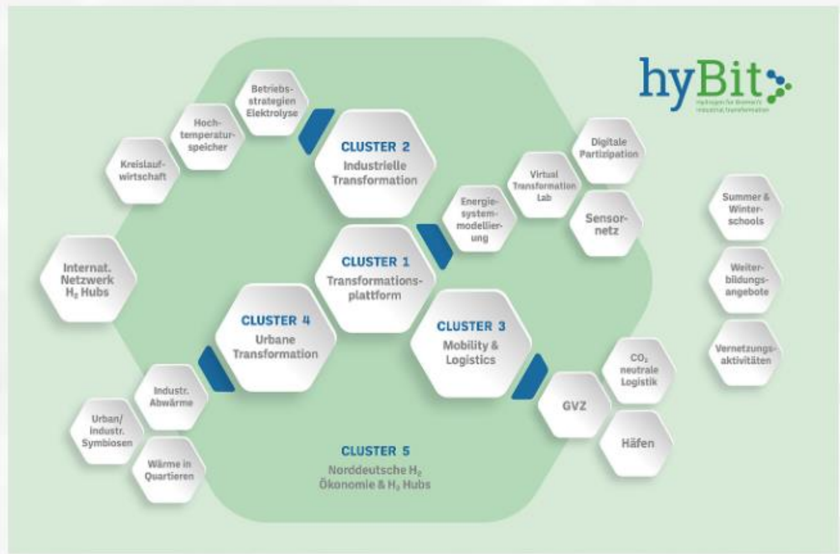
hyBit

The hyBit project started in September 2022 and is divided into five research clusters.

hyBit generates basic knowledge for the development of the hydrogen economy in the north of Germany.

The work will culminate in the creation of a virtual transformation platform - a digital twin of the site.

Structure



Source: hybit.org/en/

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.1 Introduction to hydrogen as a green energy source

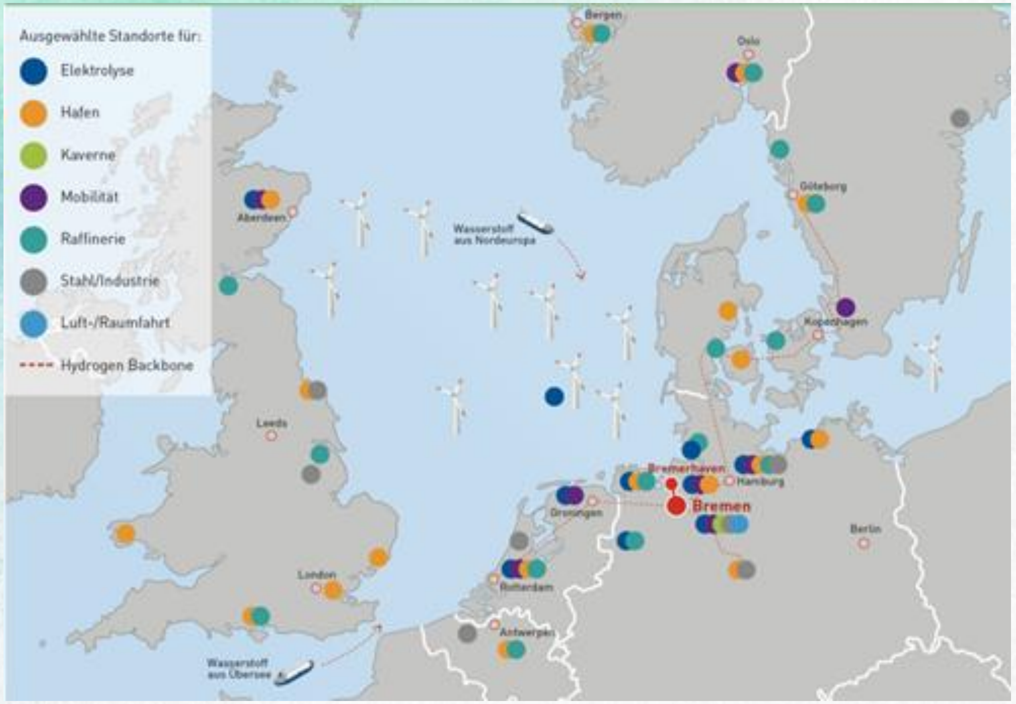
SEANERGY

- Current adoption and future potential

hyBit

In the future, the Bremen steelworks will be supplied with green hydrogen by means of electrolysis.
The focus is on the transformation of large-scale industrial infrastructures via so-called hydrogen hubs in Bremen and northern Germany.

The Region



Source: hybit.org/en/

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

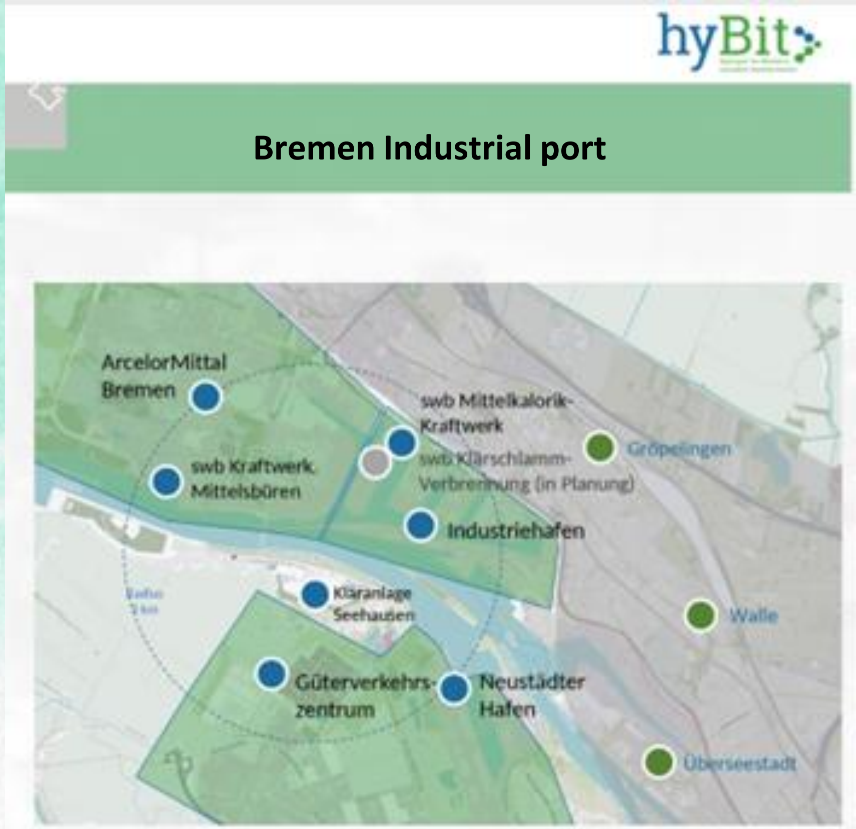
2.1 Introduction to hydrogen as a green energy source

- Current adoption and future potential

hyBit

The focus is on the transformation of large-scale industrial infrastructures via so-called hydrogen hubs in Bremen and northern Germany.

The Hydrogen Hub



Source: hybit.org/en/

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.1 Introduction to hydrogen as a green energy source

SEANERGY

- Current adoption and future potential

Example(s) – **Hinterland**:

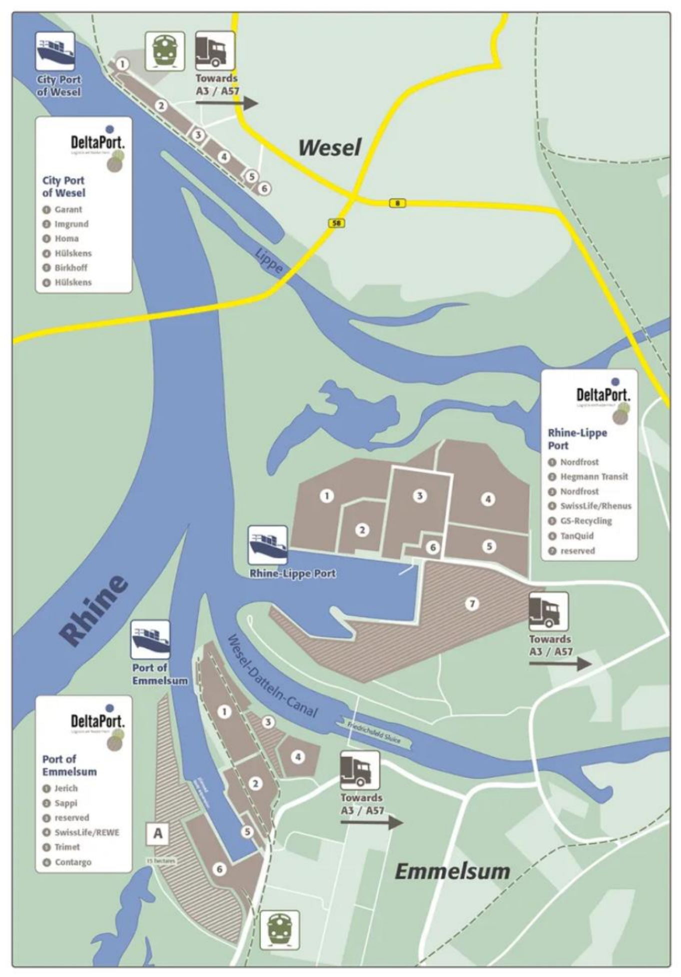
This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.1 Introduction to hydrogen as a green energy source

- Current adoption and future potential

Deltaport - (Wesel) "Ecoport813 project"

Geographic „point of view“



Source: www.deltaport.de/en/

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.1 Introduction to hydrogen as a green energy source

- Current adoption and future potential

<u>Deltaport - (Wesel)</u>

The **three port areas** of DeltaPort feature outstanding infrastructural links to domestic and European metropolitan areas.
There are 16 million consumers within a radius of 100 kilometers.
City Port of Wesel and port of Emmelsum have rail access as well close access to the hinterland via Autobahn. Historical Emmelsum port was mainly used for fossil fuel trade for the near power plant.

Connections to the Federal Motorway (Autobahn) are in the immediate vicinity. The Ruhr Area, the Emsland and the Münsterland as so called hinterland. *Source: www.deltaport.de/en/*

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.1 Introduction to hydrogen as a green energy source

- Current adoption and future potential

Deltaport - (Wesel) "Ecoport813 project"

Interview on the topic of EcoPort813
"Business cases along the hydrogen supply chain.

"…The **DeltaPort** Niederrhein **ports are expected to lose over 4 million transshipment tons of coal and mineral oil-based materials as a result of the transformation towards decarbonization of the economy.** A replacement must be found for this. **That is why we are also participating in** Europe-wide funding **projects to convert ports to Co2-free energy sources....**"

Andreas Stolte
Managing Director DeltPort.

Source: ecoport813.de

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.2 Hydrogen supply chain overview

SEANERGY

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.2 Hydrogen supply chain overview

SEANERGY

- Hydrogen production methods (e.g., electrolysis, steam methane reforming)

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

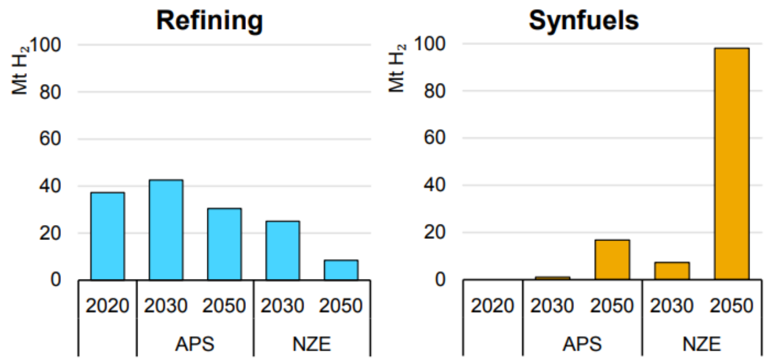
2.2 Hydrogen supply chain overview

- Hydrogen production methods (e.g., electrolysis, steam methane reforming)

SEANERGY

Hydrogen demand in refining declines as climate ambitions increase, but synfuels offer new opportunities

Hydrogen demand in refining and synthetic fuels production in the Announced Pledges and Net zero Emissions scenarios, 2020-2050



Notes: APS = Announced Pledges Scenario. NZE = Net zero Emissions Scenario.

Oil refining was the single largest consumer of hydrogen in 2020 (close to 40 Mt H_2). Refineries use hydrogen to remove impurities (especially sulphur) and to upgrade heavy oil fractions into lighter products. China is the largest consumer of hydrogen for refining (close to 9 Mt H_2/yr), followed by the United States (more than 7 Mt H_2/yr) and the Middle East (close to 4 Mt H_2/yr). Together, these three regions account for more than half of global demand.

Source: Global Hydrogen Review 2021

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.2 Hydrogen supply chain overview

- Hydrogen production methods (e.g., electrolysis, steam methane reforming)

SEANERGY

Technologies for hydrogen (H2) production fall into four main categories:

1. Thermal Processes: Thermal processes use the energy in various feedstocks (natural gas, coal, biomass, etc.) to release the H2 that is part of their molecular structure. The main hydrogen production technologies using fossil fuels are all thermal processes, and include reforming, gasification, and pyrolysis. Table 1 summarizes fossil fuel-based hydrogen production technologies.

2. Biological & Thermochemical Processes: Thermochemical processes use heat in combination with a closed chemical cycle to produce H2, while biological processes use microbes or fungi in fermentive reactions to produce gases from which hydrogen can be derived.

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.2 Hydrogen supply chain overview

- Hydrogen production methods (e.g., electrolysis, steam methane reforming)

SEANERGY

Technologies for hydrogen (H2) production fall into four main categories:

3. Electrolytic Processes: These processes use electricity to split water into its two chemical constituents, oxygen (O2) and H2, using an electrolyzer. The cost and efficiency of producing H2 via electrolytic processes is directly dependent on the cost and efficiency of the electricity used in the process.

4. Photolytic Processes: These processes use light energy to split water into H2 and O2. These processes are currently in the early stages of development and currently are not viable for large scale production.

Source: *netl.doe.gov/research/carbon-management/*

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.2 Hydrogen supply chain overview

- Hydrogen production methods (e.g., electrolysis, steam methane reforming)

SEANERGY

Table 1: Fossil fuel-based hydrogen production technologies[1]

Technology		Feedstock	Operating Conditions	Maturity
Reforming Technologies	Steam Reforming	Light hydrocarbons (less frequently from liquefied petroleum gas and naphtha)	900-1000 °C	Commercial
	Partial Oxidation	Hydrocarbons, heavy fuel oil, and coal	Temperature of > 1000 °C	Commercial
	Autothermal Reforming	Light hydrocarbons (less frequently from liquified petroleum gas and naphtha)	Temperature of > 1000 °C	Early Commercial
Pyrolysis		Hydrocarbons	500-800 °C in the absence of oxygen	Commercial
Gasification		Coal	700-1200 °C	Commercial

Table 2: NETL Fossil Fuel-based Hydrogen Plant Cases

Case	Plant Type	Feedstock	Technology Type	CO_2 Capture (%)	Hydrogen Production Capacity	Levelized Cost of Hydrogen
1	Reforming	Natural Gas	Steam Methane Reforming	0	483,000 kg/day	$1.06/kg
2				96.2		$1.54/kg
3			Autothermal Reforming	94.5	660,000 kg/day	$1.51/kg
4	Gasification	Illinois No. 6 Coal	Shell/Air Products-type oxygen-blown, entrained flow gasification	0		$2.58/kg
5				92.5		$2.92/kg
6		Illinois No. 6 Coal/ Torrefied Woody Biomass		92.6	133,000 kg/day	$3.44/kg

Source: netl.doe.gov/research/carbon-management/

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.2 Hydrogen supply chain overview

- Hydrogen production methods (e.g., electrolysis, steam methane reforming)

SEANERGY

Table 3 Non fossil-fuel based hydrogen production technologies[1]

Technology		Advantages	Drawbacks	Energy Efficiency (%)	H_2 yield ($g/kg_{feedstock}$)	Cost ($/kg of H_2
Water	electrolysis	▸ simplicity ▸ low temperatures ▸ zero carbon emissions ▸ O_2 as a byproduct ▸ integration with fuel cells	▸ high pressure is required ▸ energy storage problems ▸ low system efficiencies ▸ high capital costs	55–80	111[a]	4.15–10.30
	thermolysis	▸ clean and sustainable ▸ zero carbon emissions ▸ O_2 as a byproduct	▸ separation step is required to avoid the recombination in an explosive mixture ▸ high capital costs	20–50	111[a]	7.98–8.40
	photoelectrolysis	▸ contributes to the sustainability of the energy supply ▸ photonic and electrical energies can be converted to chemical energy ▸ low operating temperature and pressure	▸ low efficiency ▸ requires a significant surface ▸ photocatalytic material is required	0.06–14	111[a]	4.98–10.36
	biophotolysis	▸ can produce hydrogen at ambient conditions ▸ consumes CO_2	▸ requires a significant surface area to collect enough sunlight ▸ difficult operations to control the different bacteria ▸ large reactor volume	10–15	111[a]	1.42-2.13

Source: netl.doe.gov/research/carbon-management/

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.2 Hydrogen supply chain overview

- Hydrogen production methods (e.g., electrolysis, steam methane reforming)

SEANERGY

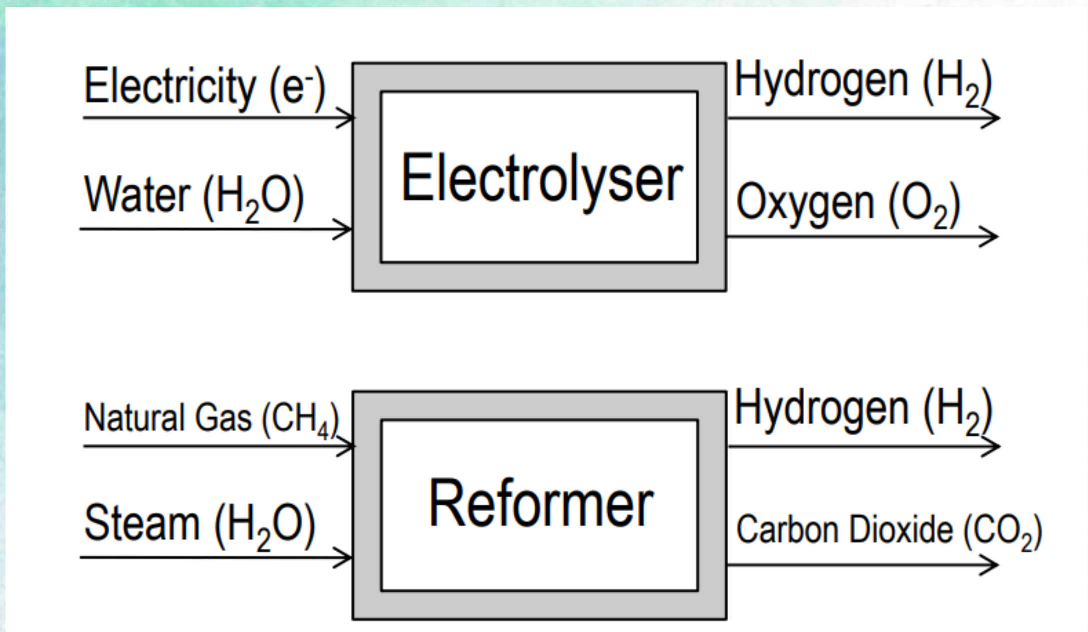
Basic Information:

Hydrogen can be produced -in large scale- by

- water electrolysis using electricity

- **steam reforming of natural gas**

(both technologies are most often used in industrial applications)



Source: HyFacts Project 2012/13

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.2 Hydrogen supply chain overview

- Hydrogen production methods (e.g., electrolysis, steam methane reforming)

SEANERGY

Water electrolysis (**dating to the late 1920s**) and **reforming technologies (introduced in 1960).**

Electrolysis [per ISO/TR 15916:2015(E)] in its simplest terms is a process in which an electric current is used to cause a chemical reaction.

Hydrogen gas produced by electrolysis technology can be used immediately or stored for later use.

The process takes place in a device with a commonly used name –
Electrolyzer (according to ISO 22734:2019 – A Hydrogen Generator Using Electrolysis of Water); which converts electrical energy into chemical energy and can also be seen as a device with the reverse operation of a fuel cell.

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.2 Hydrogen supply chain overview

- Hydrogen production methods (e.g., electrolysis, steam methane reforming)

SEANERGY

The electricity required to operate the electrolyzer can come from a variety of sources and, depending on the source of electricity, the total hydrogen production may involve CO_2 emissions or be completely CO_2 free.

If the electricity is generated from renewable sources (wind, hydro, solar, or tidal energy), then no CO_2 will be emitted;

if it is generated from fossil fuels, we are talking about associated CO_2 emissions.

Source: HyFacts Project 2012/13

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.2 Hydrogen supply chain overview

- Hydrogen production methods (e.g., electrolysis, steam methane reforming)

Electrolysers:

- producing hydrogen and oxygen from water and (green) electricity
- **scalable size (0,1 to 20.000 m3 /h)**
- **can be easily regulated from 0 to 100 %**
- **relatively short start up time (minutes)**
- **produce very pure hydrogen at elevated pressures (1 to 30 bar)**

Reformers:

- **producing hydrogen from natural gas, steam and heat.**
- **capacity** ranges from a few hundred to **more than 100 000 Nm3 /h**
- **operated 24/7 at constant load - relatively long start up time (days)**
- emit CO2
- produced **hydrogen is not very clean** and **at atmospheric pressure**

Source: HyFacts Project 2012/13

SEANERGY

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.2 Hydrogen supply chain overview

- Hydrogen production methods (e.g., electrolysis, steam methane reforming)

SEANERGY

Popular water electrolysis technologies and examples of electrolyzer types

Alkaline electrolysis is a mature hydrogen production technology. Uses **the same principle as PEM electrolysis**.
Electrolyzer has **two electrodes immersed in a liquid alkaline electrolyte**.
Most commonly concentration level 25% at 80°C to 40% at 160°C.

The electrodes (cathode and anode) are separated by a diaphragm **(membrane)**.
The diaphragm has two functions:
1. separates the gaseous products (i.e., hydrogen and oxygen),
2. allows hydroxide ions (OH-) and water molecules to pass through.

The membrane allows the ions, but not the hydrogen, to pass through.

A typical alkaline electrolyzer consists of:
-power control, associated instrumentation system;
-electrolysis system includes:
water purification node, hydrogen purification node, gas dryer, and a separator.
- Compressor

Source: HyFacts Project 2012/13

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.2 Hydrogen supply chain overview

- Hydrogen production methods (e.g., electrolysis, steam methane reforming)

SEANERGY

Safety
The main risk arises from the possibility of an explosive atmosphere forming in the system in the form of a mixture of hydrogen and oxygen,
which can lead to an internal explosion in the electrolyzer.

For this reason, sensors are implemented in the unit to monitor operating parameters to detect electrolyzer failure.
These include:
-measurement of hydrogen concentration in the oxygen line;
-Voltage and current measurement;
-temperature measurement at the input and output of the electrolyzer;
-measurement of electrolyte ion concentration.

Hazardous situations	Prevention or mitigation measures
Loss of segregation within system of H_2 and O_2 produced – process pressure is an aggravating factor as this increases amount of reactants in the system and burst pressure of equipment	Process reliability and detection of O_2 in H_2
Formation of flammable mixture in container due to a H_2 leak	Permanent ventilation and H_2 detection
Fire due to failure/overheating of high current electrical components	Electrical safety, fire detection
In case of liquid electrolyte: short circuit from electrolyte leaks	Quality of assembly, periodic inspection
In case of liquid electrolyte: corrosive electrolyte leaks	Quality of assembly, periodic inspection

Source: HyFacts Project 2012/13

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.2 Hydrogen supply chain overview

- Hydrogen production methods (e.g., electrolysis, steam methane reforming)

SEANERGY

Popular water electrolysis technologies and examples of electrolyzer types

PEM electrolyzers Electrolysis takes place in two chambers, which are separated by a proton exchange membrane (PEM). In these, **when direct current is applied, the water dissociates into hydrogen (H2) at the negative electrode and oxygen (O2)** at the positive electrode.

The electrodes and membrane usually **form a membrane electrode assembly** (MEA-Membrane Electrode Assembly) and an arrangement **similar to a fuel cell (FC) stack**.

PEM electrolyzers operate at low temperatures, and the PEM membrane serves as the electrolyte.

The devices consist of the following components:
•a process cabin containing all process components such as valves, piping, pressure vessels, pumps, etc,
•an electrical cabin containing all electrical components such as instrumentation, controls, wiring, power conditioning, etc,
•a cooling system dedicated to removing heat from the electrolysis process,
•a weatherproof enclosure.

Source: HyFacts Project 2012/13

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.2 Hydrogen supply chain overview

- Hydrogen production methods (e.g., electrolysis, steam methane reforming)

SEANERGY

Safety

The **main risk associated with PEM electrolysis** systems from **the potential for an explosive atmosphere to form in the system in the form of a hydrogen/oxygen mixture**, which can lead to an internal explosion in the process chamber of the equipment or the separator (the separator is used to separate gaseous H2 and O2 from traces of water).

To avoid hydrogen accumulation in the process chamber, the following measures are taken:

- control of pressure and the pressure difference between hydrogen and oxygen lines;
- controlling the hydrogen concentration in the chamber;
- reducing the amount of hydrogen in the gas layer of the separator as much as possible, so that in the event of a catastrophic leak, an explosive atmosphere in the form of a hydrogen-air mixture does not form in the vessel.

Source: HyFacts Project 2012/13

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.2 Hydrogen supply chain overview

- Hydrogen production methods (e.g., electrolysis, steam methane reforming)

SEANERGY

Electrolysis and wind power in a nutshell

Among the **most important criteria in designing a plant** where electrolytic hydrogen is produced **from wind energy are meteorological conditions**,

When designing a power plant, the following parameters are identified as the most important:
capacity, locations, and wind converter technologies.
In many cases, the ability to adjust the rotor blades is required, especially in large power plants, to improve start-up characteristics and limit output at high wind speeds.

Electrolysis and photovoltaic solar power plants in a nutshell

Solar generators can generally be divided into stationary, uniaxial, and biaxial "solar tracking" power plants.
The **integration of a photovoltaic solar power plant and electrolyzers** into a hydrogen generation system consists primarily of matching components in such a way that the photovoltaically generated electricity can be transferred to the electrolyzer **with the highest possible efficiency**.
For this reason, care must be taken at the design stage to ensure that the entire system follows the solar radiation dynamically avoiding any kind of loss.
Electrolyzers are almost ideal consumers of photovoltaic energy, due to the described characteristics and the possible modular design of both system components.

Source: seshydrogen.com/en/h2-safety-2-electrolyzer/

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.2 Hydrogen supply chain overview

- Hydrogen production methods (e.g., electrolysis, steam methane reforming)

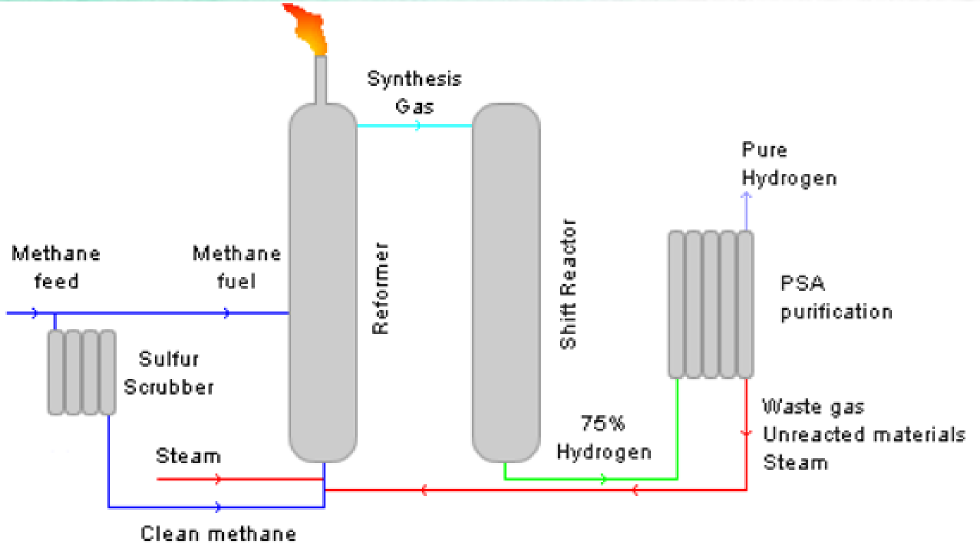
SEANERGY

Steam Reforming of Natural Gas

Large quantities of hydrogen gas are required in the petrochemical -and Steel- industry.
This hydrogen is used to change the chemical structure of crude oil.

Crude oil is a mixture of many different molecules.

About **one-quarter of the incoming natural gas is burned to provide the necessary energy for the reaction**, while the rest is stripped of its sulfur content. **High pressure steam is added, which reacts with the methane** over a nickel-alumina catalyst.
The synthesis gas contains a mixture of H2, CO2, CO, as well as unreacted CH4 and H2O.
This **gas is passed into the cooler shift reactor**. **The output** of the shift reactor **is about three quarters hydrogen.**
In the presure surge adsorption unit, the **impurities are removed, and recyled back through the burner, giving more than 99.9% pure hydrogen.**



Source: www.digipac.ca/chemical/

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.2 Hydrogen supply chain overview

- Hydrogen production methods (e.g., electrolysis, steam methane reforming)

SEANERGY

Safety

Units to be considered during safety assessment:
Burner, its flame and the combustion quality, the **reforming tubes and steam production unit**.
Explosive atmosphere might be ignited by the burner increase of flame and gas temperature would damage materials of the reforming tubes. Incomplete combustion of gases leads to formation of deposits in the exchangers Main hazard for the reforming tubes is the formation of a leak on these tubes because of an early ageing of the reforming tubes.

The **main hazard** for the steam production unit **is an abnormal pressure increase**.

Source: www.digipac.ca/chemical/

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.2 Hydrogen supply chain overview

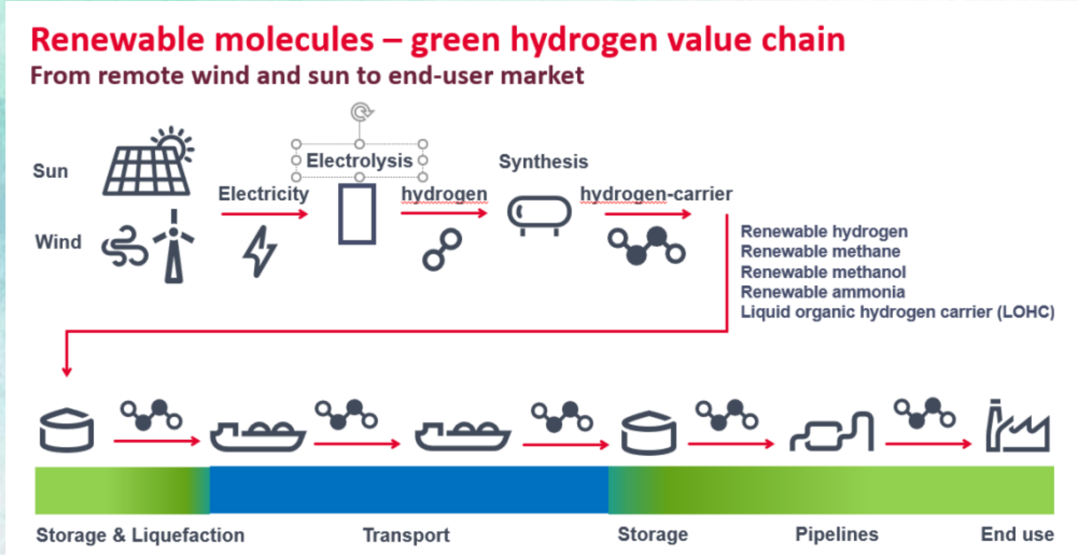
- Hydrogen production methods (e.g., electrolysis, steam methane reforming)

SEANERGY

"Ammonia and LOHC" a hype!?

Beside the present common technologies **a kind of hype** has been started about ammonia, **why?**

1. **Ammonia** is known for a long period, produced and transported in high volumes, global
2. **Main products** are is **fertilyser, chemistry** etc.
3. **Due high demand of H2 as energy carrier** and opportunity to transport ammonia cross the oceans **it comes more in a focus, globally.**



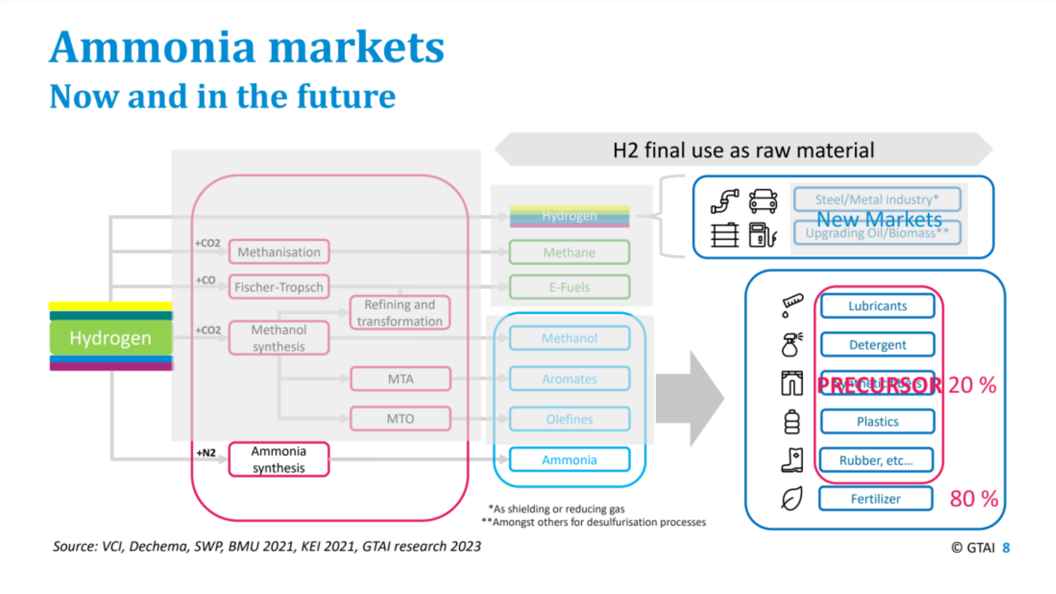
Source: Belgian Hydrogen Council Belgium as an H2 import hub for NWEurope, Antwerp 4. Juni 2024

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

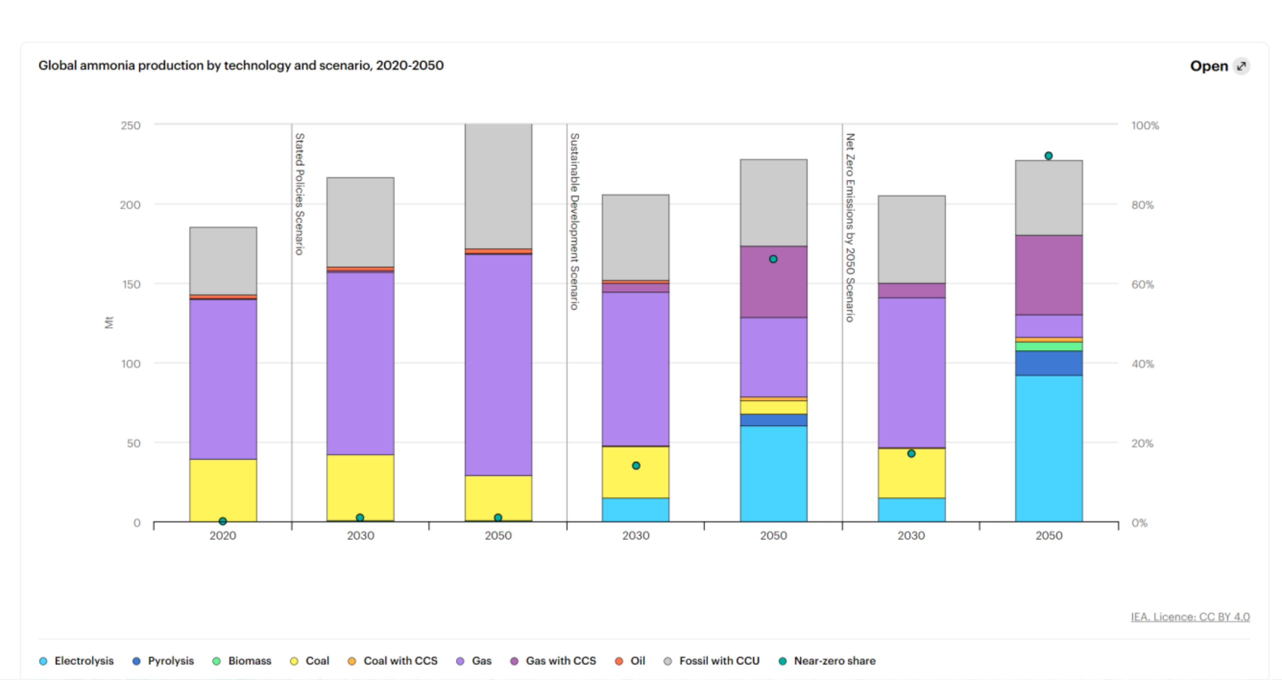
2.2 Hydrogen supply chain overview

- Hydrogen production methods (e.g., electrolysis, steam methane reforming)

  Roadmap - transformation to "green ammonia"



Source: Raphaël Goldstein, GTAI, 2024, from basic to final product
Greening the whole value chain with H2 and new processes



Source: iea.org - Ammonia Technology Roadmap

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.2 Hydrogen supply chain overview

- Hydrogen production methods (e.g., electrolysis, steam methane reforming)

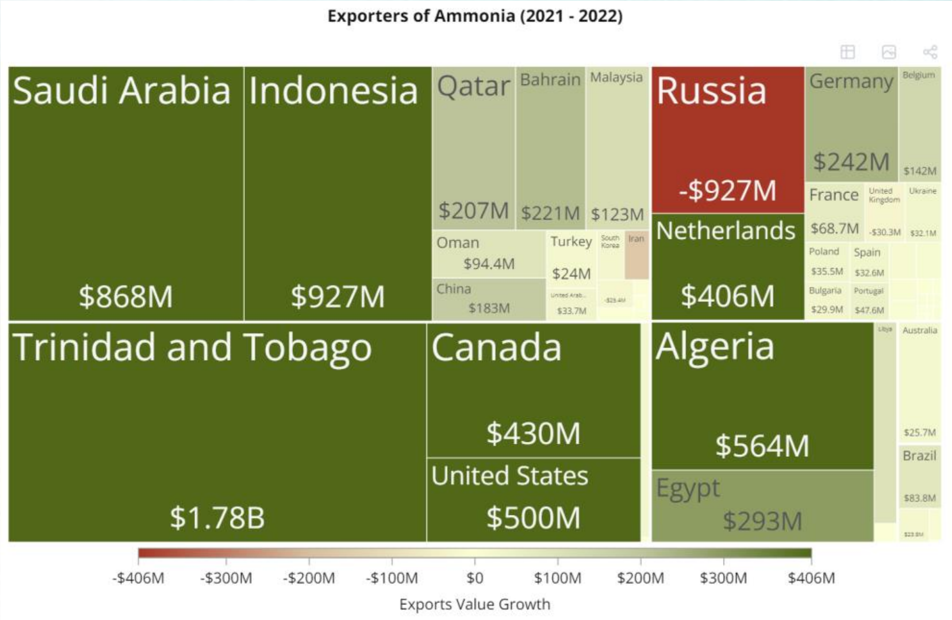
Roadmap - transformation to "green ammonia"

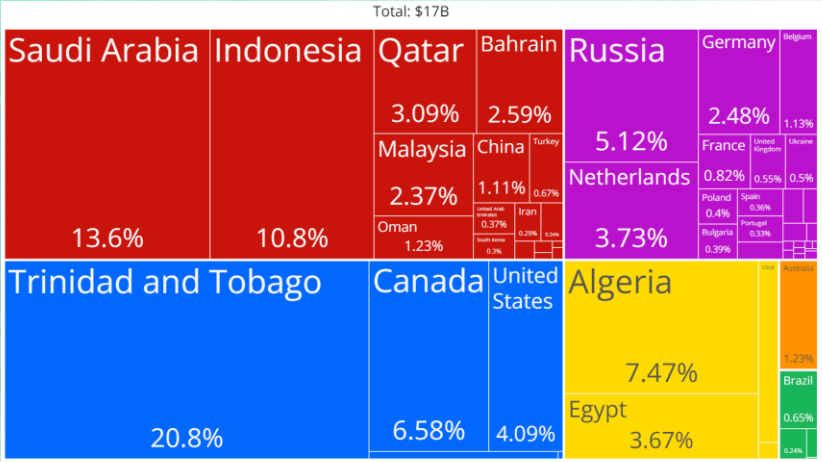
In 2022, Ammonia were the world's 250th most traded product, with a total trade of $17B.
Between 2021 and 2022 the exports of Ammonia grew by 62%

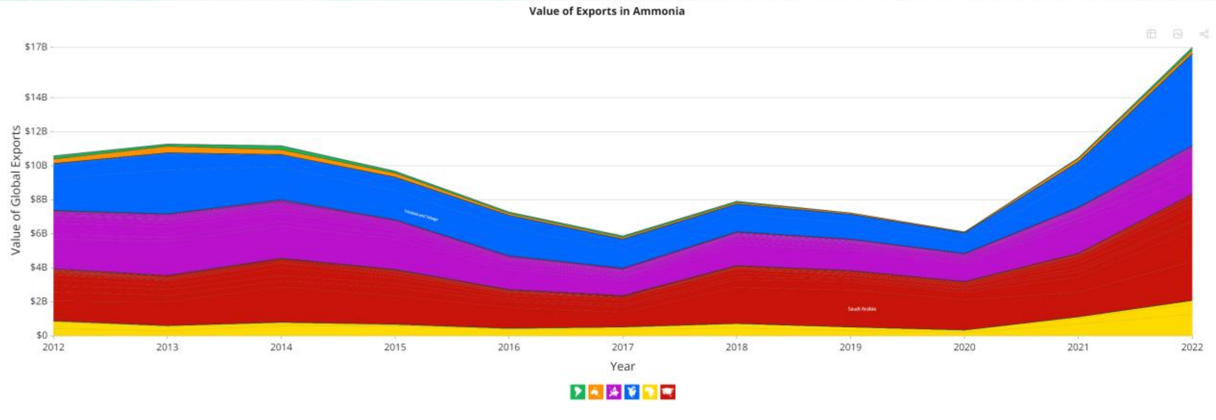
IMPORTS

In 2022 the top importers of Ammonia were United States ($2.31B), India ($2.16B), Morocco ($1.8B), South Korea ($1.14B), and Belgium ($1.06B).

Source: iea.org - Ammonia Technology Roadmap







Source: Ammonia Product Trade, oec.world

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.2 Hydrogen supply chain overview

- Hydrogen production methods (e.g., electrolysis, steam methane reforming)

Cost of Hydrogen Production

SEANERGY

The cost of H2 hydrogen production **depends heavily on the cost of fuel or electricity from which it is produced, and in the case of clean hydrogen**,

Carbon capture and storage costs must factor into the equation for non-renewable production methods.

In the Global Hydrogen Review of 2021*), the International Energy Agency surveyed recent (2020) hydrogen production costs via the major methods including natural gas reforming

(without and with carbon capture and storage [CCUS]), coal gasification (with and without CCUS), and renewables,

and compared those costs with expected future costs in net zero emissions scenarios for 2030 and 2050.

Source: *netl.doe.gov/research/carbon-management/*

*) *Link:* GlobalHydrogenReview2021.pdf

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.2 Hydrogen supply chain overview

- Hydrogen production methods (e.g., electrolysis, steam methane reforming)

SEANERGY

Cost of Hydrogen Production

Those are shown in Figure 1. Currently, hydrogen produced via all reforming and gasification methods with and without capture is less expensive

than renewable hydrogen, but with future carbon price liabilities factored in and expected future cost reductions of renewable technologies,

fossil fuel with capture and renewable technologies may be on a more even cost footing. Notably, solid fuel/coal gasification with capture may remain

a strong contender in anticipated future net-zero emissions scenarios.

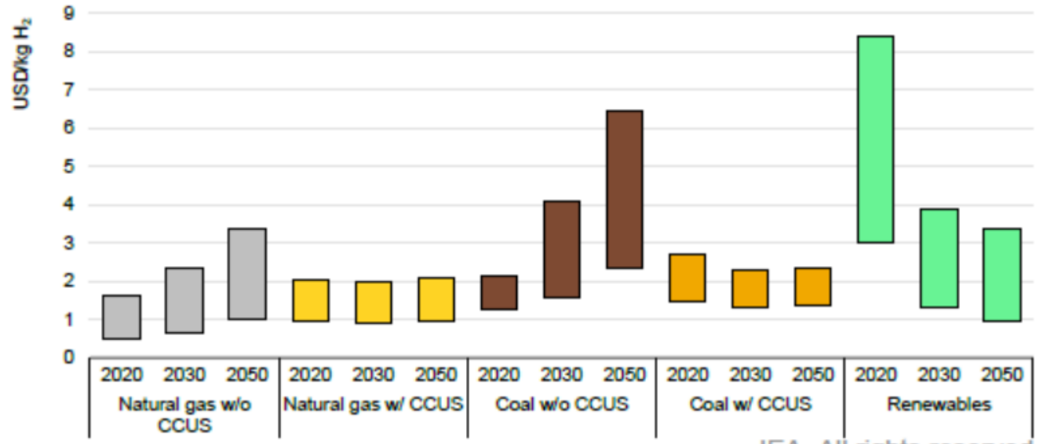


Figure 1. Levelized cost of hydrogen production by technology in 2020, and in the Net zero Emissions Scenario, 2030 and 2050[2]

Source: *netl.doe.gov/research/carbon-management*

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.2 Hydrogen supply chain overview

SEANERGY

- Storage and transportation logistics

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.2 Hydrogen supply chain overview

- Storage and transportation logistics

SEANERGY

Hydrogen storage

Hydrogen, like any fuel, must be stored, both at the small scale as on a fuel cell vehicle as well as strategically at the large scale.
Storage **technologies are** often **classified** as either physical-based storage or material-based storage.

Physical storage technologies are mature and widely used, such as compressed and liquified gases.

Commercial hydrogen vehicle refueling stations (HRS), for example, store hydrogen in two states:
high-pressure storage can exceed a pressure of 90MPa and on-site cryogenic insulated tanks where hydrogen as a liquid should be maintained at a temperature near 20 K.

The cryo-compressed concept is a combination of low temperature and high pressure to manage loss of liquid hydrogen to boil-off and a topic of technology development.

Strategic reserves of gaseous hydrogen are stored underground in salt domes at several places in the world (i.e., a proven technology).
Domal salt deposits are regional; therefore, active research projects are exploring other underground storage options,
such as bedded salts, depleted oil/gas reservoirs, aquifers, and lined hard rock caverns.

Source: Hydrogen Economy, PART III Advanced hydrogen routines and technologies doi.org/

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.2 Hydrogen supply chain overview

- Storage and transportation logistics

Hydrogen storage

…
Ammonia is perhaps **the simplest example of a hydrogen carrier** (or nonreversible material–based storage solution), but many others exist (e.g., methylcyclohexane).
Hydrogen carriers have the potential advantage of being less volatile than hydrogen; however, carriers are often fluids categorized as toxic and flammable, and thus, hazards remain.

Utilization
End uses typically involve converting hydrogen as a carrier of energy to electricity or heat.
Fuel cells are the principal example of converting hydrogen to electricity. Combustion can take forms depending on the application; for example,
hydrogen could replace natural gas in everything from gas turbines for electricity production to boilers for space heating. The deployment of hydrogen
conversion can be grouped into three broad categories: transportation, power and heating, and manufacturing.

Source: Hydrogen Economy, PART III Advanced hydrogen routines and technologies doi.org/

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.2 Hydrogen supply chain overview

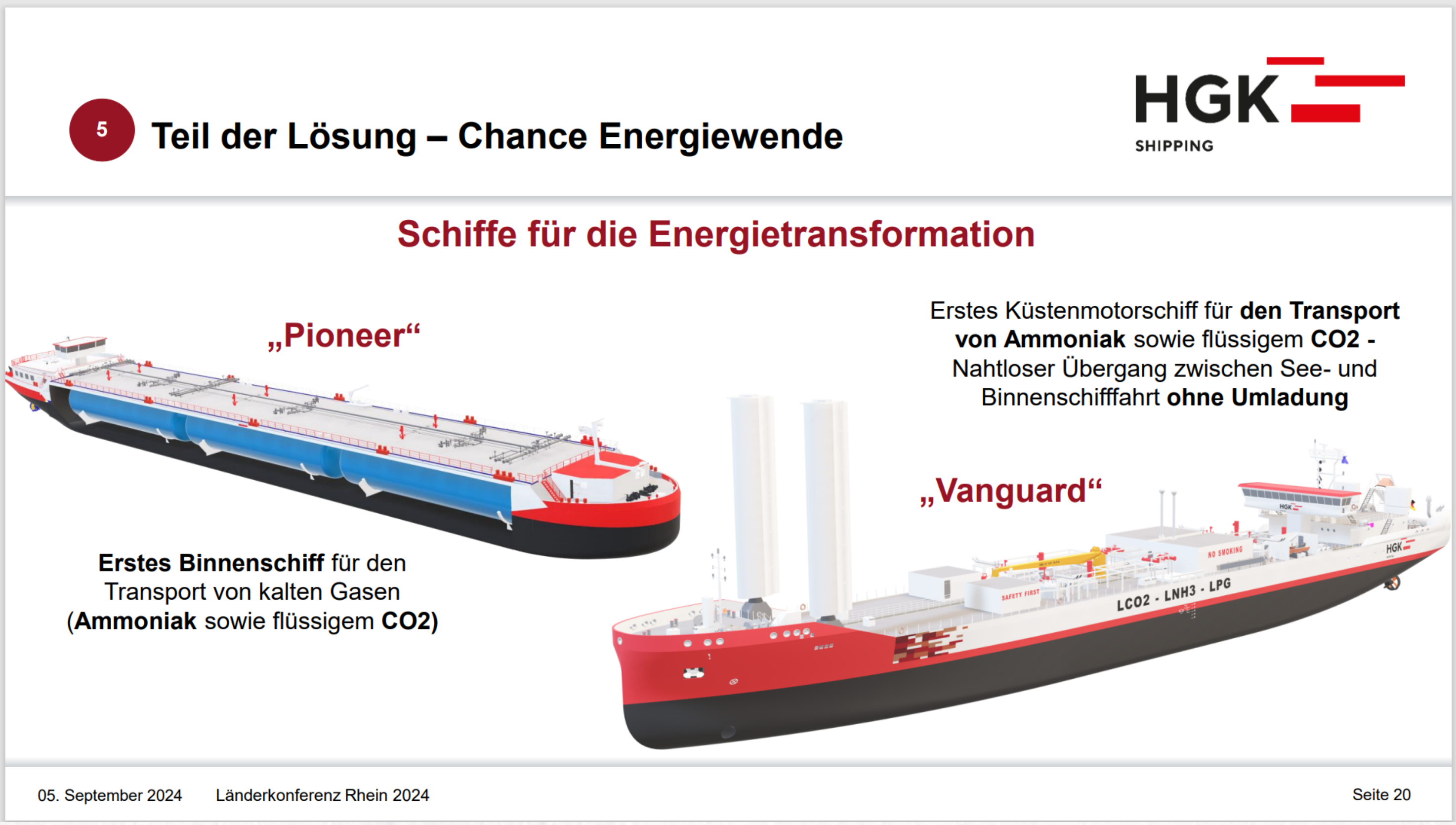
- Storage and transportation logistics

SEANERGY

Hydrogen transport opportunities (Examples)

(left) Vessel and barge transport: Coast line or from sea ports to the hinterland

(right) Amonia transport for later on-site hydrogen production (cracker technology) in the hinterland as well ltransport of liquid CO2.



Source: Federal States Rhine Conference 2024, Steffen Bauer, CEO HGK Shipping GmbH

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

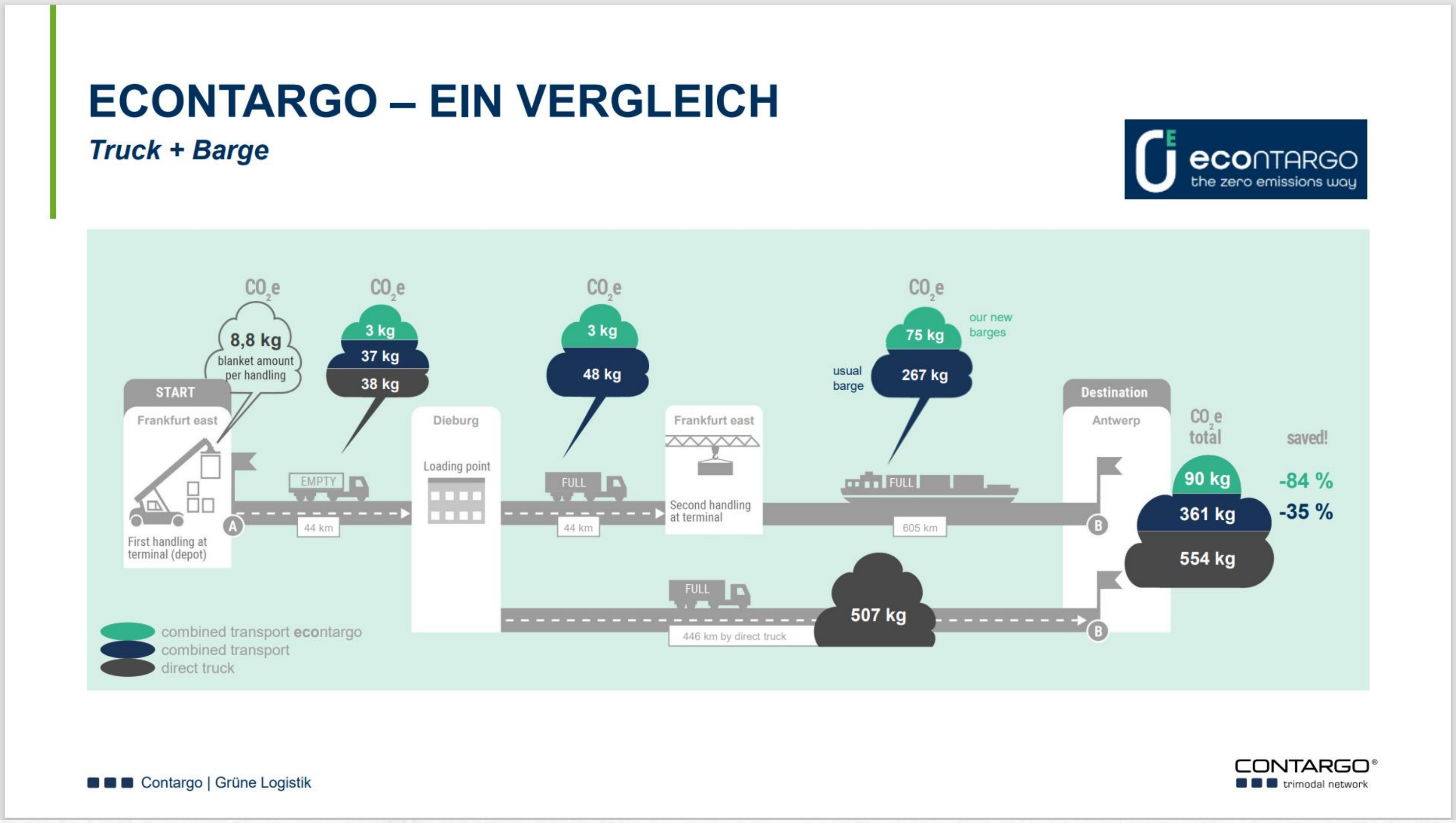
2.2 Hydrogen supply chain overview

- Storage and transportation logistics

SEANERGY

Hydrogen transport opportunities
(Examples)

comparison truck versus barge
Co2 savings



Source: Federal States Rhine Conference 2024, Jürgen Albersmann, CEO Contargo GmbH & Co. KG

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.2 Hydrogen supply chain overview

- Storage and transportation logistics

SEANERGY

Pipelines (gas-grid):

- The **supra-regional European Hydrogen Backbone** is **expected to cover** 28,000 km by 2030 and **53,000 km by 2040**
- The **pressure in a hydrogen pipeline** is **up to around 80 bar**
- **31 gas companies from 28 countries are involved** in the European Hydrogen Backbone

Source: www.hysolutions.de/

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

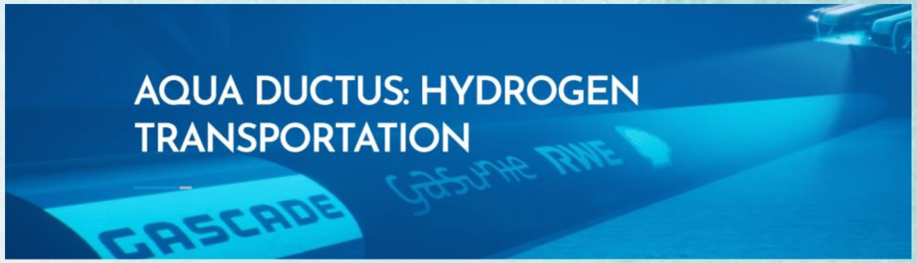
2.2 Hydrogen supply chain overview

- Storage and transportation logistics

SEANERGY

Pipelines (gas-grid):

Hydrogen transport of compressed hydrogen gas via transport in pipelines



In the future, the AquaDuctus transport pipeline will transport green hydrogen from the North Sea directly to the mainland.
As of 2035, AquaDuctus is expected to deliver up to one million tons of green hydrogen per year to the mainland

Source: www.hy-5.org/

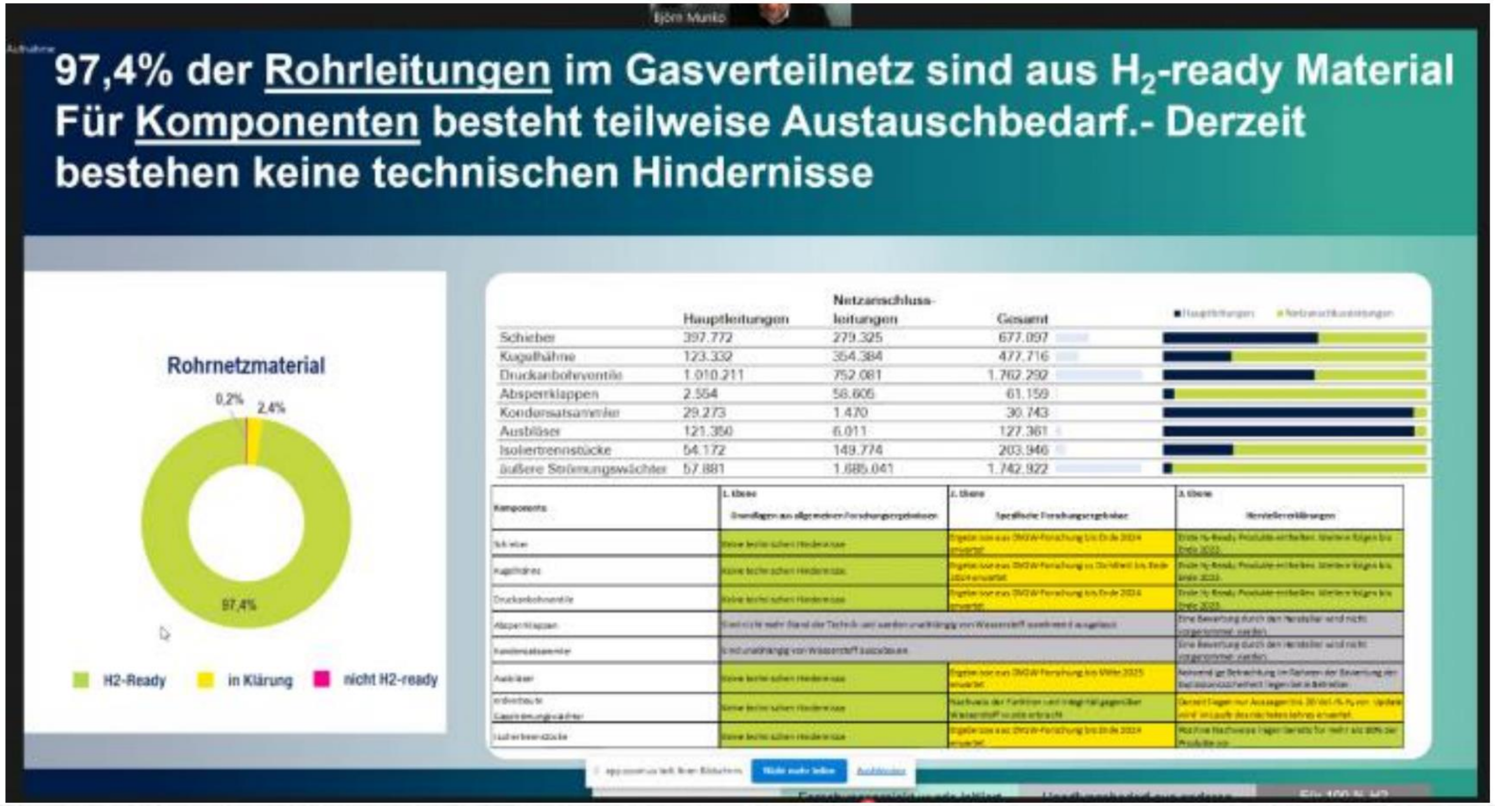
This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.2 Hydrogen supply chain overview

- Storage and transportation logistics

Pipelines (gas-grid):

„German gas grid: 90% ready with slight conversions possible 60/40% 2032 Core network 10,000km 5,000 of which rededicated“.



Source:_ "Kölnisch H2" - Wasserstoffnetzte - H2 Readiness der Gasinfrastruktur" Björn Munko DVGW e.V. 06.12.2023 Webinar

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.2 Hydrogen supply chain overview

- Storage and transportation logistics

Road Transport:

Hydrogen transport of:

- Compressed Hydrogen Gas (CHG) or
- Liquid Hydrogen gas (LH2) as well
- Liquid Organic Hydrogen Carrier (LOHC)

via transport in trailers and containers.

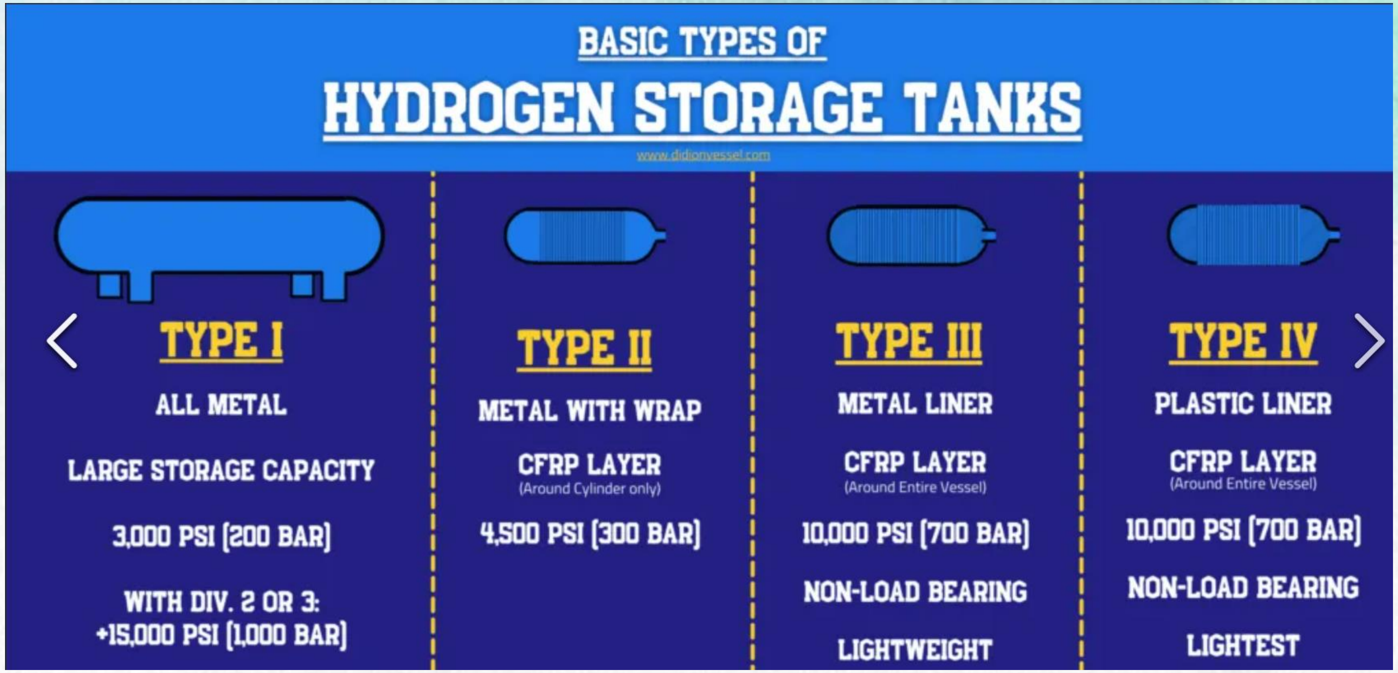
This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.2 Hydrogen supply chain overview

- Storage and transportation logistics

Road Transport (and on-site storage):

Compressed Hydrogen Gas (CHG) – tank Types defined in ISO standard (latin letters I….IV (V))



Source: www.didionvessel.com

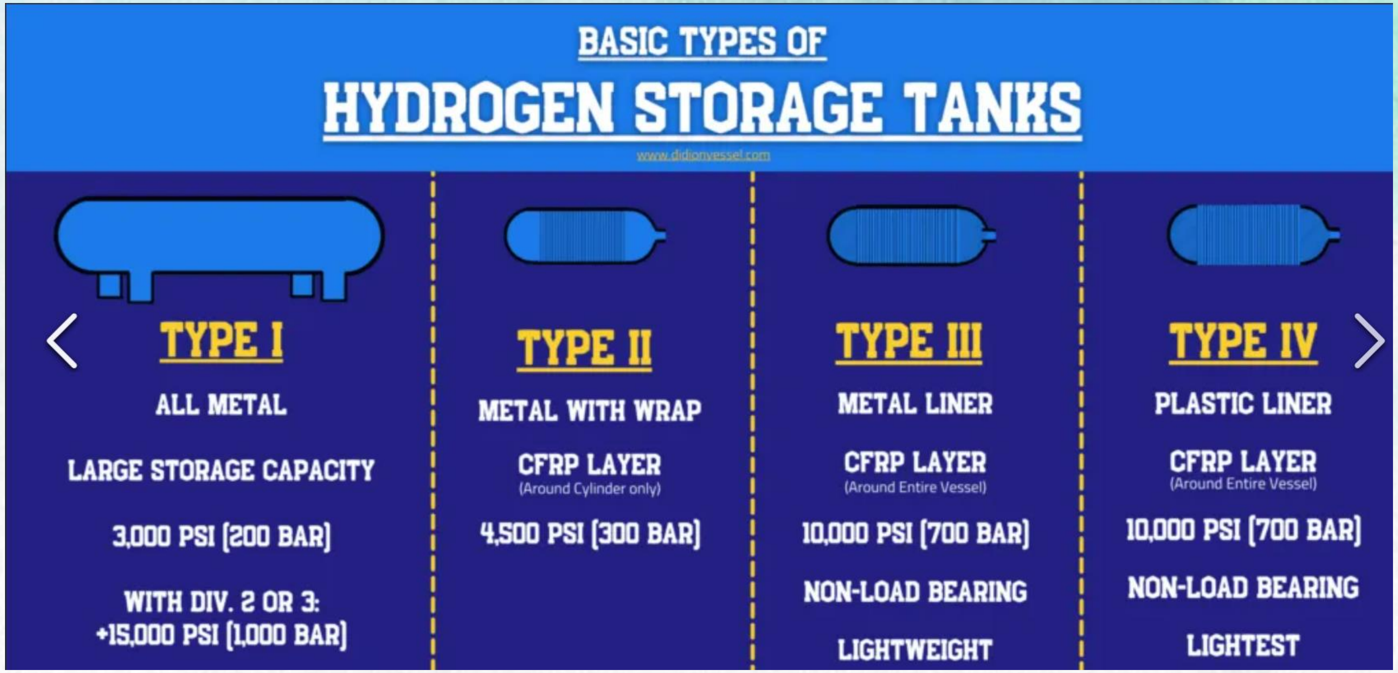
This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.2 Hydrogen supply chain overview

- Storage and transportation logistics

Road Transport (and on-site storage):

Compressed Hydrogen Gas (CHG) – tank Types defined in ISO standard (latin letters I....IV (V))



Source: www.didionvessel.com

Source: Argo-Anleg GmbH (Demo Tank System with ISO TYP) IV

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.2 Hydrogen supply chain overview

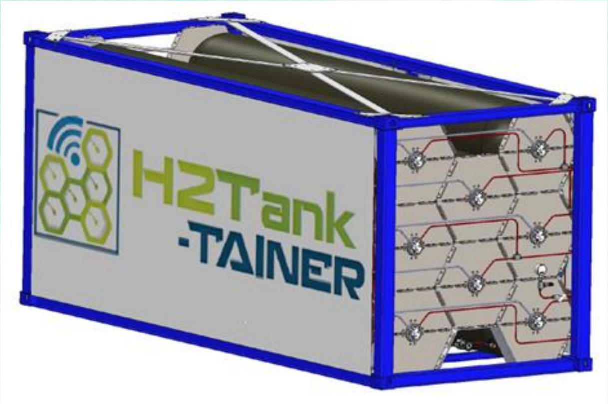
- Storage and transportation logistics

For CHG - definition split in:

Tube trailers (tubes ar fixed to the chassis, mainly steel tubes (old/currend standard).
Max. load:
200kg H2@ 200…300bar

MEGC (Multible Element Gas Container) based on ISO container footprint and heights. Steel frame to carry several cylinders. Max. load: 500kg H2@380…500bar(20ft)1.100kg@500bar (40ft)

Source: www.gefahrgut-online.de



Source: www.argo-anleg.de

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.2 Hydrogen supply chain overview

- Storage and transportation logistics

MEGCs shall comply with the design, construction and testing requirements specified in 6.7.5 ADR.
The elements of the MEGC shall be periodically tested in accordance with the provisions of 4.1.4.1 ADR packing instruction P 200 and 6.2.1.6 ADR.
source: [MEGC (weka.de)]

In both cases the cylinders are connected via piping and valves as well safety devices. For Road transport within EU ADR approval is required MEGC may be able to be transported by rail (see reference study DB). in this case the MEGC's require a RDN approval. **For transport on inland vessels other approvals are necessary.**
in summary a trimodal transport case is possible.

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.2 Hydrogen supply chain overview

- Storage and transportation logistics

SEANERGY

There are new solutions available which allow a higher safety level (higher versus current ADR) in the means of:

•cylinder concept based on automotive concept (both Boss of each **cylinder holds an OTV (On-Tank-Valve) as well TPRD (Thermal pressure relieve device.**

•**additional sensors** allow to **measure individual pressure, temperature**, as well the **angle of the MEGC and a shock sensor detecs abnormal forces.**

•**Such an MEGC** is newly **called "H2Tank-tainer"** as it **can be used as hybrid as a tank - provide gas on site a HRS or feed an FC on a ship as well act as a "container" as it transport the gas.**

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.2 Hydrogen supply chain overview

- Storage and transportation logistics

SEANERGY

LH2 - definition:

Storige and transport of liquid H2 (LH2) in bulk storage tanks or semitrailers.

FUEL TANKS - Liquefied hydrogen has a temperature of -253 °C and is one of the coldest cryogenic gases there is, which places system components and materials under extreme stresses. Once liquefied, hydrogen is reduced to 1/800th of its volume compared to that of its gas phase, facilitating a more-efficient distribution. But it needs fuel tanks four times the size of those for petrol.

Source: www.elizabethqueenseaswann.com/

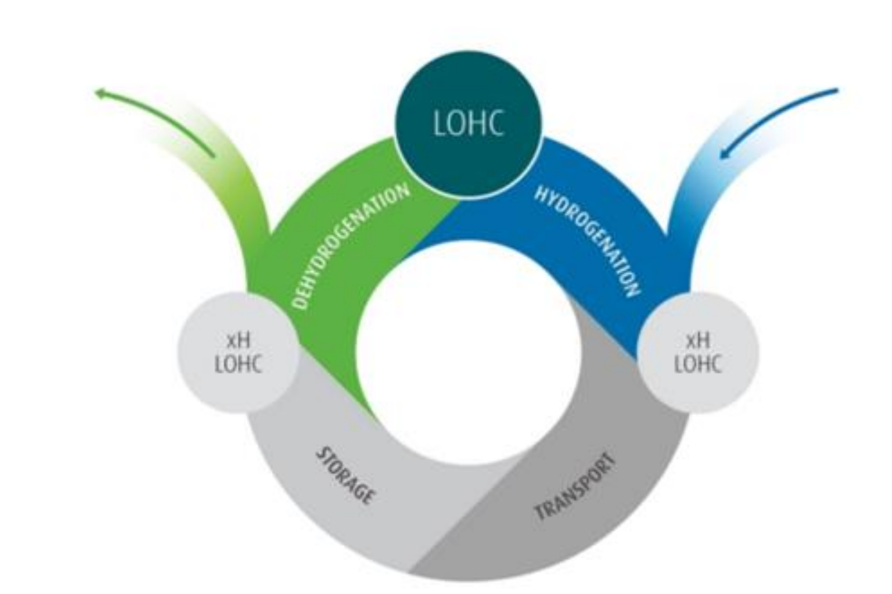
Source: chartindustries.com

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.2 Hydrogen supply chain overview

- Storage and transportation logistics

LOHC - definition:



Source: UMICORE

LOHC stands for liquid organic hydrogen carrier. These are oil-like liquids consisting of hydrocarbons such as benzyltoluene. Hydrogen can be bound to these carrier liquids and released again when required.

Hydrogen release requires a lot of energy.

The energy carrier has a low density under normal conditions. It must therefore either be compressed under high pressure, liquefied at three-digit sub-zero temperatures or chemically bound at ambient pressure in order to be put to good use. One option for storing and transporting hydrogen is LOHC technology.

Source: energieforschung.de

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.2 Hydrogen supply chain overview

- Storage and transportation logistics

LOHC:

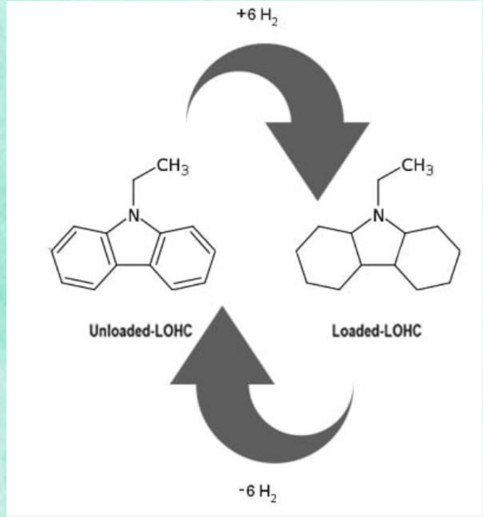
LOHC **is still in R&D** and not scaled into industry like volumes.
Thus current and proven technologies are now available and shall be considered for short term solutions.
In chapter 3.5 a marine project (LOHC use on vessel) will be presented.

Hydrogen storage takes place through a reversible reaction of hydrogen with the low-hydrogen LOHC compound.
This means that heat is released during hydrogenation, which must be dissipated from a reactor. After this reaction, the hydrogen is then reversibly bound to the hydrogen-rich LOHC compound.

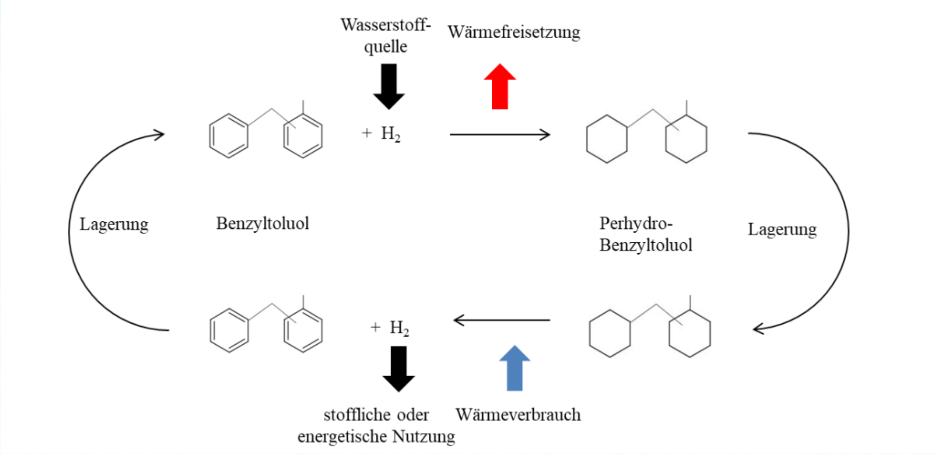
The hydrogen-rich LOHC compound is a liquid and can therefore be stored efficiently at ambient conditions and transported if necessary.

If there is a need for hydrogen again, the hydrogen can then be released from the hydrogen-rich liquid by adding heat during dehydrogenation.

Such a storage cycle of hydrogen storage is shown in the figure (right).



Source: www.advancedsciencenews.com



Source: www.fz-juelich.de/

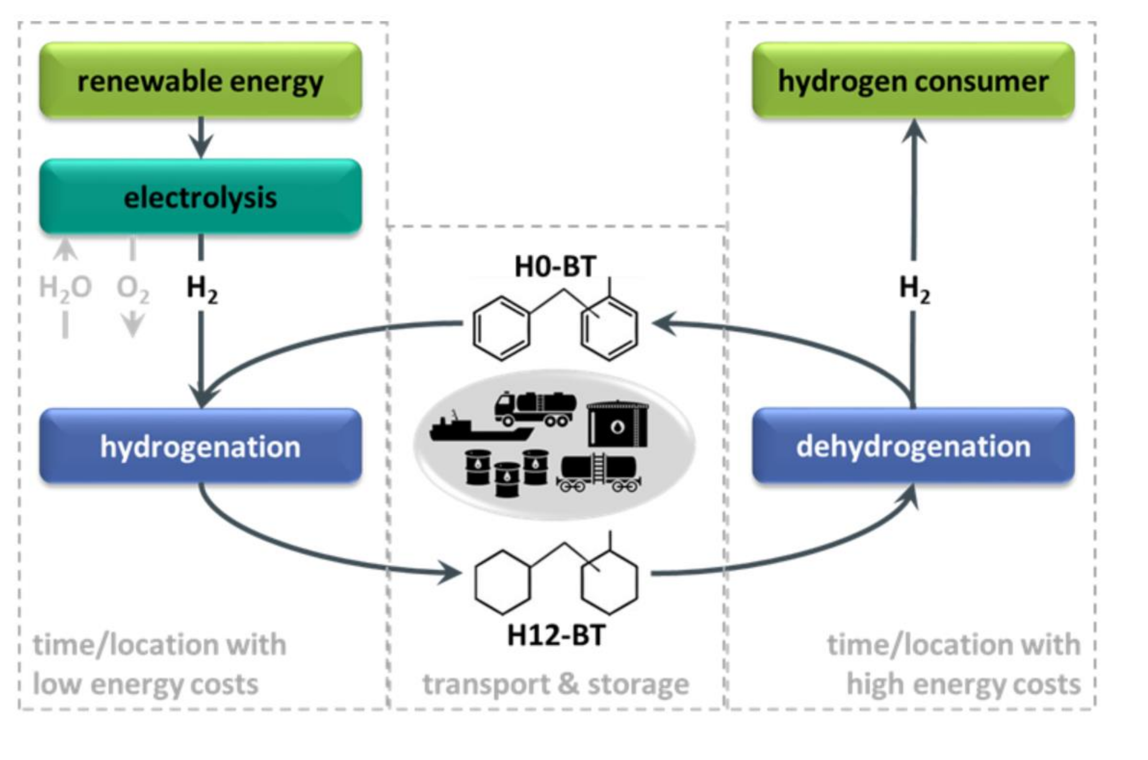
This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.2 Hydrogen supply chain overview

- Storage and transportation logistics

LOHC – process overview:

(How does LOHC – Technology work?)



Circular use of liquid organic hydrogen carriers (LOHCs) for storage and global transportation of hydrogen; ©Moritz Wolf

Source: https://www.ikft.kit.edu/

Source: lohc Youtube video (german language)

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.2 Hydrogen supply chain overview

SEANERGY

- Integration with existing port and supply chain infrastructure

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.2 Hydrogen supply chain overview

- Integration with existing port and supply chain infrastructure

-Backbone and port gas grids for methane gas to be converted. Notified bodies, engineering companies and gas distributors shall be able to support port authorities.

-Risk assesments and trainings shall skill all relevant stakeholders
-H2 due its hazard properties shall be handled with care and an inteligent supply chain, storage, transport and documentation strategy shall help to integrate.

-Last but not least a digital solution support (cloud and cyber security tools)

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

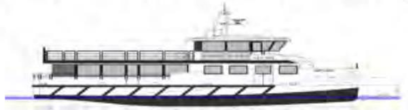
2.2 Hydrogen supply chain overview

- Integration with existing port and supply chain infrastructure

SEANERGY

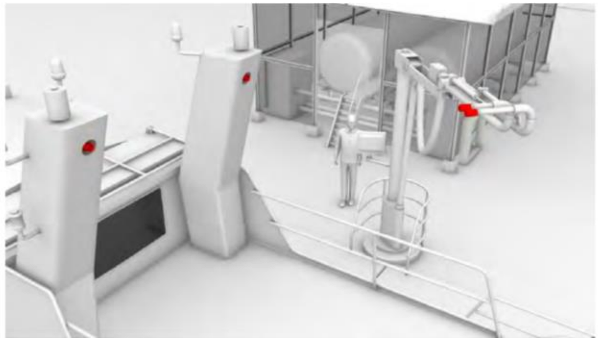
Any kind of material and person transport / handling via train, trucks, barge as well intra-logistic (fork-lifts Reach-stacker) is common today and all mentioned applications **can be easy converted from DIESEL to BEV or FCEV / ICEEV technology**
HRS can be stationary or mobile. (see below examples)

Emissions free ferry



Passanger Boat for Island connection
2 x 125 KW Fuel Cell Power
Fixed Storage H2 tank-System,

Betankungslösungen für Schiffe



Projekt Hamburg

Source: Anleg GmbH

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.3 Applications of hydrogen in ports

SEANERGY

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.3 Applications of hydrogen in ports

- Case-studies of application in maritime, land transport, and logistics

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.3 Applications of hydrogen in ports

- Case-studies of application in maritime, land transport, and logistics

Maritime hydrogen users - Study on the hydrogen requirements of Germany's maritime industry

The study concludes that the German maritime industry has a long-term demand of more than 3.5 million tons of hydrogen or hydrogen-based fuels per year.

Maritime sub-sector	Demand in tonns annual	Demand in TWh annual
ports in total	50.000	1,3
innland ports	20.000	0,5
seaports	30.000	0,8
Shipbuilding and suppliers total	10.000	0,4
Shipbuilding and suppliers without steel production	4.000	0,16
Shipping total	>3.500.000	117,8
inland shipping	120.000	3,8
Ocean shipping	3.400.000	114
Total	3.634.000	239

source: Ludwig Bölkow Systemtechnik GmbH

Note: table converted into english and summary added manual

Link: Study

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

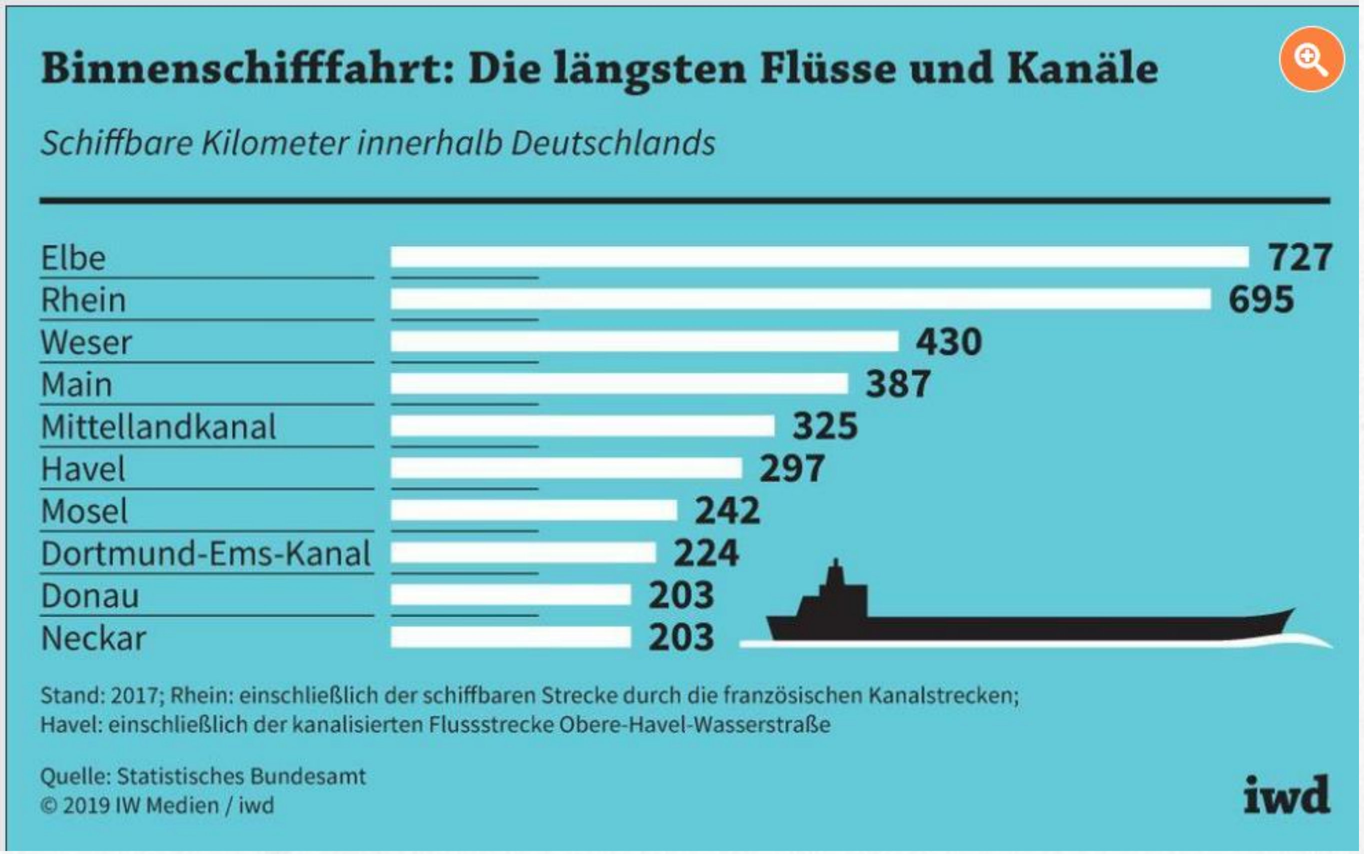
2.3 Applications of hydrogen in ports

- Case-studies of application in maritime, land transport, and logistics

SEANERGY

Inland shipping longest rivers and channels (Germany)

- The Rhine is by far the most important inland waterway in Europe for freight transport.
- Inland shipping is the most climate-friendly mode of transport in relation to transport volumes.



Source: Binnenschifffahrt: Deutschlands längste Wasserstraßen - iwd.de

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.3 Applications of hydrogen in ports

- Case-studies of application in maritime, land transport, and logistics

SEANERGY

Reference Projects:

„DeltaPort – EcoPort813“

DeltaPort is located directly on the Rhine River **at kilometer 813**, near the entrance to the Wesel-Datteln Canal, the gateway to the German inland canal grid, and ideally situated in close proximity to the ARA ports (Antwerp, Rotterdam, Amsterdam).

Source: www.deltaport.de

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.3 Applications of hydrogen in ports

- Case-studies of application in maritime, land transport, and logistics

SEANERGY

„DeltaPort – EcoPort813“

The port environment has already stakeholders such as international as well local companies and connected ports which founded a **„Association for the Promotion of Hydrogen & Sustainable Energy“**

Source: www.ecoport813.de

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

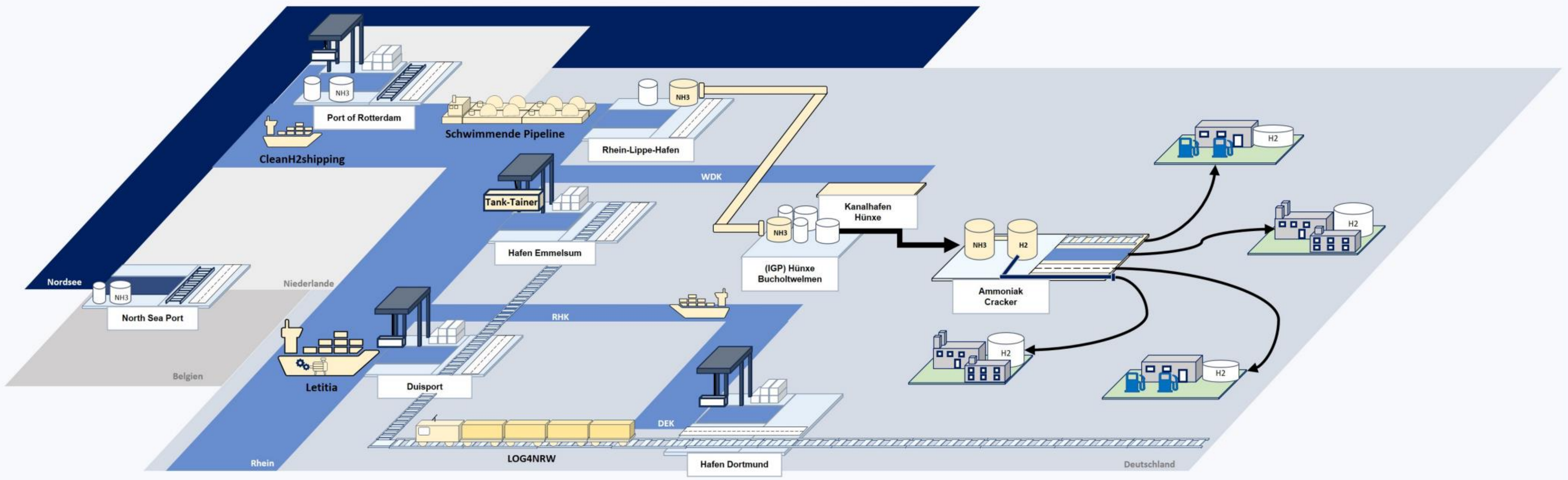
2.3 Applications of hydrogen in ports

- **Case-studies of application in maritime, land transport, and logistics**

„DeltaPort – EcoPort813“

Project approach visualisation and public access via intactive "website presentation"

ECOPORT813
MISSION TO ZERO EMISSIONS



Source: www.ecoport813.de

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.3 Applications of hydrogen in ports

- Case-studies of application in maritime, land transport, and logistics

SEANERGY

„DeltaPort – EcoPort813“

Project profiles are used to **generate a project landscape map**. A concept model of the project landscape map is intended to provide a visual and geographical allocation of all association projects.
This is an “**interactive model**”. The map is published on the website and **displayed in 2 modes. i.e. "public mode" and "mode for members" with more detailed information**.

Note: As this is **only a concept model**, not all project profiles are included. **The association has focused on the "LOG4NRW projects" and the "feasibility study" for illustration purposes**.

Sustainabilty from the point of view "marketing":
*The **name of the project “EcoPort 813” is partly due to the ecological aspect** of the project **and partly because the number “813”** refers to the **corresponding kilometer of the Rhine where the project site is located on the Lower Rhine.***

Source: www.ecoport813.de

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.3 Applications of hydrogen in ports

- Case-studies of application in maritime, land transport, and logistics

SEANERGY

„H2HN Development prospects for the port of Heilbronn through H2“

© Fraunhofer IAO

Initial situation and project objective

With an annual throughput of around 2.5 million tons of goods, Heilbronn is the **most important port on the Neckar** and one of the largest inland ports in Germany. Thanks to its trimodal connection to water, rail and road, it is an important logistics hub for freight transport in the Heilbronn industrial region.

The aim of the "H2 Port Heilbronn" study was to develop exemplary implementation paths towards a hydrogen economy with local stakeholders and thus make a contribution to climate protection.

Source: www.kodis.iao.fraunhofer.de)

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.3 Applications of hydrogen in ports

- Case-studies of application in maritime, land transport, and logistics

SEANERGY

„H2HN Development prospects for the port of Heilbronn through H2“

Guideline

A key result of the project was the development of the guideline “Building a hydrogen economy using the example of inland ports”.

This is intended to support decision-makers, port operators and their direct environment in finding starting points for a transformation towards a hydrogen economy

Video Link: H2-Logistiksimulation in Heilbronn

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.3 Applications of hydrogen in ports

- Case-studies of application in maritime, land transport, and logistics

SEANERGY

„sMArt Green Ports as Integrated Efficient multimodal hubs“

HORIZON 2020

funding from the European Union’s Horizon 2020 (MFF 2014-2020) research and innovation programme under Grant Agreement 101036594.

Source: www.haropaport.com

MAGPIE project has 45 partners and 6 different stakeholders groups.

Transport modalities, energy supply companies, regulators, and local communities are represented and dispatched in :

1. Civil society and governments (local, national, European)
2. Inland waterway transport professionals
3. Road transport professionals
4. Rail transport professionals
5. Energy sector (clean & fossil) professionals
6. Port authorities and port-based industry

Source: www.magpie-ports.eu

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.3 Applications of hydrogen in ports

- Case-studies of application in maritime, land transport, and logistics

SEANERGY

„sMArt Green Ports as Integrated Efficient multimodal hubs“

The EU-funded **MAGPIE project will embark on 12 pilot activities in three key areas**:

1. **alternative energy sources**;
2. **smart technologies** applied to power operations;
3. and **river and rail connections with the hinterland**.

The **ports of Rotterdam** (Netherlands) and **Sines** (Portugal), as well as **Haropa Port** (France) and the **DeltaPort** association (Germany) are **supporting the project**.

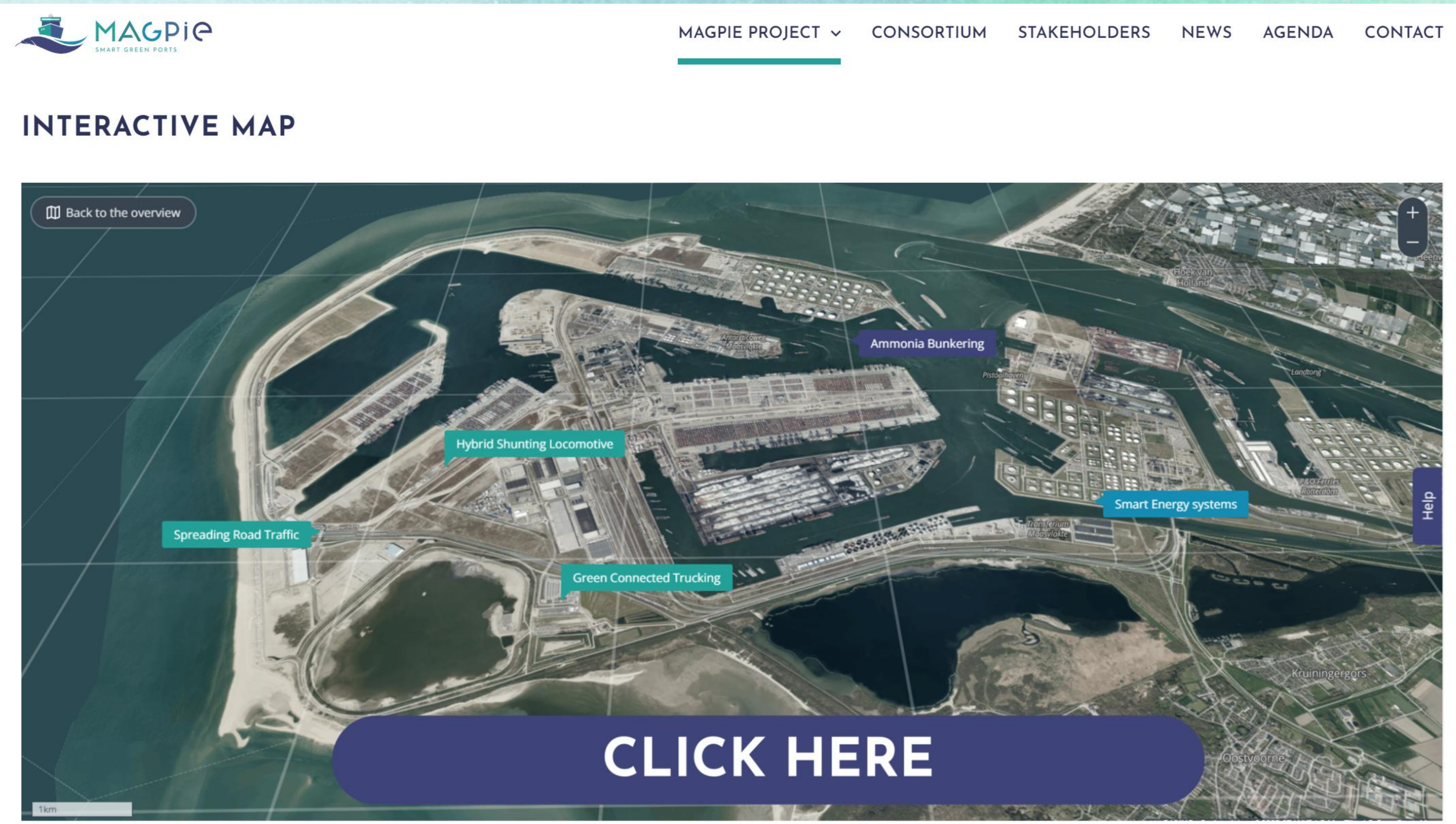
MAGPIE will combine the accelerated **introduction of green energy carriers with logistics** optimisation **in ports through automation and autonomous operations**.

Source: https://cordis.europa.eu/project/id/101036594>

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.3 Applications of hydrogen in ports

- Case-studies of application in maritime, land transport, and logistics



Source: www.magpie-ports.eu - interactive map of port Rotterdam, NL

MAGPIE is **developing innovation in a "living laboratory" approach**. A dozen pilot projects will be conducted in this way in **three key** areas :

•the **energy transition** and the development of alternative, low-carbon forms of energy,

•the **digital transition** as applied to port operations,

•**connections to port hinterlands**.

Source: www.haropaport.com

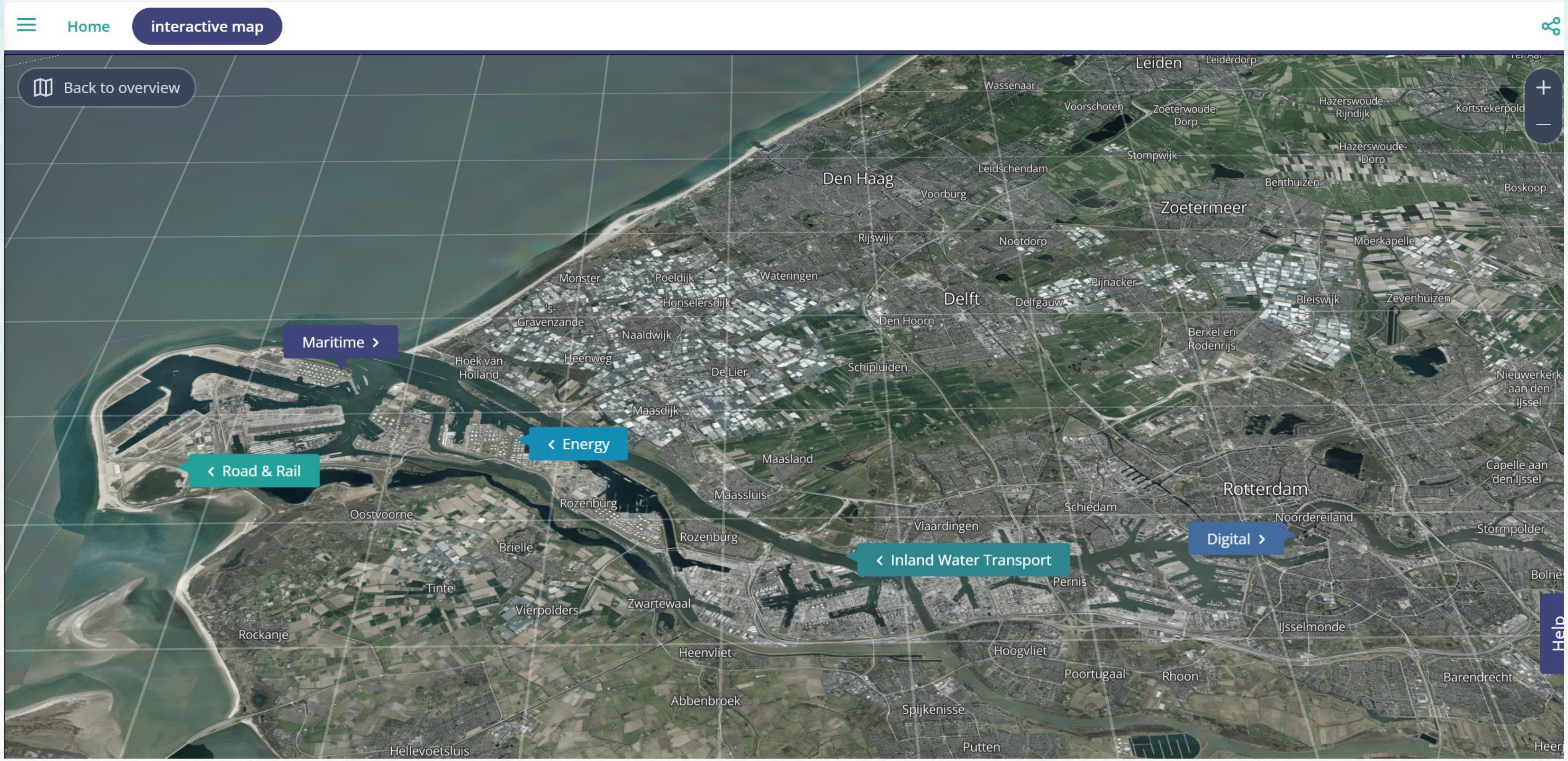
This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.3 Applications of hydrogen in ports

- **Case-studies of application in maritime, land transport, and logistics**

Zoom out - Seaport of Rotterdam, NL

SEANERGY



Source: [Project Atlas | interactive map port of magpie]

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.3 Applications of hydrogen in ports

- **Technological innovations in hydrogen applications**

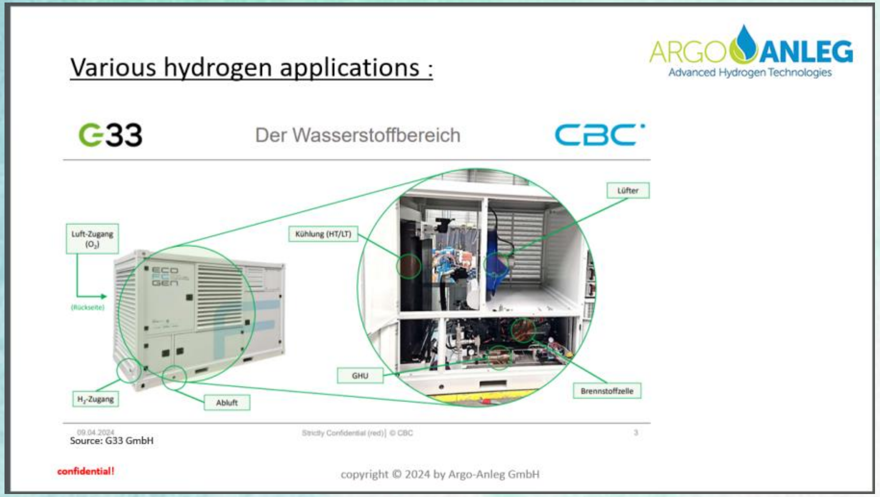
(few examples to inspire)

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.3 Applications of hydrogen in ports

- Technological innovations in hydrogen applications

Fuel cell based decentralized power generator (funded project)



Source: Argo-Anleg GmbH

Hydrogen distribution by H2Tank-Tainer, H2 bundle, trailer
Hydrogen gas handling and pressure reduction including pressure and temperature controll inside the Genset (GHU).
Max. Power 20…60KW, constant power 50KW
Priority & focus: Pilot project & prototyping in a foreign target country

Source: cbc-group.org/en/

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.3 Applications of hydrogen in ports

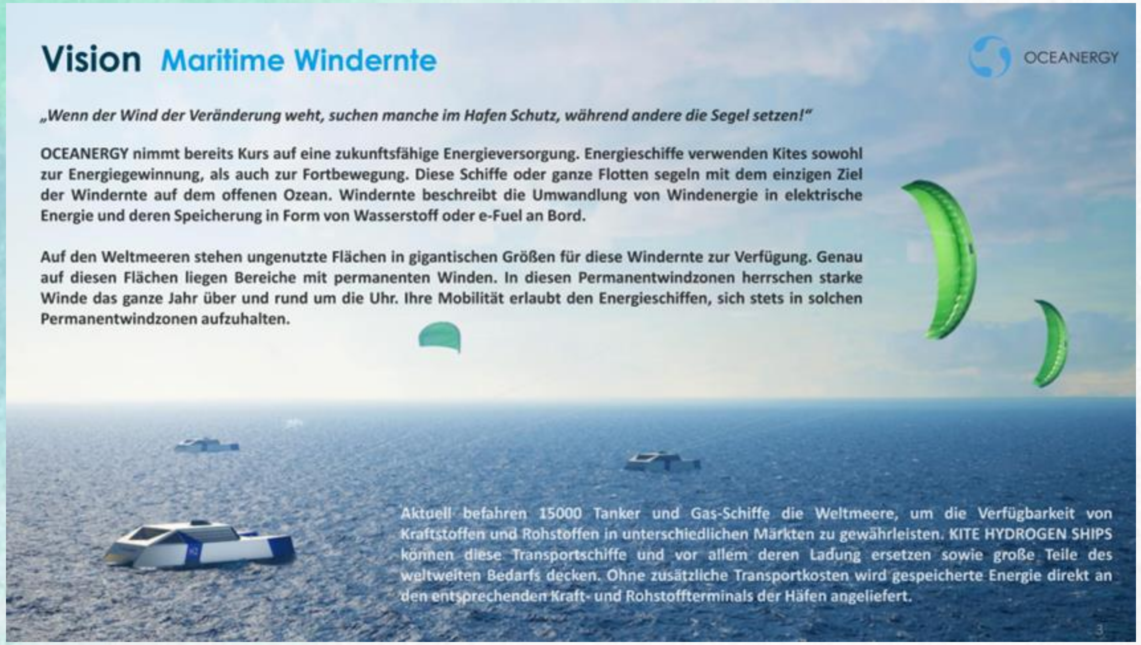
- Technological innovations in hydrogen applications
  „KITE HYDROGEN SHIP“

SEANERGY

OCEANERGY's mission is low-cost, 100% ecologic and reliable supply of green hydrogen or e-fuels. Intermittent green electricity will not be sufficient to turn energy and feedstock systems green.

The KITE HYDROGEN SHIP is a breakthrough **innovation for base-load green electricity from wind**.
A world's first. **It has the potential to dominate the future of green fuels production.**
YOU can participate in this phenomenal technology today.

Dr. Wolfram Reiners, CEO



Source: www.OCEANERGY.com

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.3 Applications of hydrogen in ports

- Technological innovations in hydrogen applications „truck-trailer - cooling generator powered by H2“

SEANERGY

Cooling-Container
energy production
Fuel Cell PEM: 10 KW & 15 KW
Hydrogen Storage: 14kg…20kg

Source: www.anleg.de

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.3 Applications of hydrogen in ports

SEANERGY

- Examples of successful hydrogen projects in ports/logistics/hinterlands

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.3 Applications of hydrogen in ports

- Examples of successful hydrogen projects in ports/logistics/hinterlands

SEANERGY

<u>Lighthouse project:</u>
Example project (Ongoing)

"MultiRELOAD"
European cooperation for the development of innovative inland port solutions for efficient, effective and sustainable multimodality

Source https://multireload.eu/

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.3 Applications of hydrogen in ports

- Examples of successful hydrogen projects in ports/logistics/hinterlands

SEANERGY

Recommendation to network and strengthen competences supraregional

<u>Succesful examples:</u>

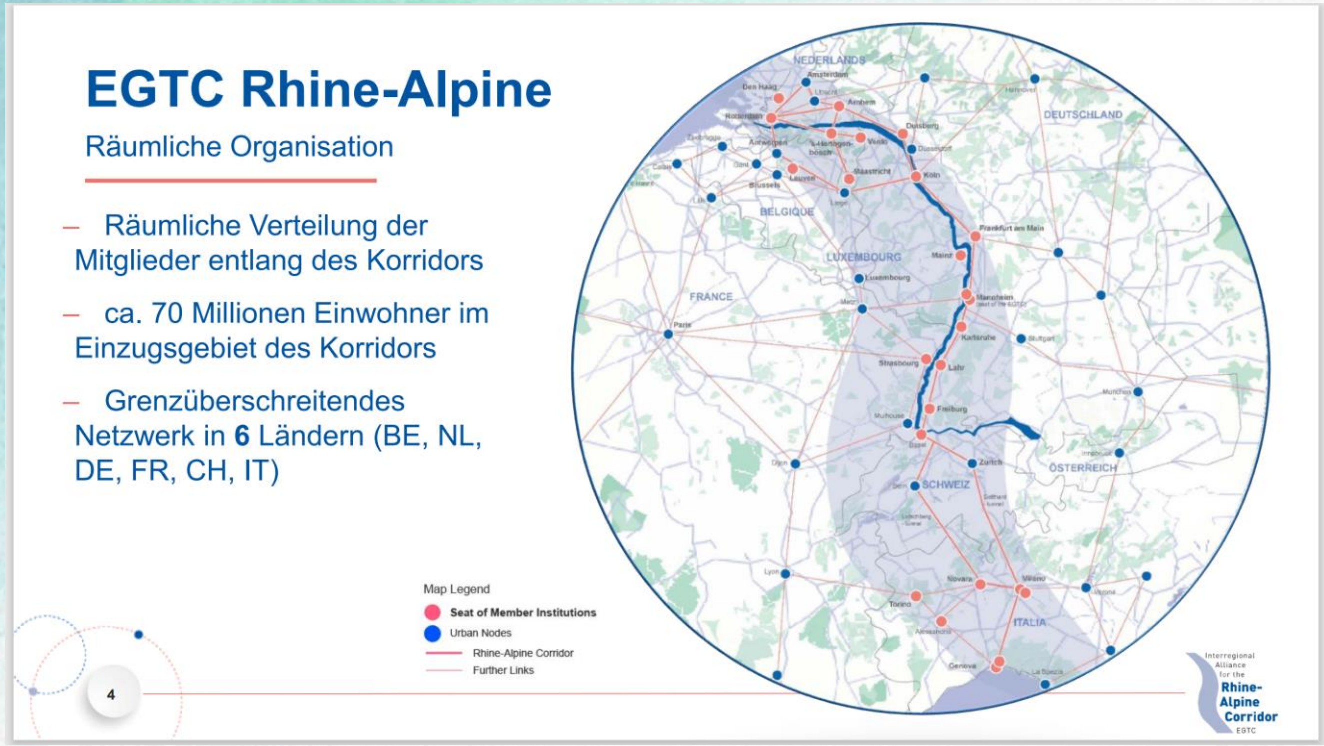
<u>Foundation of EGTC</u>

STRENGTHENING THE RHINE AXIS AS THE CORE OF THE EU TRANSPORT NETWORK

Follow-up of an EU-funded project called CODE24 with 18 partners from 5 countries along the main north-south connection in Europe.

Result: **Joint strategy for the Rhine-Alpine corridor and establishment of the Interregional Alliance for the Rhine-Alpine Corridor** EGTC in year 2015.

Source: egtc-rhine-alpine.eu/



Source: Dr. Cecilia Braun, Director Interregional Alliance for the Rhine-Alpine Corridor EGTC

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.3 Applications of hydrogen in ports

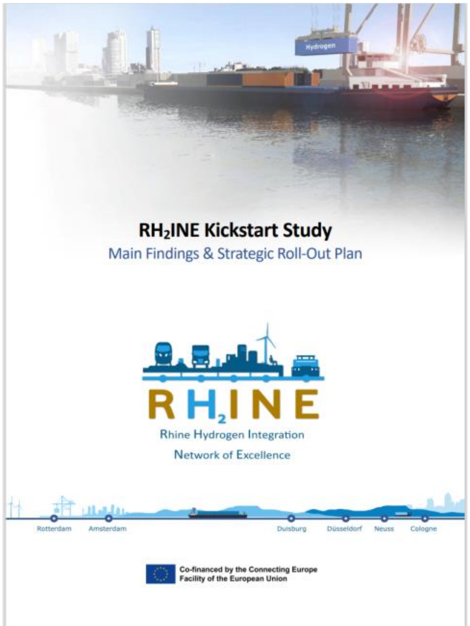
- Examples of successful hydrogen projects in ports/logistics/hinterlands

SEANERGY

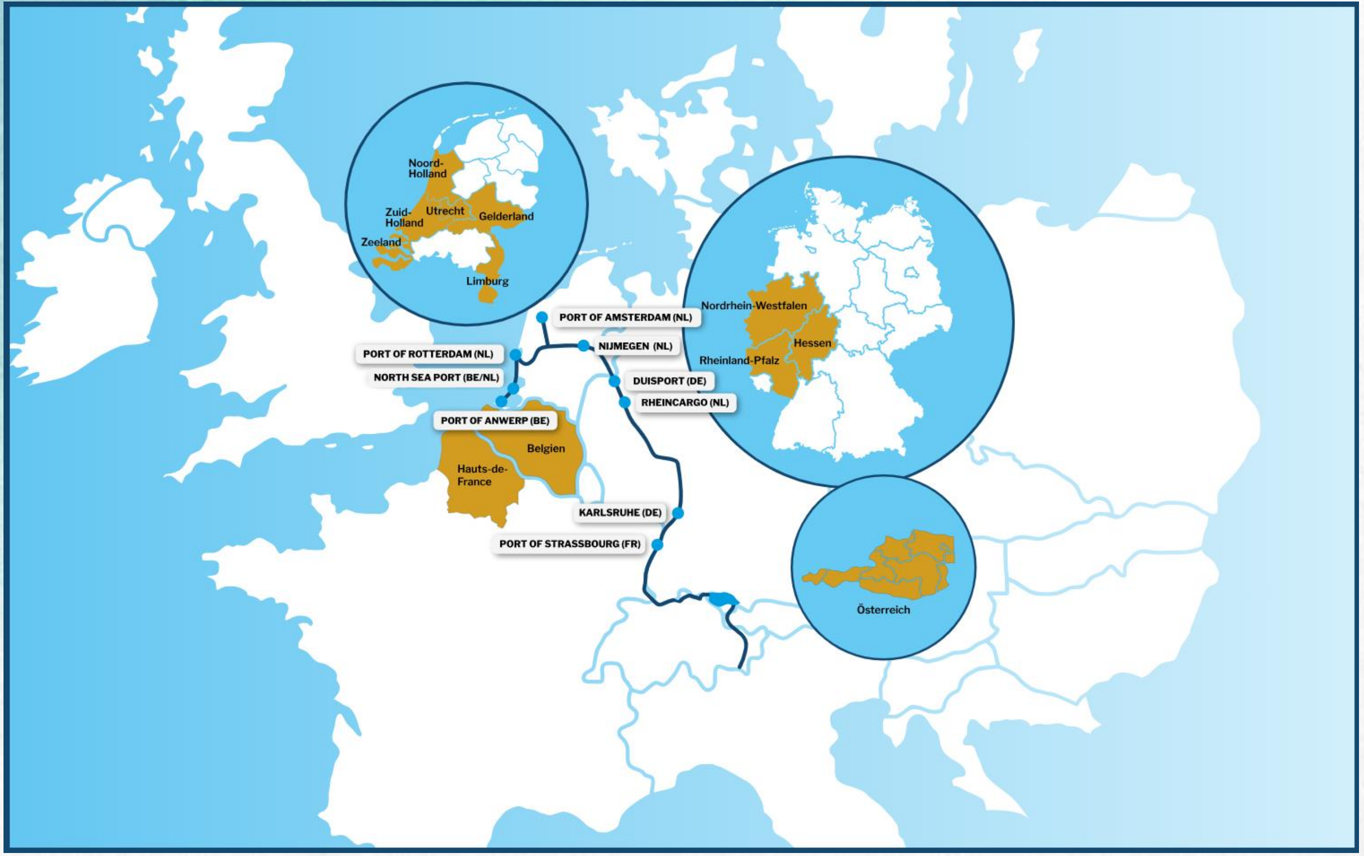
RH$_2$INE initiative

"Rhine Hydrogen Integration Network of Excellence - RH2INE"

To support a cross-border hydrogen infrastructure along the Rhine-Alpine corridor



Source: Georg Dura, Department Hydrogen Infrastructure
RH$_2$INE Kickstart Study, ZBT Duisburg, 2021



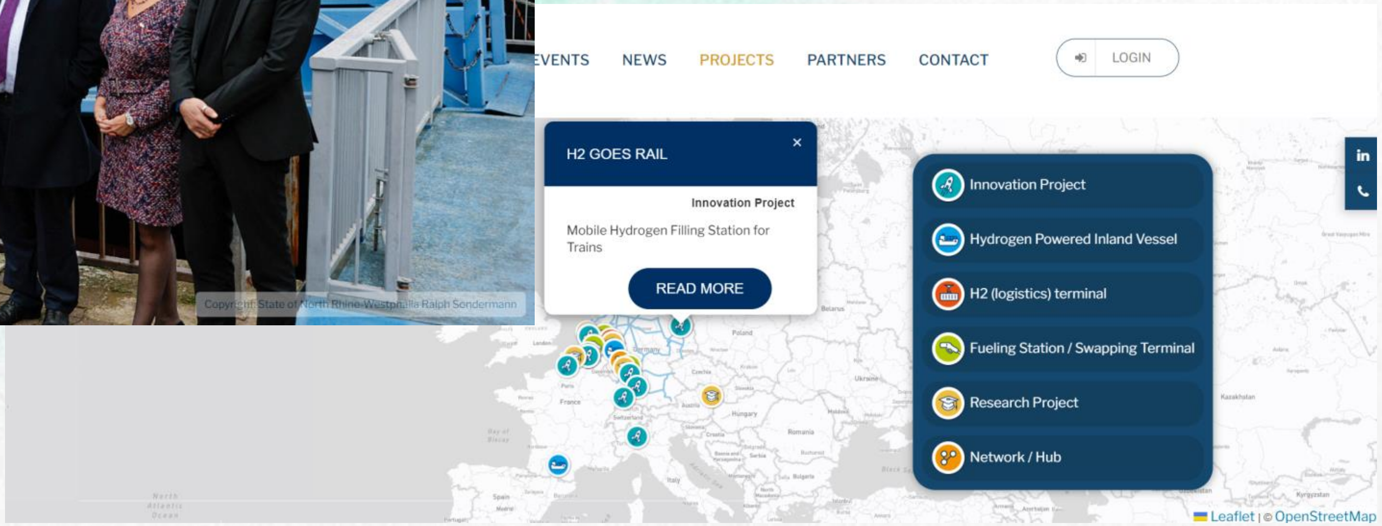
Source:RH2INE_Kickstart_Study.pdf

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.3 Applications of hydrogen in ports

- Examples of successful hydrogen projects in ports/logistics/hinterlands

RH$_2$INE initiative



Source: rh2ine.eu

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.3 Applications of hydrogen in ports

- Examples of successful hydrogen projects in ports/logistics/hinterlands

SEANERGY

Port of Dortmund - Network to other ports and stakeholder:

"With our specific competencies, potential and trimodal logistics connections, **Dortmund's port can assume an important regional hub function for the planned development of a waterway supply chain**". says Bettina Brennenstuhl, Board of Management Dortmunder Hafen AG.

Source: [www.dortmunder-hafen.de (02/2024)](www.dortmunder-hafen.de)

Das Magazin für den Dortmunder Hafen

Eine starke Hafen-Allianz

Dortmunds Hafen hat sich dem Verein EcoPort813 angeschlossen. Das Ziel: der Aufbau einer Wasserstoff- und Logistikinfrastruktur.

Die Abkehr von fossilen Energieträgern, verbunden mit einer deutlichen Reduzierung des CO_2-Ausstoßes, stellt auch Dortmunds Hafen wie alle Binnenhäfen an Rhein und Ruhr ökologisch und ökonomisch vor große Herausforderungen. Mit Blick auf die bevorstehende Transformation der Binnenhäfen ist es von entscheidender Bedeutung, dass sich Akteure vernetzen, gemeinsam Projekte zur Dekarbonisierung auf den Weg bringen, Synergien nutzen und auch alternative Ansätze finden.

Vor diesem Hintergrund haben Bettina Brennenstuhl, Vorständin der Dortmunder Hafen AG, und Andreas Stolte, Vorstandsvorsitzender „EcoPort813 Förderverein Wasserstoff und nachhaltige Energie e.V." und gleichzeitig Geschäftsführer der Dealt-Port Niederrheinhäfen, den Aufnahmeantrag unterzeichnet. Damit ist Dortmunds Hafen nun offiziell Mitglied von EcoPort813. Das gemeinsame Ziel: der Aufbau einer Wasserstoff- und Logistikinfrastruktur. Experten sind sich einig, dass grüner, mit regenerativen Energien produzierter Wasserstoff, im künftigen Energiemix eine große Rolle spielen wird.

Ein Fundament dafür ist der Aufbau einer

EcoPort813

Auf gute Zusammenarbeit: Bettina Brennenstuhl, Vorständin Dortmunder Hafen AG, und Andreas Stolte, Vorstandsvorsitzender EcoPort813.

Logisitc-hub for green steel

Logistik-Hub für grünen Stahl

Der weltweit operierende Logistikdienstleister Rhenus investiert am Dortmunder Hafen und beabsichtigt, einen Green Steel Logistics Hub zu etablieren. Das Ziel: Stahl transportieren, aber weniger CO_2 emittieren.

„Der Trend geht immer mehr dahin, dass Stahlwerke auf mit Wasserstoff betriebene Produktion umsteigen", stellt Michael Petersmann, Geschäftsführer der Rhenus Port Logistics Rhein-Ruhr, fest. „Und wir wollen im Ruhrgebiet Vorreiter sein, wenn es darum geht, unseren Kunden eine CO_2-reduzierte Lieferkette anzubieten", fügt der 35jährige an. Es sei nicht mehr zeitgemäß, grünen Stahl mit dem Diesel-Lkw anzuliefern.

Kernstück der Sanierung der Gebäude an der Kipperstraße ist die Installation einer 4.000 qm großen Photovoltaikanlage auf dem Hallendach. Mit dem so gewonnen Strom würden sowohl die Krananlagen, das Gebäude als auch die bestellten vier E-Lkw versorgt. Der Liefertermin der E-Lkw ist im August, bis dahin seien die Sanierungsarbeiten beendet. „Wir planen zum Hafenspaziergang am 31. August fertig zu sein."

Rund 300.000 Tonnen Stahl werden künftig auf dem 36.000 qm großen Gelände am Mathieshafen jährlich umgeschlagen. Material, das die Kunden in den Stahlanarbeitungsbetrieben im östlichen Ruhrgebiet oder im Sauerland aus den großen Seehäfen oder den europäischen Stahlwerken erreicht. Transportiert über den im Vergleich zur Autobahn emissionsärmeren Wasserweg bis nach Dortmund und ab Herbst feinverteilt über die E-Lkw in einem Umkreis von rund 50 km um Dortmund herum.

Michael Petersmann, Geschäftsführer der Rhenus Port Logistics Rhein-Ruhr

Ein Projekt, das durch das Bundesministerium für Digitales und Verkehr mit insgesamt 1.580.781,82 Euro gefördert wird. „Ohne das Förderprogramm hätten wir die Zukunftsversion für unser Hafenterminal in Dortmund nicht umsetzen können", stellt Michael Petersmann klar.

Die Bemühungen der weltweit tätigen Rhenus-Gruppe um mehr Umweltschutz seien mit dem Green Steel Logistics Hub aber noch nicht am Ende. „Wir arbeiten ebenfalls daran, demnächst Binnenschiffe einzusetzen, die noch weniger CO_2 ausstoßen", sagt Michael Petersmann. Gemessen an der CO_2-Emmission, sei die Öko-Bilanz eines Binnenschiffs im Vergleich zum Lkw-Verkehr schon jetzt besser. „Ein Binnenschiff transportiert 2.500 Tonnen Stahl, dafür müssen sonst etwa 120 Lkw fahren", rechnet er vor. In Sachen Etablierung klimaschonender Lieferketten sei Rhenus mit weiteren potenziellen Kunden im Gespräch. „Die meisten Logistiker betrachten nur ein Rädchen in der Lieferkette ‚grün'. Wir versuchen das ganzheitlich zu tun", sagt der Betriebswirt. Kapazitäten für weitere Projekte seien jedenfalls noch vorhanden.

Zur Rhenus Port Logistics Rhein-Ruhr-Region gehören zehn Terminals mit 110 Mitarbeitern. „Wenn das hier gut anläuft, werden wir an den anderen Standorten nachziehen", kündigt Geschäftsführer Michael Petersmann an.

Der neue Green Steel Logistics Hub von Rhenus an der Kipperstraße im Dortmunder Hafen.

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.3 Applications of hydrogen in ports

- Examples of successful hydrogen projects in ports/logistics/hinterlands

SEANERGY

Port Logisitics – Hydrogen technology :

HYFACTS

Material Handling applications with fuel cells

Early market:	Material handling vehicles or municipal vehicles
Advantage:	Short refuelling time Constant operating speed (As batteries get „weaker“, working speed decreases) No exchange of batteries necessary Less space required for refuelling (3 minutes consecutively)
Power requirement:	1.5 – 10 kW_{el}
In operation:	2,300 pcs. in North America (2011)
Refuelling:	Either by hydrogen dispenser or exchange of bottles

Picture 3: Forklifts with fuel cell

Funded by FCH JU (Grant agreement No. 256823)

Source:(h2euro.org)

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.3 Applications of hydrogen in ports

- Examples of successful hydrogen projects in ports/logistics/hinterlands

Port Logisitics – Hydrogen technology :

Port of Los Angeles, USA

Hyster Company announces testing of a top-pick container handler powered by hydrogen fuel cells (HFC) at Fenix Marine Services in the Port of Los Angeles.
LOS ANGELES (Oct. 11, 2022)

By DC Velocity Staff
Oct 11, 2022

Source: www.dcvelocity.com

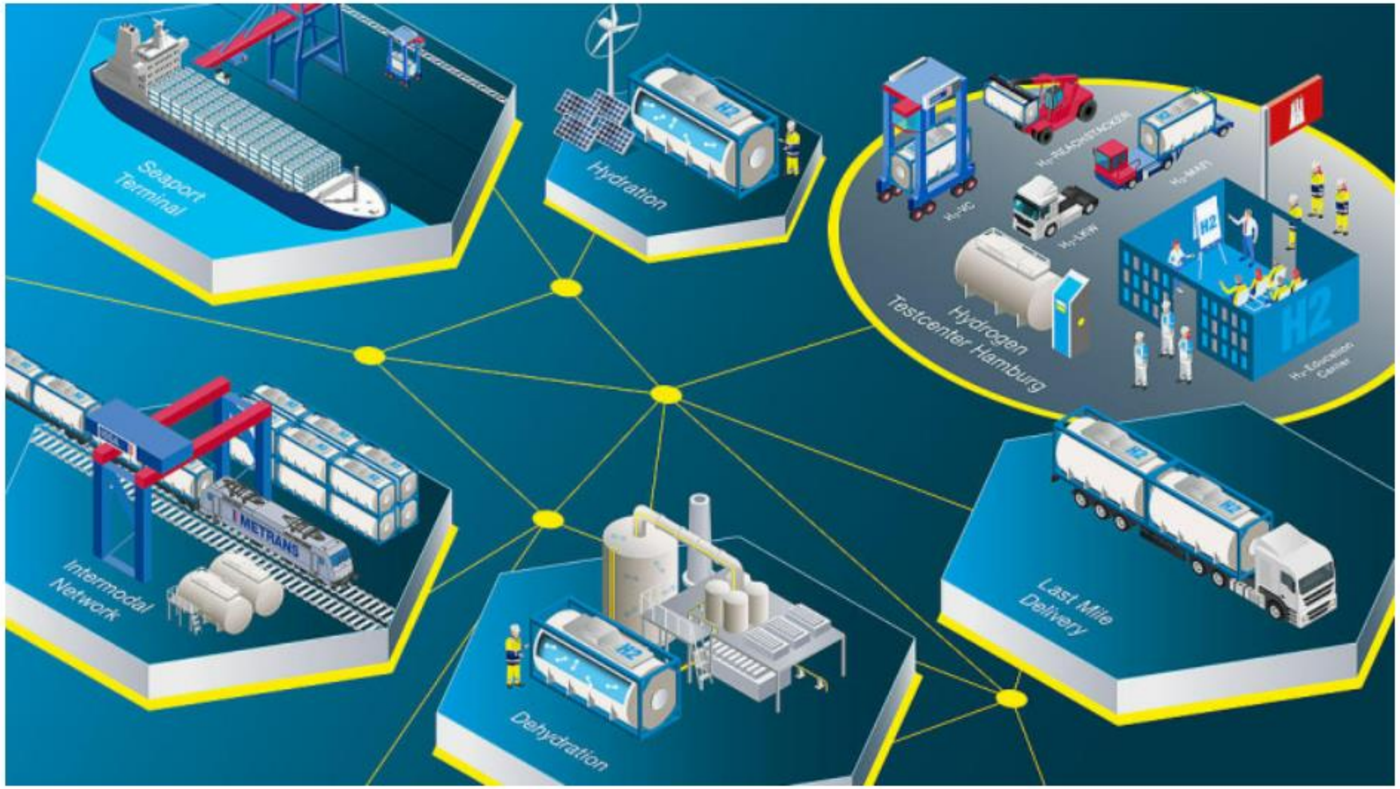
SEANERGY

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.3 Applications of hydrogen in ports

- Examples of successful hydrogen projects in ports/logistics/hinterlands

Port Logisitics – Hydrogen technology :



Der Hamburger Hafenlogistiker HHLA erprobt in den kommenden Jahren den Einsatz wasserstoffgetriebener Geräte im Güterumschlag

© Foto: Hamburger Hafen und Logistik AG

Source: www.verkehrsrundschau.de

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

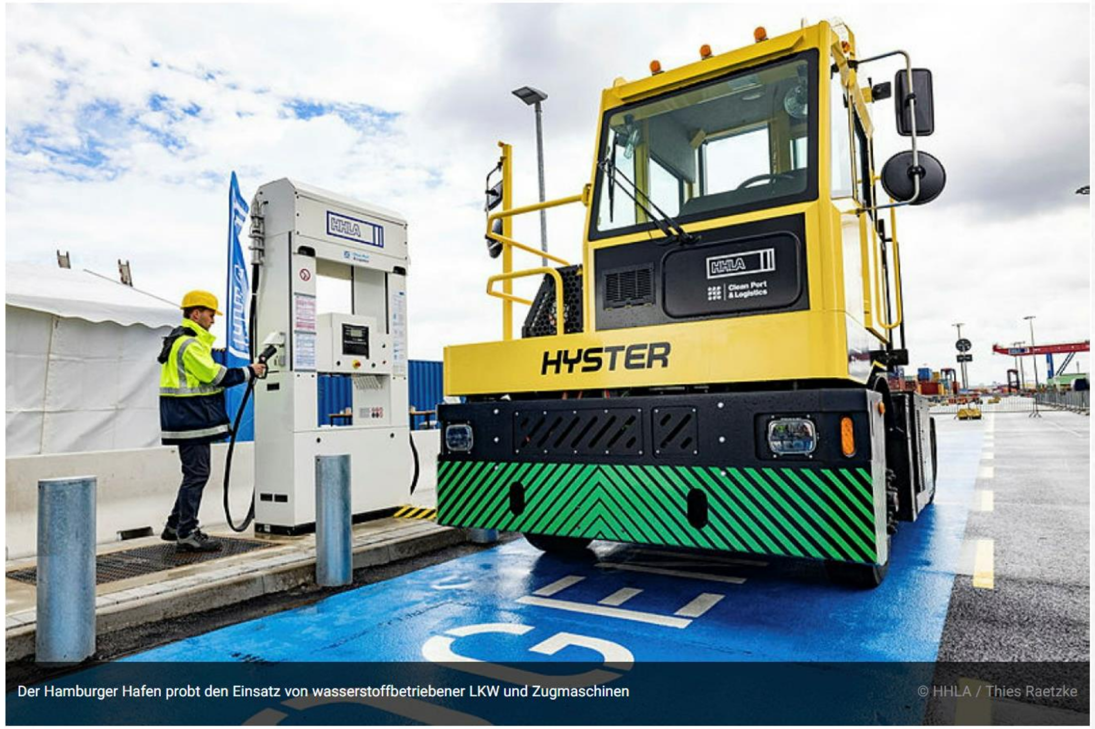
2.3 Applications of hydrogen in ports

- Examples of successful hydrogen projects in ports/logistics/hinterlands

Port Logisitics – Hydrogen technology :

Hydrogen test field starts in Hamburg

Hamburger Hafen und Logistik AG (HHLA) has opened the first test field for hydrogen-powered port logistics, including a hydrogen filling station, in the Port of Hamburg.
Here, the port operator is testing the use of hydrogen under real conditions, for example with fuel cell trucks and tractor units.



Source: Magnus Schwarz | 15.07.24 *h2-news.de*

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.3 Applications of hydrogen in ports

- Examples of successful hydrogen projects in ports/logistics/hinterlands

Port Logisitics – Hydrogen technology :

INTRALOGISTIK

Hyster: wasserstoffbetriebene Umschlaggeräte für HHLA

Bild: HHLA

Mit «Clean Port & Logistics» (CPL) hat die HHLA gemeinsam mit seinen Partnern (wie zum Beispiel Hyster) einen Cluster zur Erprobung von wasserstoffbetriebenen Geräten in der Hafenlogistik gegründet. Als Zentrum der Aktivitäten entsteht ein Testcenter für diese Geräte am HHLA-Container-Terminal Tollerort in Hamburg.

Bild: HHLA

PUBLISHED ON 09 May 2022
Forklift truck manufacturer Hyster has announced that the company is supplying Hamburger **Hafen und Logistik AG (HHLA)** with **two Hyster electric vehicles with fuel cell technology for container handling.**

Hyster is thus bringing the world's first hydrogen-powered empty container stacker into real-life use **and is also delivering its first terminal tractor in Europe.**

Both vehicles are powered by 'Nuvera' fuel cells.

The hydrogen is produced on site at the 'HHLA Hamburg Green Hydrogen Hub'.

Source: logistik-online.ch/intralogistik

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.3 Applications of hydrogen in ports

- Examples of successful hydrogen projects in ports/logistics/hinterlands

Port Logisitics – Hydrogen technology :

Demonstrating zero-emission port vehicles at the Port of Valencia

Source: *https://blog.ballard.com/marine*
(see embeded video on website)

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.3 Applications of hydrogen in ports

- Examples of successful hydrogen projects in ports/logistics/hinterlands

Port Logisitics – Hydrogen technology Examples:

SEANERGY

Container terminal in Kreuztal, (NRW)

An alliance of several ports and rail operators in North Rhine-Westphalia wants to make around 27,000 truck journeys superfluous in future and transfer them to rail and ship.

Source: LOG4NRW - Logistik-heute.de

Cost-covering from 20 TEU*)
The fact that the train departing from Kreuztal to Hamburg on this day can hardly cover its costs with seven 40-foot containers is
something that the initiators of this exhibition are prepared to accept this time:
“We need around 20 container units to be able to transport a train economically from Kreuztal to the seaports,” explains Uwe Stupperich.
This time it is only 14 TEU, which is the valid unit of measurement.

Source: siegener-zeitung.de

© Max Schepp

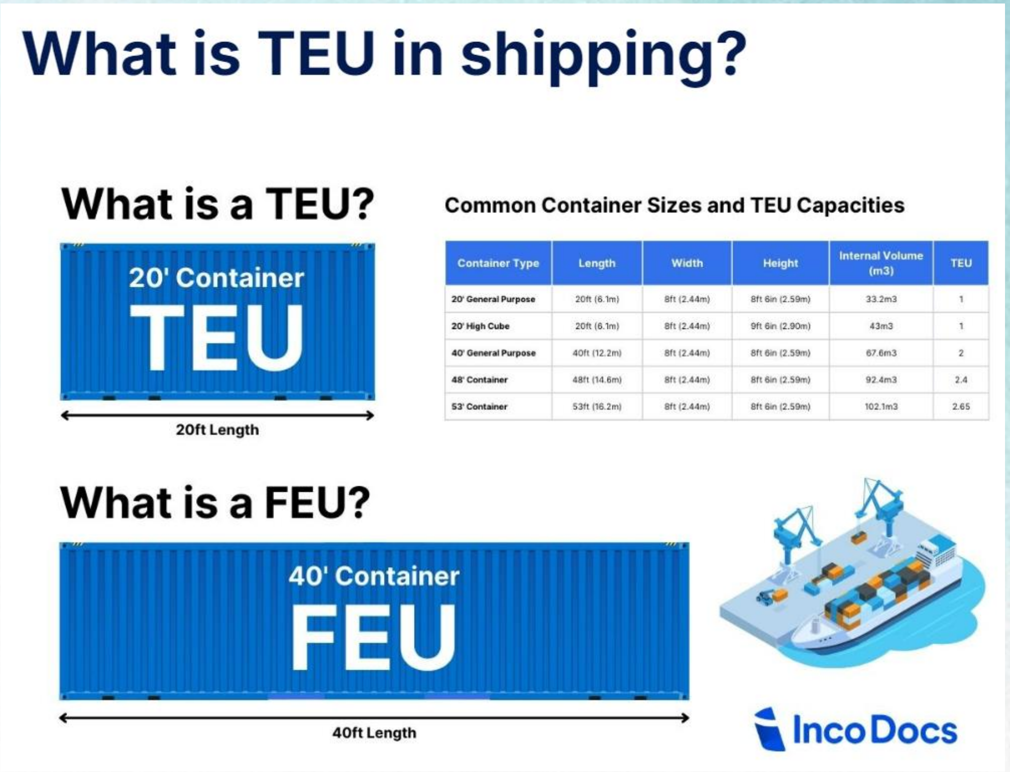
This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.3 Applications of hydrogen in ports

- Examples of successful hydrogen projects in ports/logistics/hinterlands

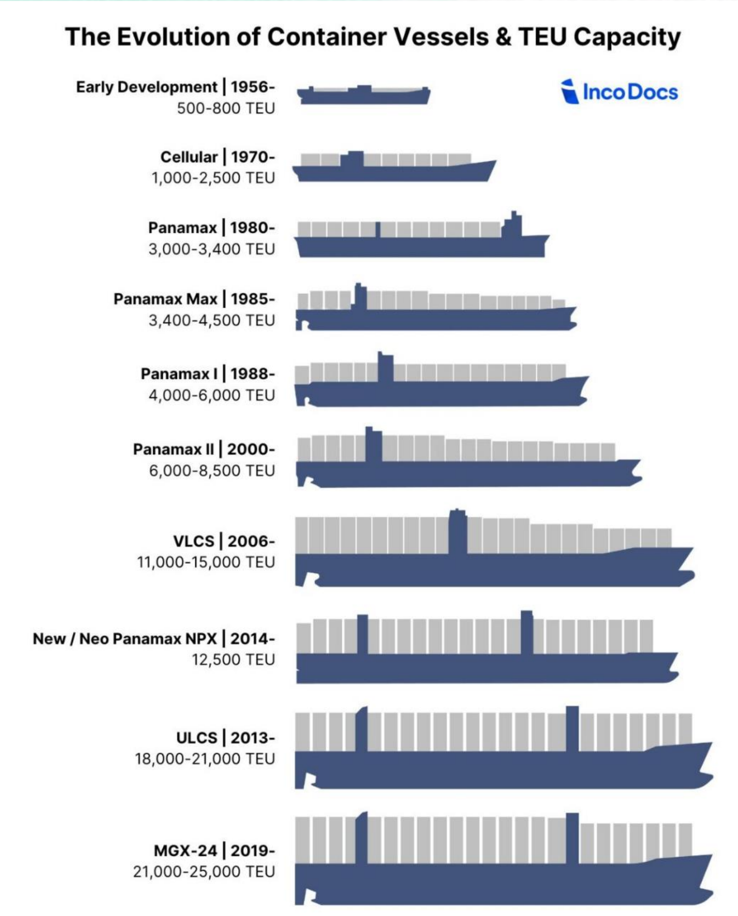
Port Logisitics - Technology Examples:

***)** For a better understanding a relation to vessel transport:



Common Container Sizes and TEU Capacities

Container Type	Length	Width	Height	Internal Volume (m3)	TEU
20' General Purpose	20ft (6.1m)	8ft (2.44m)	8ft 6in (2.59m)	33.2m3	1
20' High Cube	20ft (6.1m)	8ft (2.44m)	9ft 6in (2.90m)	43m3	1
40' General Purpose	40ft (12.2m)	8ft (2.44m)	8ft 6in (2.59m)	67.6m3	2
48' Container	48ft (14.6m)	8ft (2.44m)	8ft 6in (2.59m)	92.4m3	2.4
53' Container	53ft (16.2m)	8ft (2.44m)	8ft 6in (2.59m)	102.1m3	2.65



Source: incodocs.com

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.3 Applications of hydrogen in ports

- Examples of successful hydrogen projects in ports/logistics/hinterlands

SEANERGY

Hydrogen application in a building:

Hydrogen and fuel cell opportunities are limited in buildings but worth exploring

Opportunities for hydrogen in transport, buildings and power With consumption of almost 70 EJ, **space and water heating in buildings accounts for nearly 55% of energy use in buildings globally and 4.3 Gt CO2 of emissions….**
Improving the thermal performance of building envelopes and integrating clean, efficient low-temperature equipment are priorities to decarbonise heating in buildings.

Prospects for deploying hydrogen in this sector remain limited, reflecting the high efficiency of electricity-based solutions and the energy losses that result from converting and transporting hydrogen. For instance, PV-powered heat pumps require 5-6 times less electricity than a boiler running on electrolytic hydrogen to provide the same amount of heating.

Source: The Future of Hydrogen Chapter 5: The Future of Hydrogen (iea.blob.core.windows.net)

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.3 Applications of hydrogen in ports

- Examples of successful hydrogen projects in ports/logistics/hinterlands

Hydrogen application in a building:

Four main groups of technologies can operate on hydrogen at the building level:

-

1. **Hydrogen boilers can be practical where gas networks exist because consumers will be familiar with the basic technology and its upfront capital costs**. From a lifecycle perspective, however, higher fuel consumption than more efficient technologies makes this option less attractive overall for most buildings.

1. **Fuel cells that co-generate heat and electricity** include solid oxide fuel cells **(SOFCs**) and polymer electrolyte membrane fuel cells (**PEMFC**s). SOFCs require a high temperature but also provide high electrical efficiency and a more stable load compared with PEM cells, which work at a lower temperature (60-80°C) on intermittent load schedules but offer lower electrical efficiency.

As SOFC efficiency typically declines when operated with pure hydrogen, optimising the system layout to address this issue is a key research focus. Natural gas field testing in Europe shows micro-cogeneration unit electrical efficiencies of 35-60% for SOFCs and 35-38% for PEMFCs, with corresponding cogeneration system efficiencies of 80-95% (SOFCs) and 85-90% (PEMFCs).

Source: The Future of Hydrogen Chapter 5: The Future of Hydrogen (iea.blob.core.windows.net)

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.3 Applications of hydrogen in ports

- Examples of successful hydrogen projects in ports/logistics/hinterlands

Hydrogen application in a building:

Four main groups of technologies can operate on hydrogen at the building level:

…

3. Hybrid heat pumps - **combine a boiler with an electric heat pump**. The boiler operates only when the heat pump cannot meet heating demand. Hybrid heat pumps are an interesting option in cold climates where hydrogen can be used to cover peak demand during very cold periods, but they have additional capital costs and require both electricity and hydrogen connections.

4. Gas-driven heat pumps have a gas engine that produces electricity to run a heat pump. Thousands of units are already operating in Asia and Europe, primarily in non-residential buildings.

Source: The Future of Hydrogen Chapter 5: The Future of Hydrogen (iea.blob.core.windows.net)

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.3 Applications of hydrogen in ports

- Examples of successful hydrogen projects in ports/logistics/hinterlands

Hydrogen application in a building:

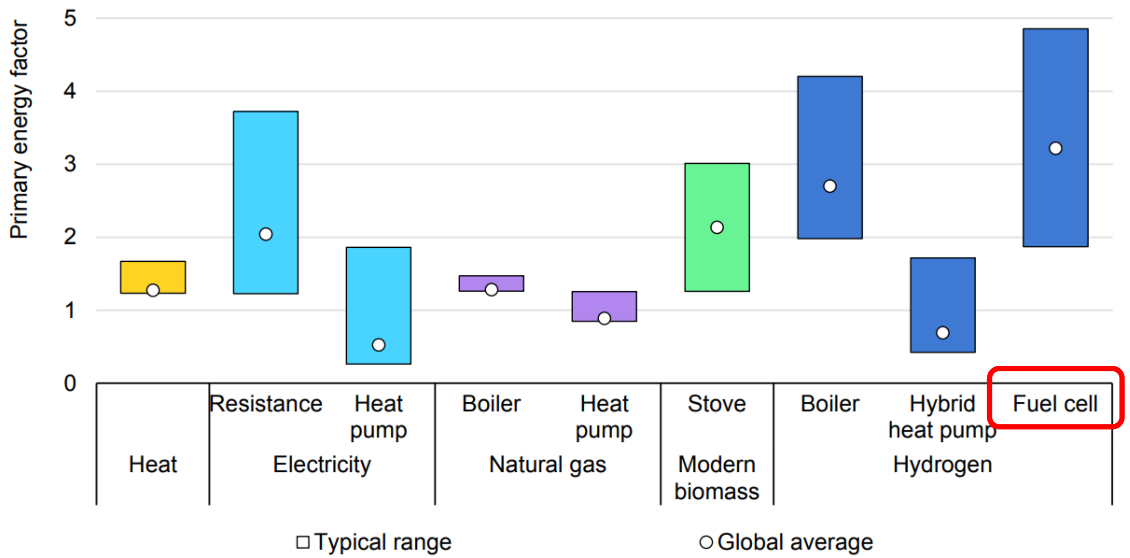
Hydrogen can be blended with or replace a portion of natural gas, which currently meets 35% of global energy demand for heating.

Depending on the region, such blending (at volumes of 5-20%) can leverage current natural gas infrastructure without requiring major network modifications.

Blending hydrogen at 20% would reduce carbon intensity by 7% at most
– well short of the level needed for long-term buildings sector decarbonisation.

Source: [The Future of Hydrogen (iea.blob.core.windows.net)]

Primary energy factors of heat production by equipment and fuel, 2020



Notes: Hybrid heat pumps are assumed to use 25% hydrogen. Heat refers to district heating. Assumptions available in the Annex

Source: Nielsen et al.: Status on Demonstration of Fuel Cell Based Micro-CHP Units in Europe FUEL CELLS 19, 2019, No. 4, 340–345, 2019 WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.3 Applications of hydrogen in ports

- Examples of successful hydrogen projects in ports/logistics/hinterlands

Hydrogen application in a building:

Over the last years, an increasing number of fuel cell based micro combined heat and power systems have been demonstrated in field trials in Europe. …

…More than 1,000 small stationary fuel cell systems for residential and commercial applications have been demonstrated in 10 European countries in the project „ene.field“

Source: E. R. Nielsen, C. B. Prag, Project Report, Technical University of Denmark (DTU), Denmark, 2017.

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.3 Applications of hydrogen in ports

- Examples of successful hydrogen projects in ports/logistics/hinterlands

Hydrogen application in a building:

This „best practice examples“ show that **H2 technology** is on it‘ way to **enter building market**

Source: www.homepowersolutions.de/en/picea-plus/

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.3 Applications of hydrogen in ports

- Examples of successful hydrogen projects in ports/logistics/hinterlands

Hydrogen application in a building:

This „best practice examples“ show that **H2 technology** is on it‘ way to **enter building market**

This example (right) shall inspire that also buildings in ports can anticipate from H2 by just switching from natural gas to premix our use up to 100% H2.

Until middle of 20. century so called "town gas" already has had up to 50% H2 gas content.

Source: https://gas.info/...wasserstoff-im-gas-netz

First hydrogen boiler demo under way in homes

Source: egisteredgasengineer.co.uk

Hall heating powered by H2

A lighthouse project for green steel production with a green heating system

Source: Schwank

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

2.3 Applications of hydrogen in ports

- Examples of successful hydrogen projects in ports/logistics/hinterlands

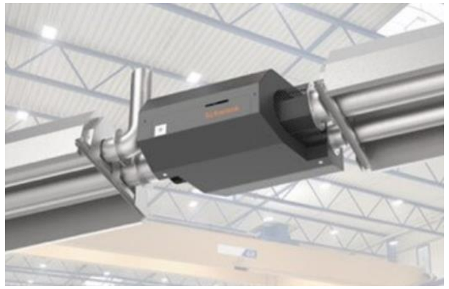
<u>Hydrogen application in a building:</u>

This „best practice examples“ show that **H2 technology** is on it‘ way to **enter building market**

The entire energy requirements of the business, whether for lighting, air conditioning, forklift trucks or heating the offices and warehouse, are covered by self-generated green electricity. The company's own photovoltaic system generates the energy required for this and stores it in lithium-ion batteries for short-term needs and as hydrogen for long-term, seasonal requirements. **The hydrogen is mainly produced from the surplus electricity from the photovoltaic system in summer with the help of an electrolysis system (power-to-gas) and stored in tanks.**

Source: Schwank

The first 100% hydrogen-powered dark radiator has gone into real operation in Ulm(Germany).



Source: Schwank

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

Part 2: Conclusions and take-home message

SEANERGY

- ✓ **The transition to sustainable energy practices within European ports is not just a regulatory requirement but a strategic necessity for long-term competitiveness and environmental stewardship.**

- ✓ **By adopting key tools and certifications, ports can significantly reduce their carbon footprint, improve energy efficiency, and align with global/EU greening goals.**

- ✓ **The integration of smart technologies, coupled with a commitment to continuous improvement through certifications like ISO 50001 and EcoPorts, will position European ports at the forefront of the green transition, ensuring they meet the challenges of tomorrow's energy landscape…**

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.

SEANERGY

THANK YOU
FOR YOUR ATTENTION

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only the author's view; the Commission is not responsible for any use that may be made of the information it contains.