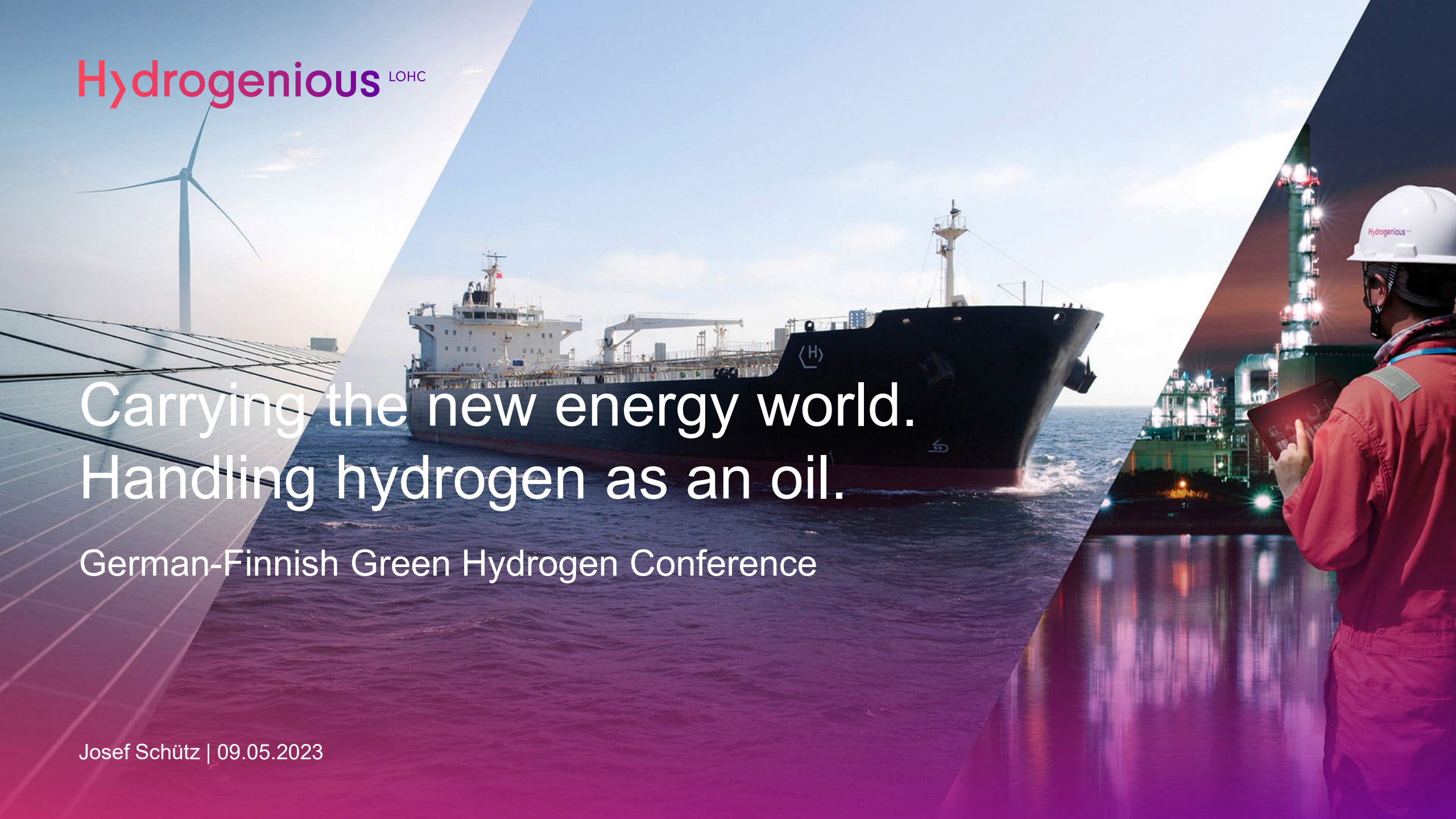
Hydrogenious LOHC



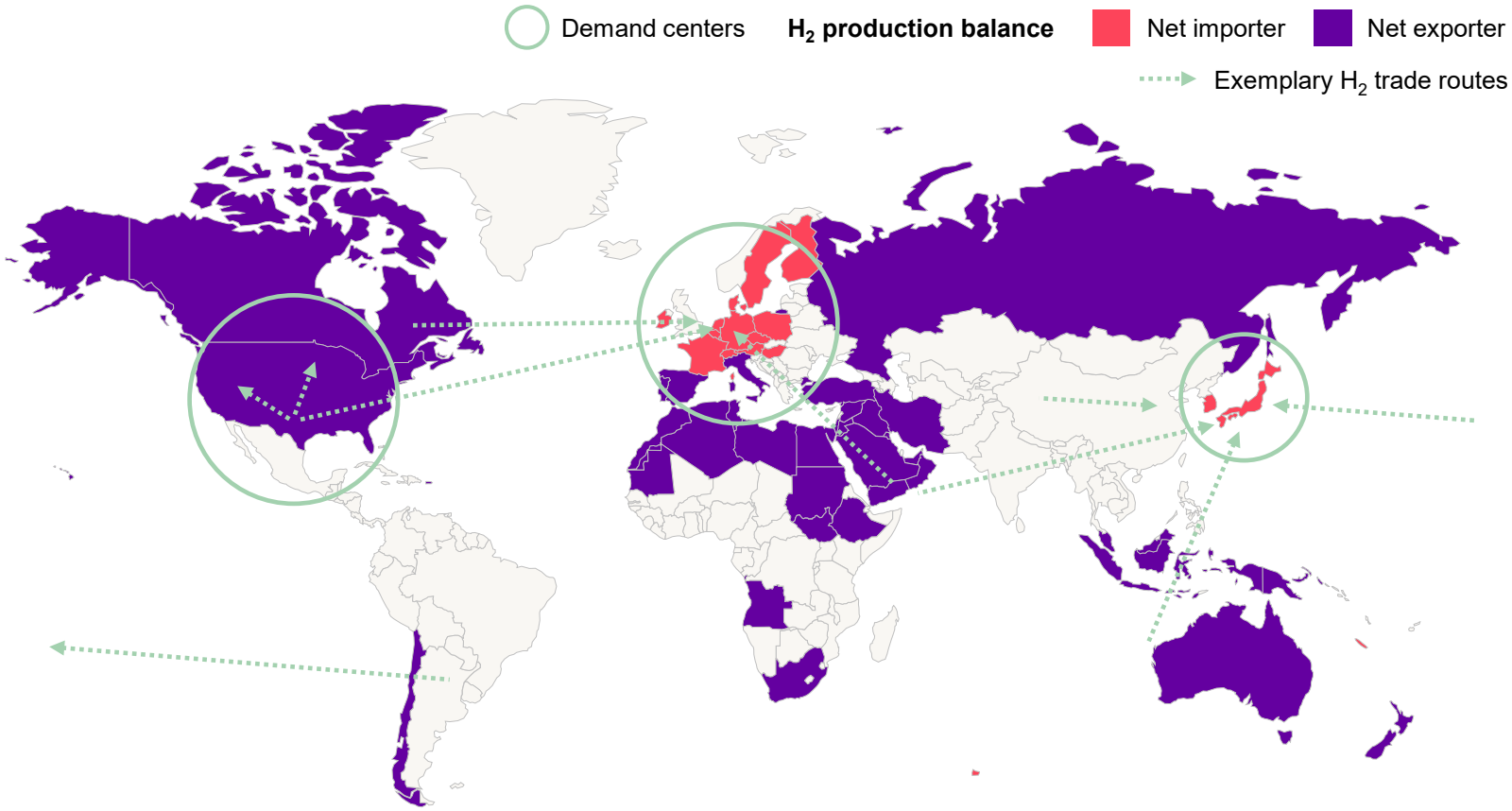
Carrying the new energy world. Handling hydrogen as an oil.

German-Finnish Green Hydrogen Conference

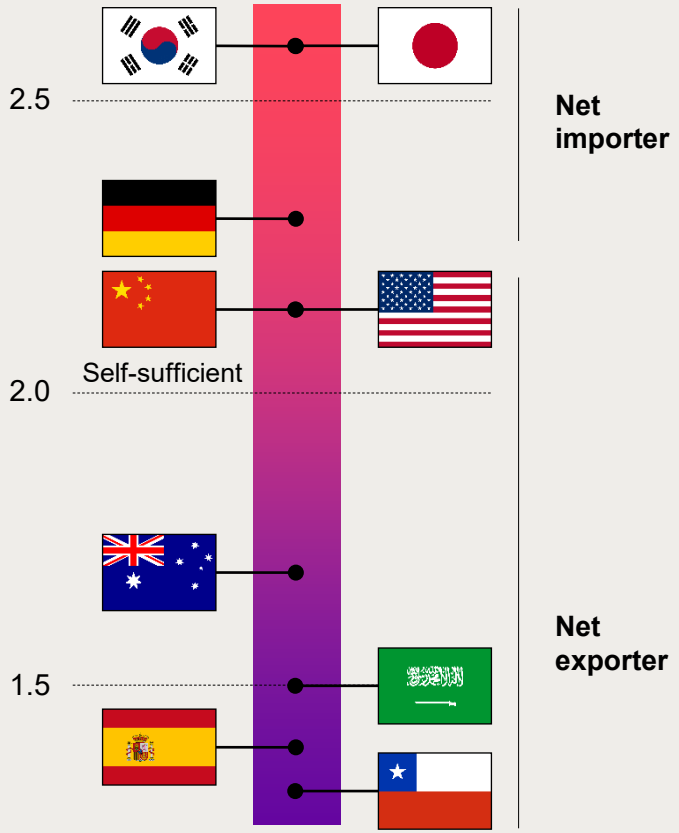
Josef Schütz | 09.05.2023

Hydrogenious LOHC

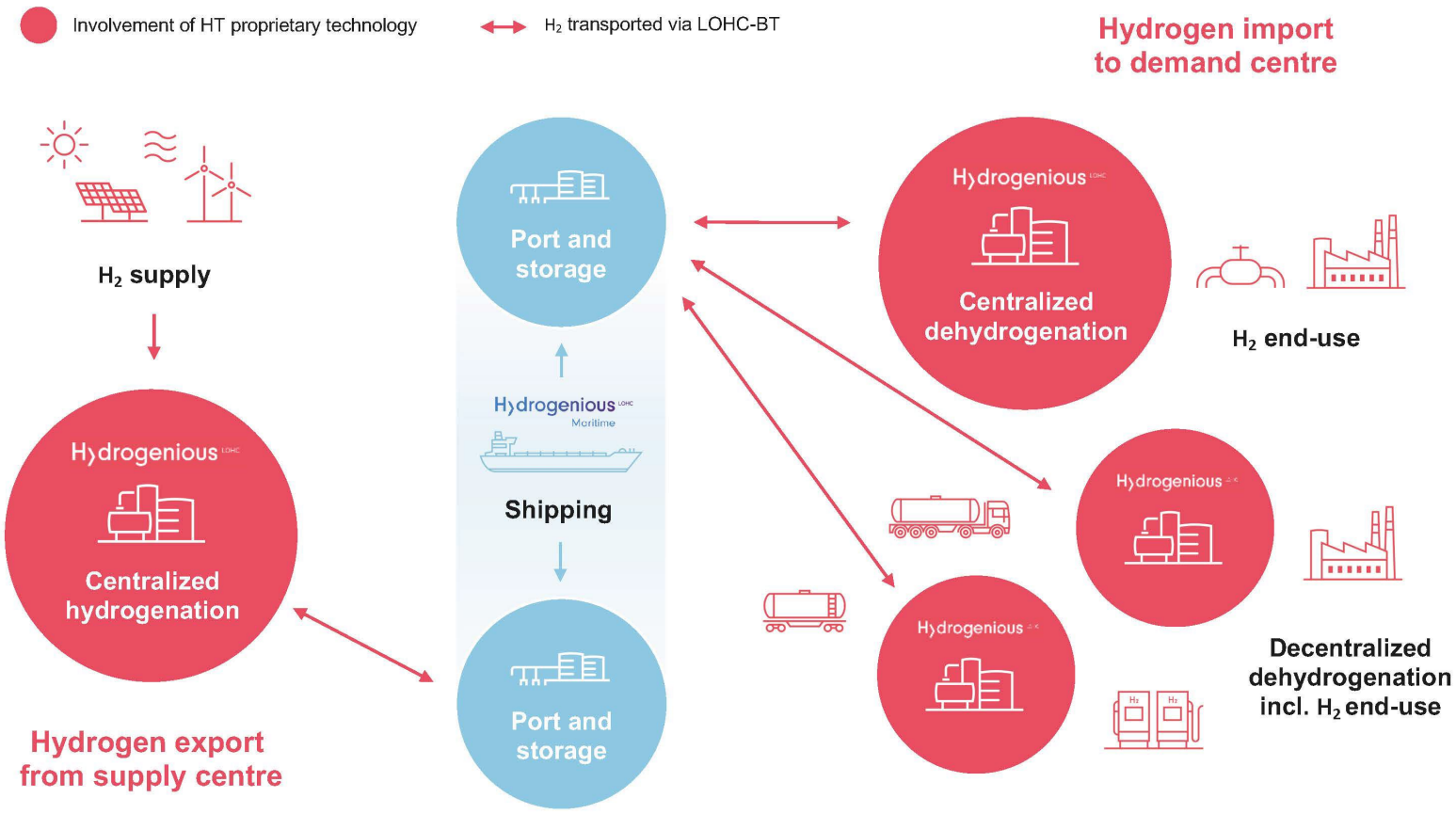
Mismatch of key supply and demand centers driven by capacity constraints and cost differentials will propel global H_2 trade



Green hydrogen cost in USD/kg 2030



LOHC-BT enabling H_2 end-to-end-imports



Hydrogenious LOHC

Our LOHC-BT technology is disrupting hydrogen infrastructure

Superior safety

- No handling of molecular hydrogen
- Hardly flammable with flash point 130 °C, nonexplosive, even when loaded with hydrogen
- Hazard potential even smaller than for diesel and thus clearly superior to ammonia

Enhanced flexibility

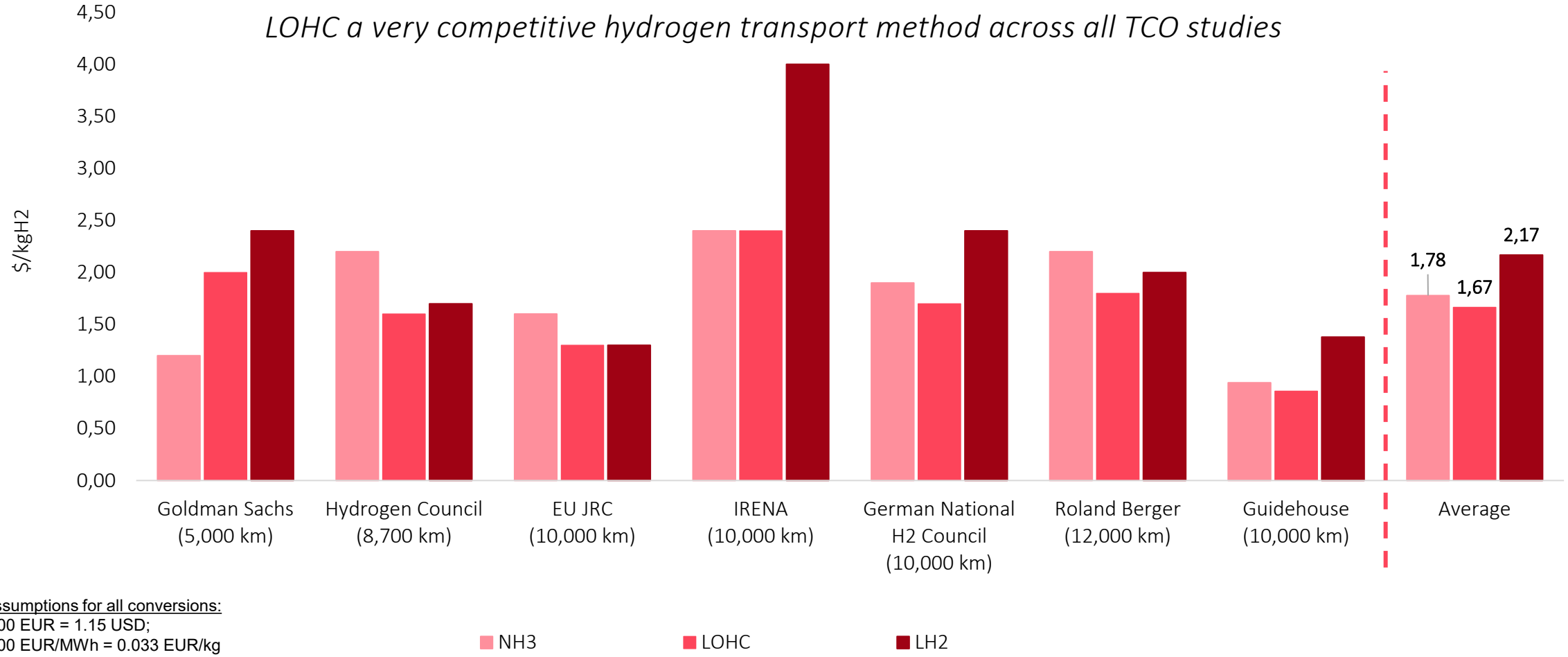
- Conventional liquid fuel infrastructure usable
- Handling at ambient temperatures and pressure during storage and transport
- No self-discharge over time – multi-month storage without losses

High efficency

- Competitive volumetric storage density of 54 kg hydrogen per m^3 LOHC
- Carrier material commercially available and reusable hundreds of times
- Fuel cell grade hydrogen purity according to ISO 14687 by using off-the-shelf purification technology

Overview over Studies of Costs of large-distance Hydrogen Transport

Time period from 2030 to 2050 depending on the study



Assumptions for all conversions:
1.00 EUR = 1.15 USD;
1.00 EUR/MWh = 0.033 EUR/kg

Hydrogenious LOHC

We have proven the LOHC value chain and are currently developing projects for international large-scale hydrogen trade routes

Containerized systems

- Proven technology
- Successful implementation in Germany, Finland and the US

12 systems delivered

Proven LOHC value chain

- Successful implementation of a comprehensive LOHC value chain
- Currently operating at the hydrogen refuelling station Erlangen

In operation

Capacity scale up for LOHC plants

- Capacity
  - Up to 24 H_2 tpd
- Reference Projects
  - Project Hector
  - Northern Green Crane
  - H2A

In construc-tion

Large-scale plants for int. H_2 import / export

- Capacity
  - Up to 500 H_2 tpd
- Reference Projects
  - Joint cooperation ADNOC-Jera-Uniper UAE <> Europe
  - Cooperation Greenergy Canada <> UK

Feasibility studies

Early Proof Points in Finland

Kokkola – Espoo

Successful Operation at -23°C

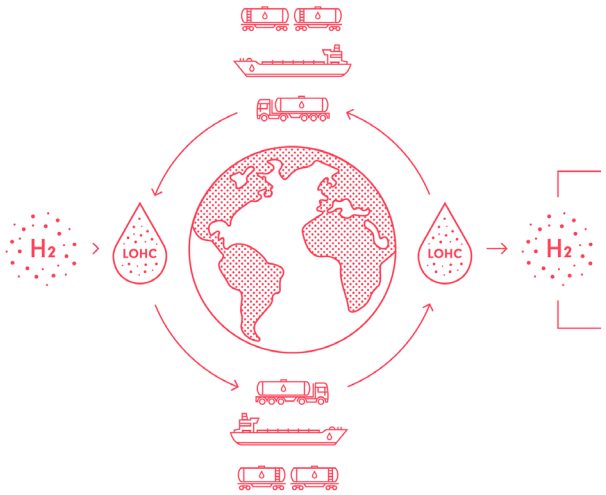
- **Scope:** H2 Production, H2 Storage, Transport, Release via LOHC & Operation/H2-Quality Test
- **Project consortium:** VTT, WOIKOSKI, FAU, crt, HYGEAR, Hydrogenious LOHC
- **Operation** Start: 11/2020 & 02/2021 End: 03/2022
- **Input/Output** 24kg (H_2)/day
- **Funding & Support** FCH | FUEL CELLS AND HYDROGEN JOINT UNDERTAKING, HySTOC

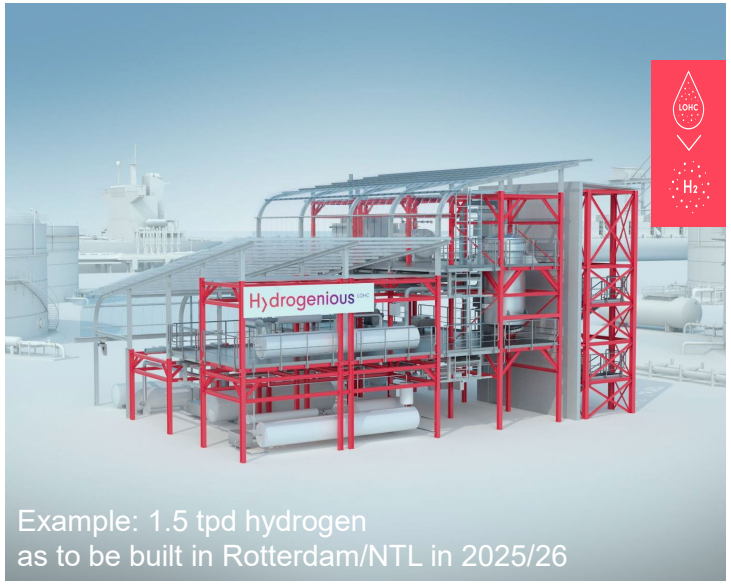
H_2 Production, H2 Storage StorageBOX

Gas analysis, H_2 Release ReleaseBOX

Skid-based industrial hydrogenation/dehydrogenation unit to match with renewables and hydrogen hubs

Example: 5 tpd hydrogen
as to be built in Chempark Dormagen/GER in 2024





Example: 1.5 tpd hydrogen
as to be built in Rotterdam/NTL in 2025/26

Hydrogenation process

Exothermic, with solid catalyst

Heat Release

Approx. 10 KWh/kg H_2, 200 – 250°C
Approx. reaction pressure: 15 – 30 barg

Dehydrogenation process

Endothermic, with solid catalyst

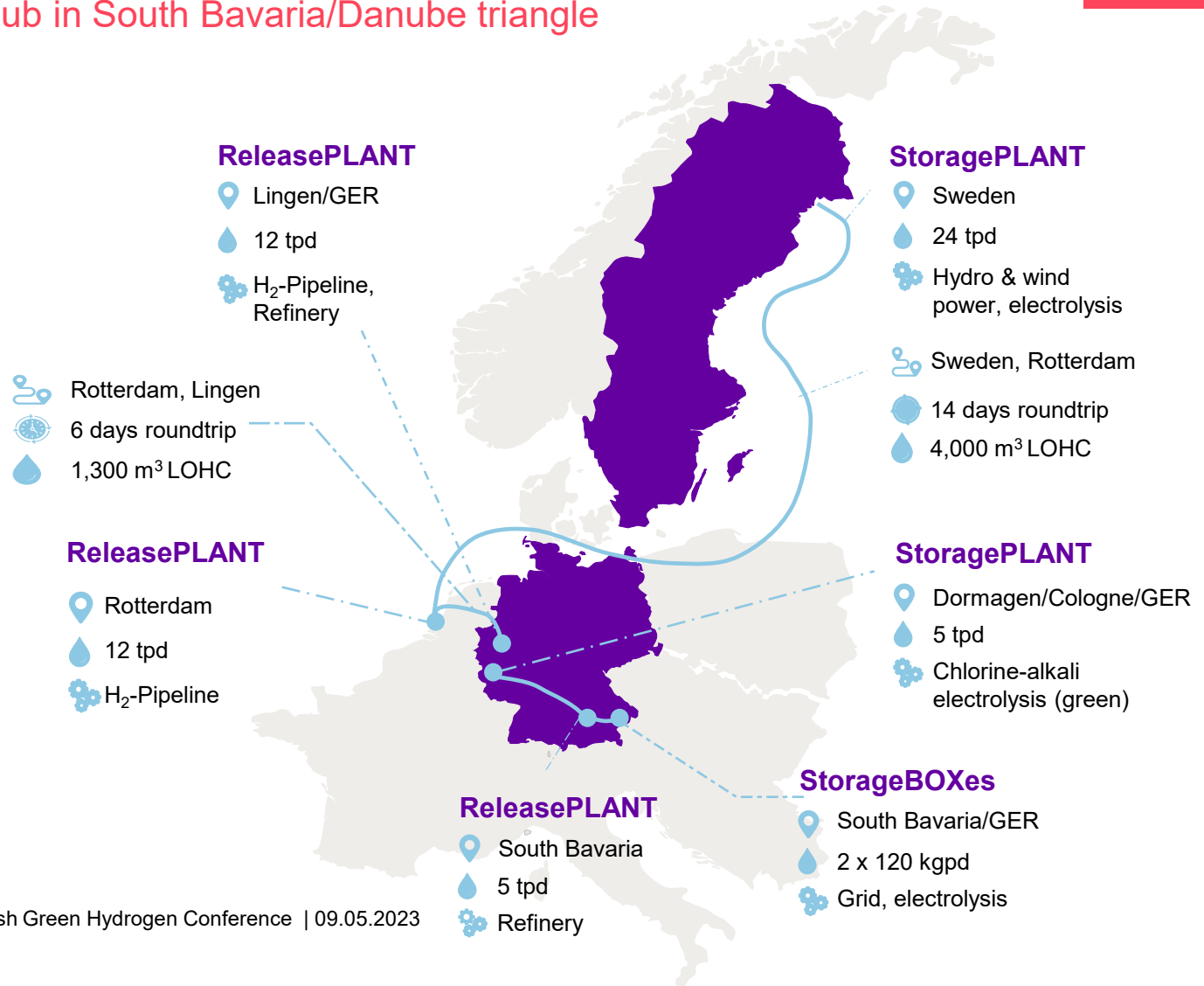
Heat Demand

Approx. 11 KWh/kg H_2, 250 – 300°C
Approx. reaction pressure: 2-3 barg

Hydrogenious LOHC

German IPCEI pre-candidates

LOHC supply chain Sweden <> Netherlands <> Germany
LOHC hub in South Bavaria/Danube triangle



Northern Green Crane & Green Hydrogen@ Blue Danube

Building the LOHC infrastructure within Europe, erecting several storage & release plants

Both projects qualified in Germany in the IPCEI pre-selection process (among 62 others in Feb 2021) along with partner applications in Sweden and the Netherlands (part of fast moving RHATL wave)

Hydrogenious LOHC

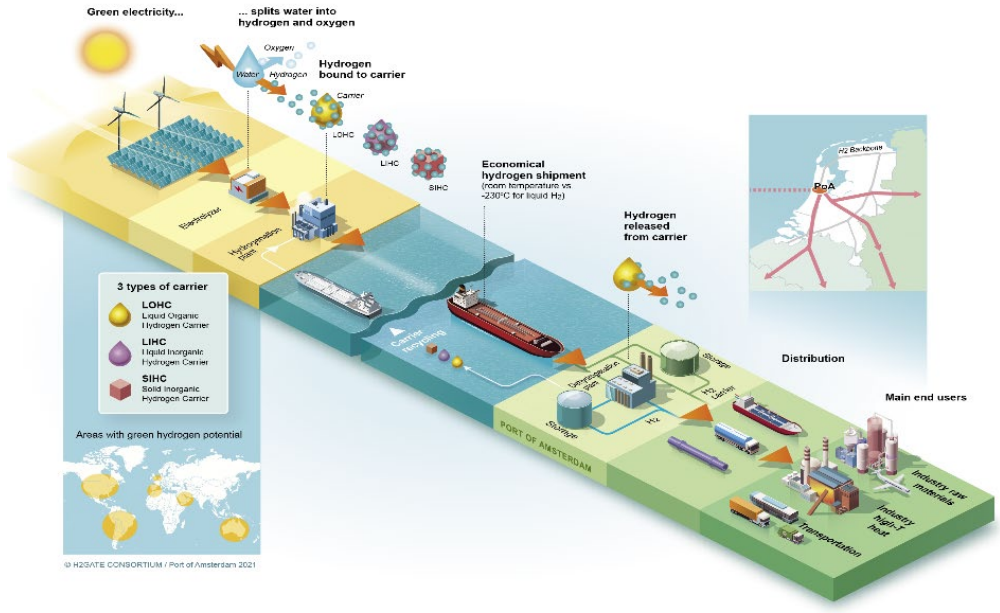
Port of Amsterdam-Hydrogenious-Evos

NTL/Port of Amsterdam

Up to 1 mn green H_2 tpa imports final size

› **Feasibility study:**	Conducted in previous H2Gate project with LOHC as ideal H_2 carrier option
› **Project consortium:**	Port of Amsterdam EVOS
› **Commissioning:**	Before end of decade
› **Hydrogen storage and transport:**	Up to 30 H_2 ktpa [~100 tpd]

H2A
one million tons of green hydrogen



International hydrogen supply chains at scale

Europes hydrogen supply by joint efforts on three continents

UAE/Abu Dhabi <> Europe

أدنوك ADNOC uniper JERA

Canada <> UK

Greenergy

Morocco <> Europe

CWP GLOBAL

Hydrogenious LOHC

Established in 2013, we are the global leading technology pioneer for LOHC

Investors

APVentures ADVANCE & PIONEER
ANGLO PLATINUM
Vopak
covestro
HYUNDAI
Chevron
jera Energy for a New Era
Pavilion Capital
TEMASEK
Mitsubishi Corporation
Winkelmann Group

Key partners

Østensjø Rederi
MAN Energy Solutions
FRAMES
BILFINGER
EASTMAN
ARKEMA
CLARIANT

Technology cooperation partners

FAU Friedrich-Alexander-Universität Erlangen-Nürnberg
HI ERN Helmholtz Institute Erlangen-Nürnberg part of Forschungszentrum Jülich
HC·H2 Helmholtz-Cluster Wasserstoff

>200
employees

>55
patent families

>80mn
investor funding

Q&A

Kiitos!

Let’s carry the new energy world together.

Contact

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Hydrogenious LOHC

World's 1st LOHC supplied hydrogen refueling station in Erlangen, Germany

Green H_2 supply chain scheme
Solar Power – PEM Electrolyser – LOHC Storage – Transport – LOHC Release – HRS

HRS opened in 2022

Minimal footprint

Worldwide first underground storage of 1.5 tons of hydrogen via LOHC-BT (ambient conditions)

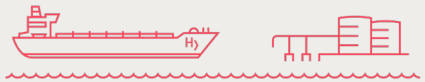
Hydrogen quality (fuel cell purity) according to ISO 14 687-2

LOHC storage tanks
ambient conditions
2x 30m³

1,500 kgH_2

Hydrogenious LOHC

LOHC logistics is easy and efficient: We utilize conventional liquid fuel infrastructure



By ship

- Hydrogen transport capacity per trip: up to **17,000 t** (VLCC)
- Ideal for large scale hydrogen transport over long distances
- Import of low-cost green hydrogen to consumption markets

By train & barge

- Hydrogen transport capacity per trip: up to **59 t**
- Ideal for transport and distribution over medium distances
- Highly flexible distribution enabling global market supply

By tank truck

- Hydrogen transport capacity per trip: up to **1.6 t**
- Ideal for short distances and distribution
- Standard unpressurized aluminum tank
- Connecting isolated regions to the hydrogen world
- Simultaneous receiving and discharging of LOHC (up to 1,000 l/min)

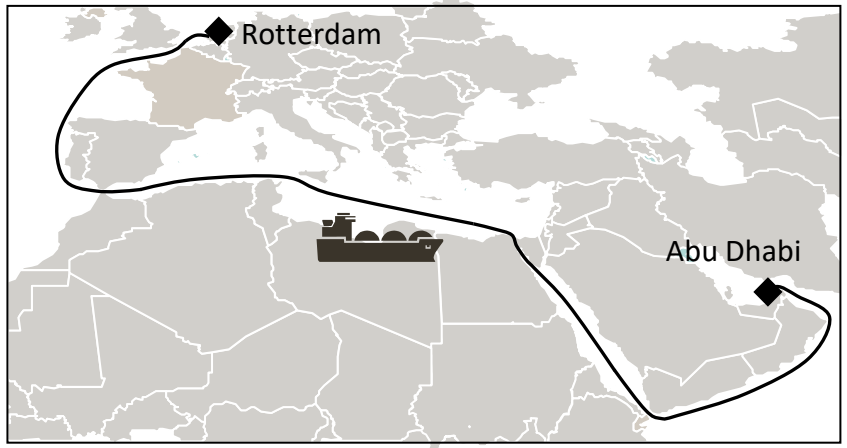
Infrastructure

- Storage and transportation at ambient conditions
- Easy and fast handling by pumping a liquid
- Low CAPEX due to reuse of conventional fossil fuel equipment
- Repurposing of infrastructure for port and other energy hubs as well as ship, rail and train

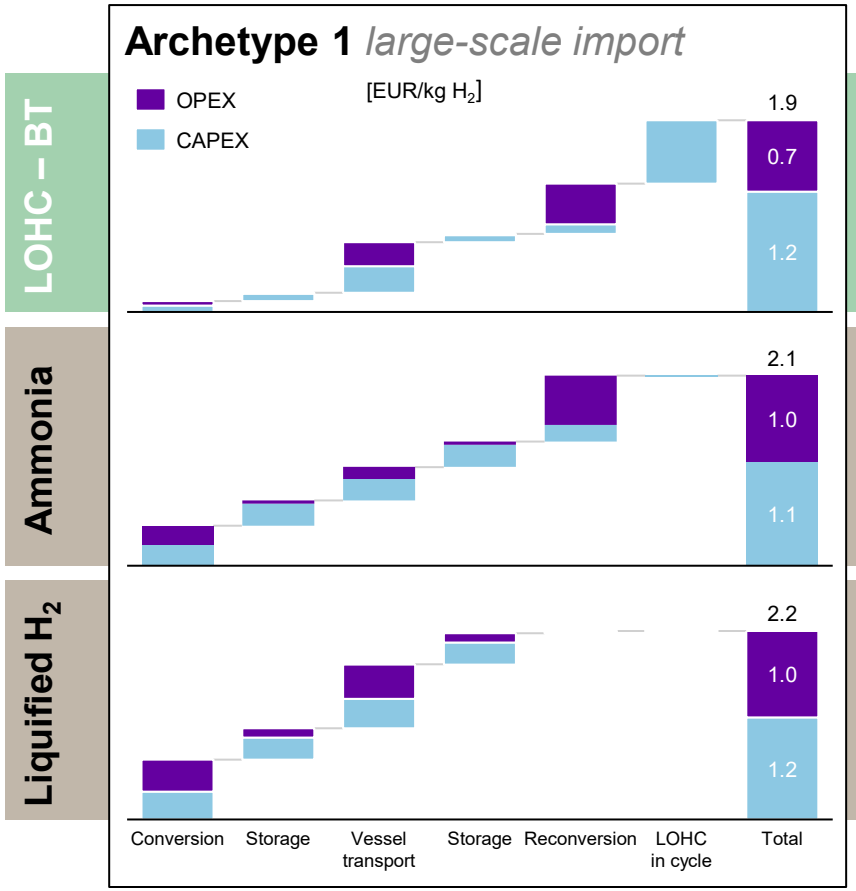
Hydrogenious LOHC

LOHC-BT with strong TCO competitiveness in long-distance and upside from advantageous hazard and toxicity profile versus NH_3

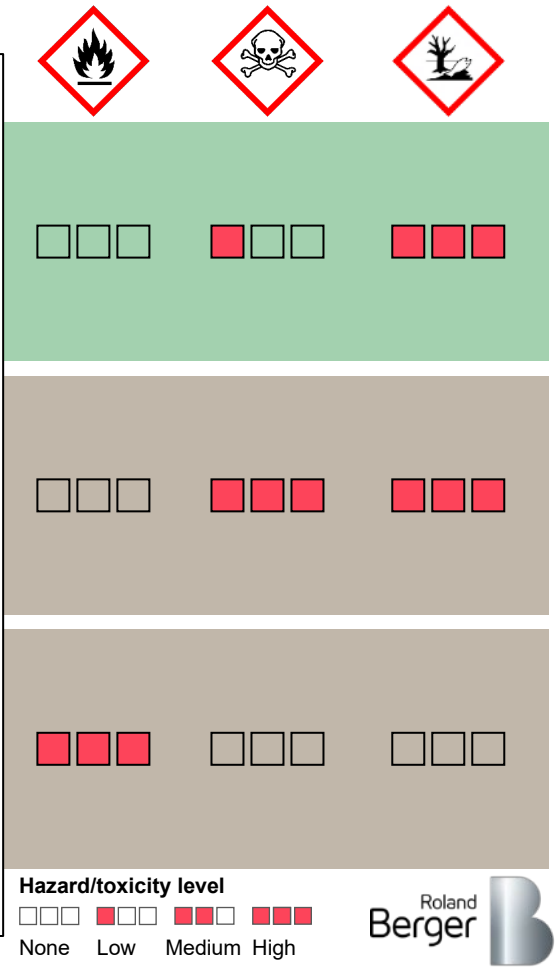
Archetype 1: Large-scale import – year 2030



- 200 tpd
- 2 x 100 tpd
- ~12,000 km via vessel (one-way)
- ~46 days per roundtrip (incl. port days)
- ~50,000 DWT[1)] (vessel)
- 4 vessels
- 180,000 m^3 of storage capacity at each location
- ~236,260 t LOHC in the system



Hazard and toxicity profile



1. Depending on technology

Source: Roland Berger 2021; 2030 TCO values from linear interpolation between 2025 and 2035

Various studies confirm that LOHC is a highly cost competitive, high potential mid-stream solution

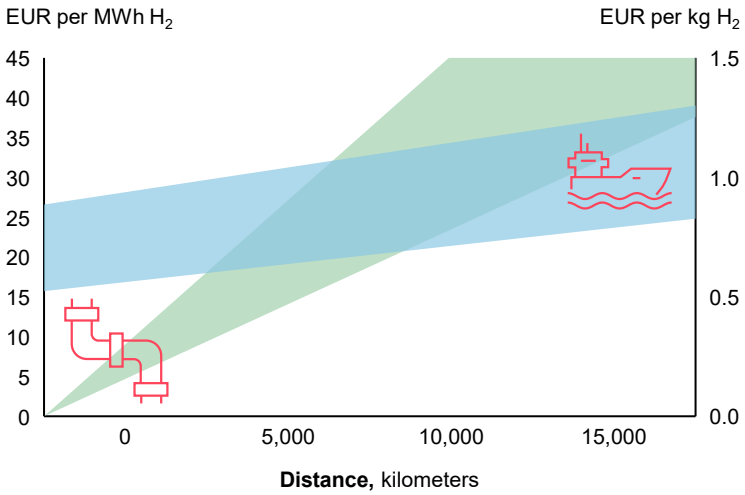
H_2 transport cost via ship (upper: liquefied H_2, lower: LOHC)

H_2 transport cost via pipeline (upper: 48 inch new, lower: 48 inch retrofitted)

Guidehouse: Covering Germany's green hydrogen demand: Transport options for enabling import

Cost comparison of shipping and pipeline hydrogen transport routes

Note: Pipeline transport assumes 48 inch (1,200 mm) in thickness, 12.7 GW and 80 bar for both new and repurposed pipelines



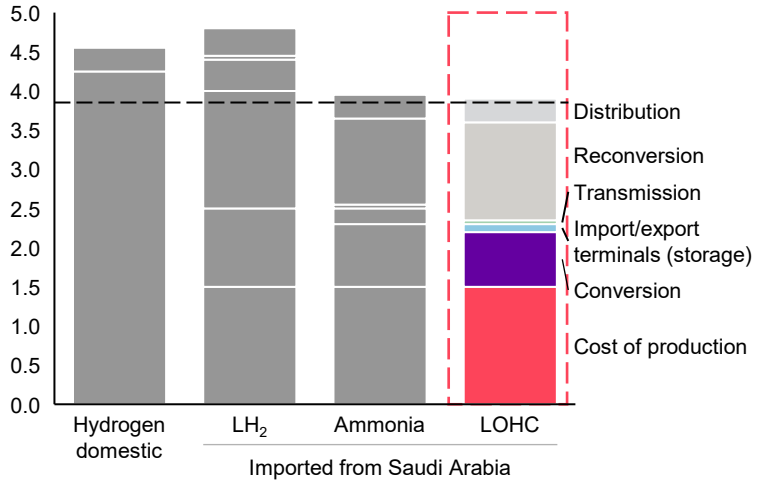
Long-term, **LOHC is the most economic option for transport via shipping**

Goldman Sachs: Carbonomics (2022)

All-in costs for North-West Europe importing green hydrogen from Saudi Arabia in 2022

Cost of delivering green hydrogen from Saudi to Europe

USD per kg H_2



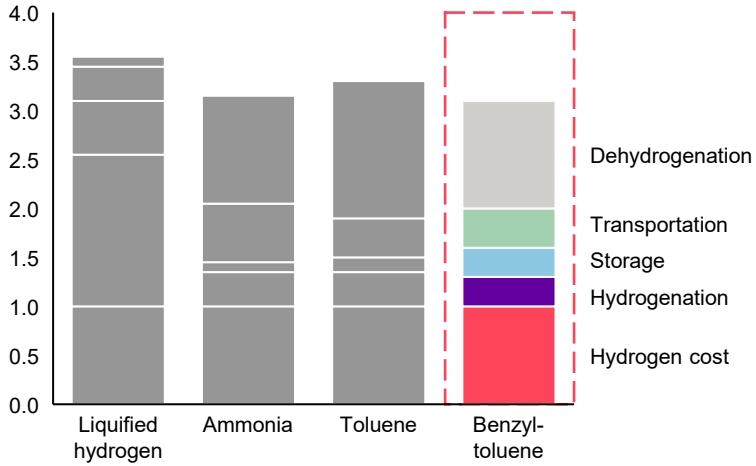
LOHC as „the" hydrogen carrier in terms of TCO and other aspects

Lux research: Hydrogen economy- The Cost of storage (2022)

Liquid and chemical hydrogen storage in 2022

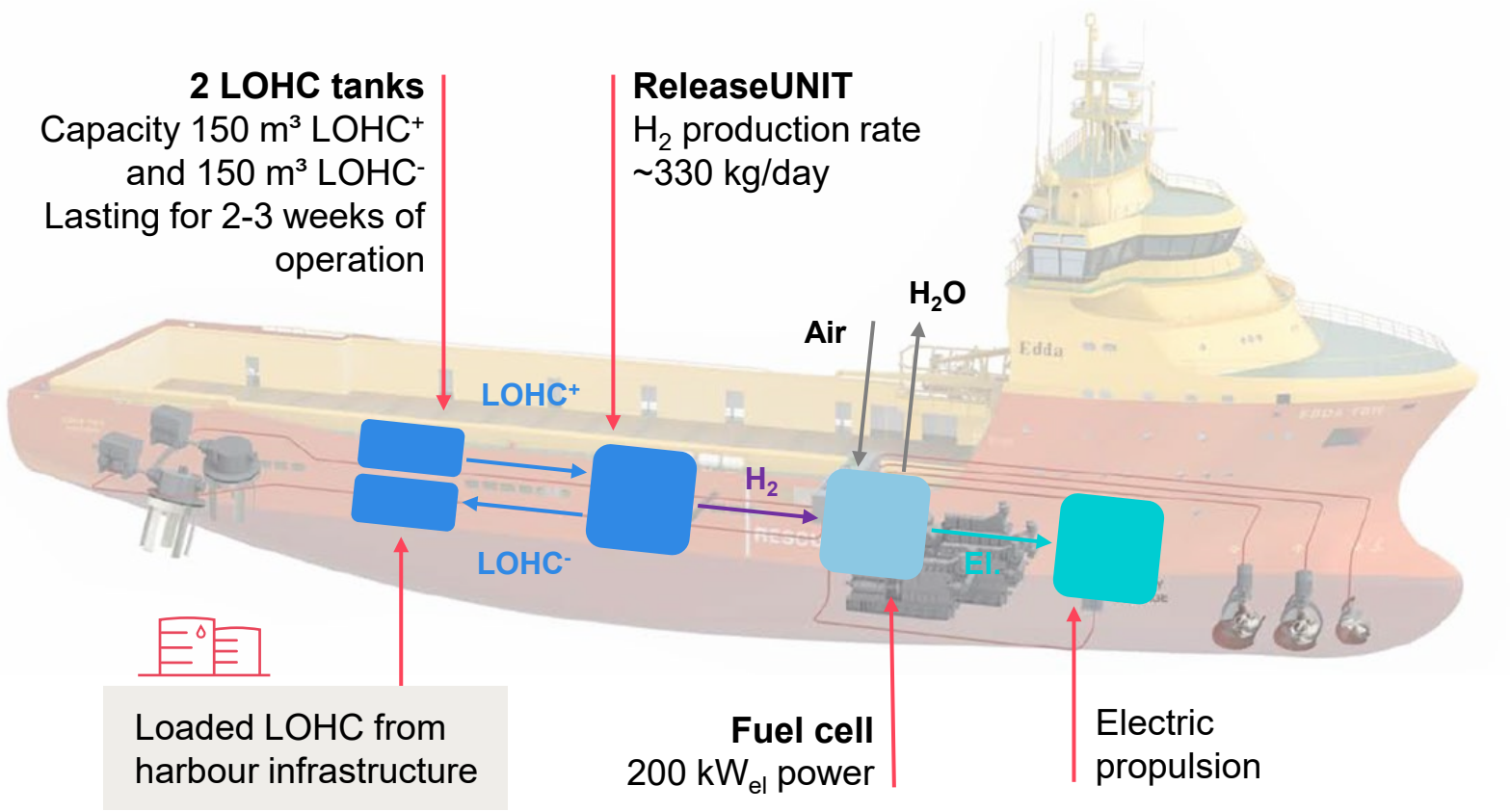
Cost of storage and transport

USD per kg H_2



LOHC, **in particular BT well positioned** vs. alternatives

In our Norwegian JV we work on making LOHC become a maritime fuel with commercial pilots on the way



Østensjø Rederi

JV formed in 2021
for development and commercialization of LOHC-BT fueled powertrain with Østensjø.

Partnerships established with

Alma

- JDA with Alma Clean Power for developing first-of-its-kind LOHC-SOFC system
- System integrator for power management and electric drive
- End-customers

Hydrogenious LOHC Maritime

First ships for integrated LOHC-powered on-board drivetrain: 2 LOHC-BT ready ships delivered, 4+ in order pipeline

First-of-their kind ships LOHC-BT ready hybrids with LOHC-BT rooms installed

Initially 200 kW LOHC-BT-fuel cell system to power vessel's auxiliary power

Upgrade to MW system powering vessel propulsion envisioned