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LOHC TECHNOLOGIES

LIQUID ORGANIC HYDROGEN CARRIERS – A TECHNOLOGY TO OVERCOME COMMON RISKS OF HYDROGEN STORAGE

ICHS2021 – Hydrogen storage – ID5

21st September 2021

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Agenda

- LOHC technology and its market
- Chemistry, physical and eco toxic properties
- Projects, risks and scale-up
- Outlook on marine systems

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Hydrogenious LOHC Technologies GmbH

Established in 2013, we are a global technology leader for Liquid Organic Hydrogen Carrier today

>120
Employees

>45
Patent families - growing

€ >80 Mio
Investor Funding received

Hydrogenious is **well-known worldwide and considered a pioneer in its field**

Hydrogenious has a **strong position in IP and patent protection world-wide.**

Investors

ANGLO PLATINUM
APVentures ADVANCE & PIONEER
covestro
HYUNDAI
株式会社JERA
Chevron
Pavilion Capital
Winkelmann Group
Vopak
TEMASEK
Mitsubishi Corporation

Technology Cooperation Partners

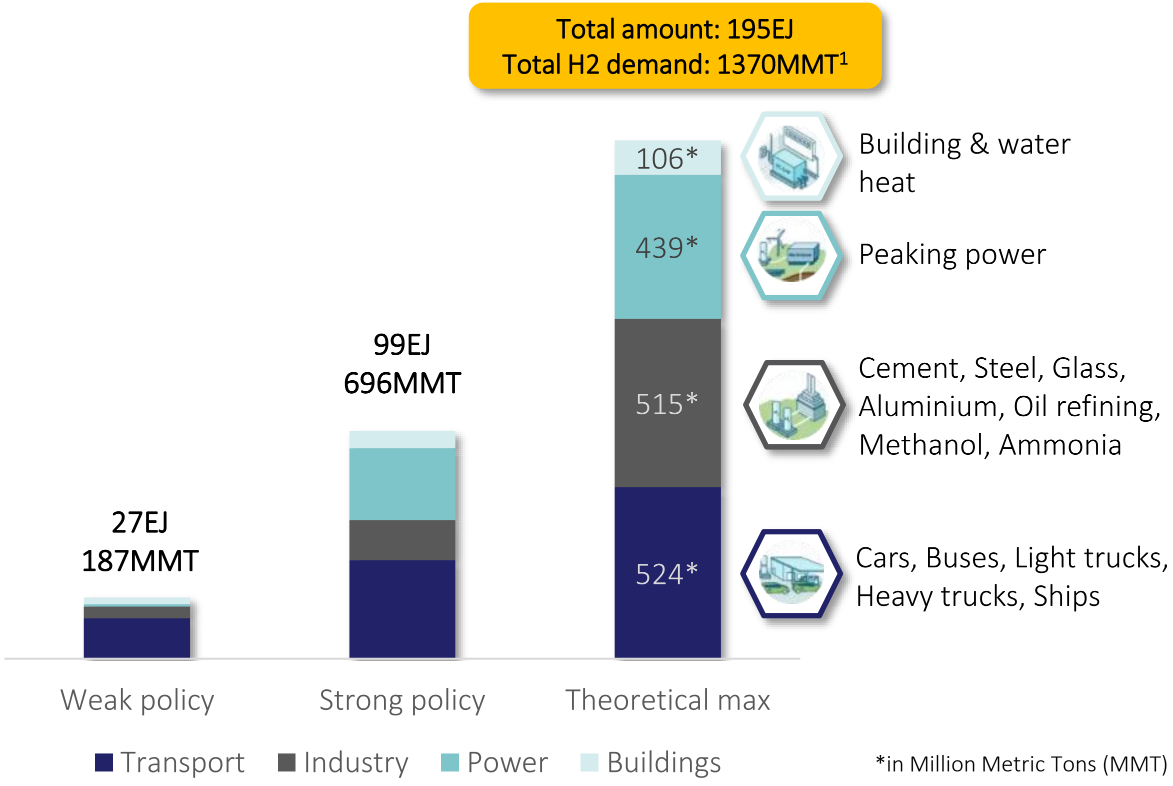
FAU Universität Erlangen
HI ERN Helmholtz Institute Erlangen-Nürnberg part of Forschungszentrum Jülich

Key Partners

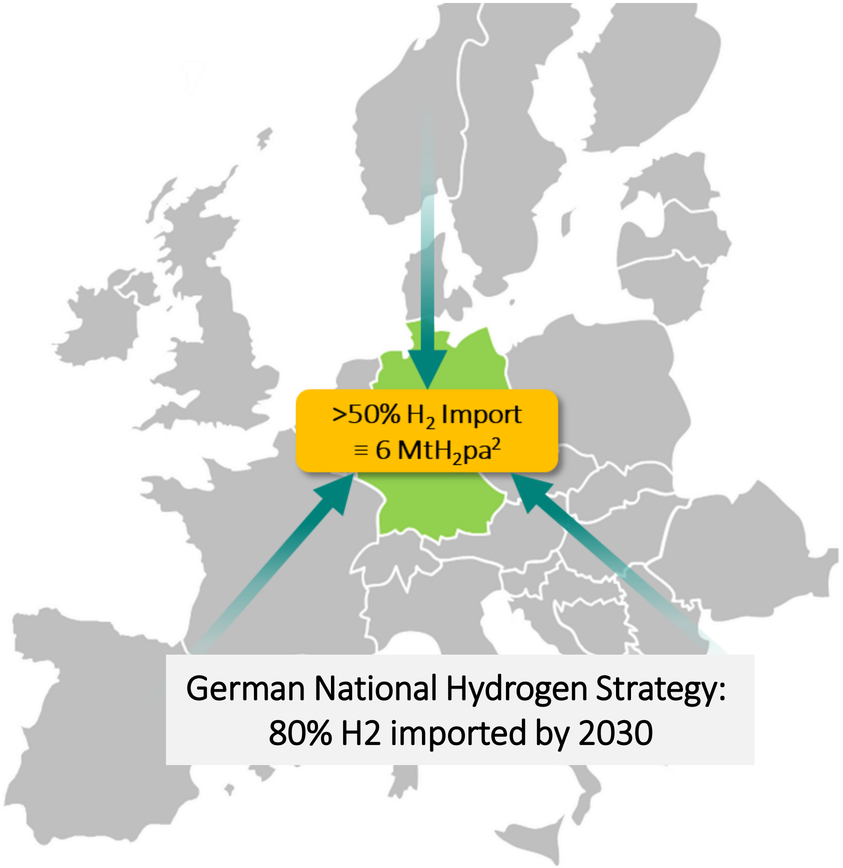
Østensjø Rederi
MAN Energy Solutions
FRAMES
CLARIANT
ARKEMA INNOVATIVE CHEMISTRY
EASTMAN

Decarbonise the world: Hydrogen demand will increase dramatically and also the demand for safe and easy transport of hydrogen

Potential global demand for hydrogen by 2050



Prognosis of hydrogen imports for Germany by 2050



Europe: Large scale hydrogen import will be mandatory due to limited national H2 production capacities

1) BloombergNEF, 2020

2) Juelich Institute, M.Robinius et al. „Wege für die Energiewende“, 2019

Global H_2 value chain and transport options needed due to cost differences in H_2 production – LOHC as the “Missing link”

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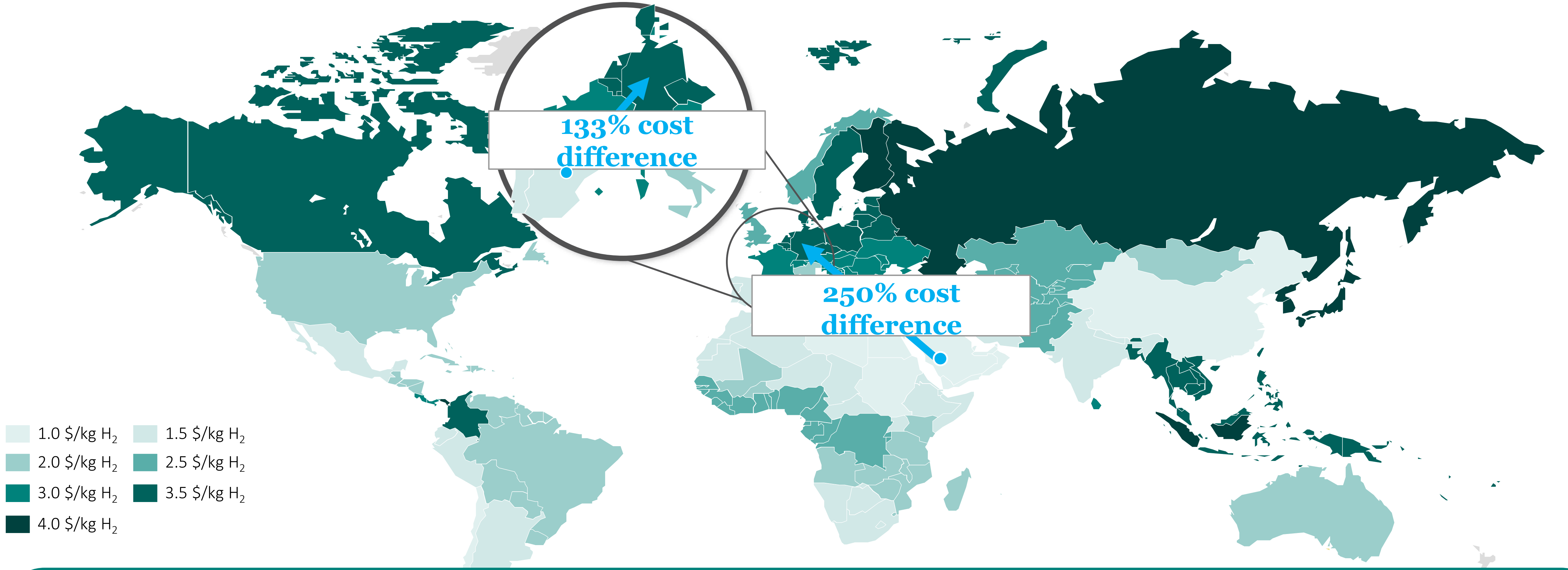
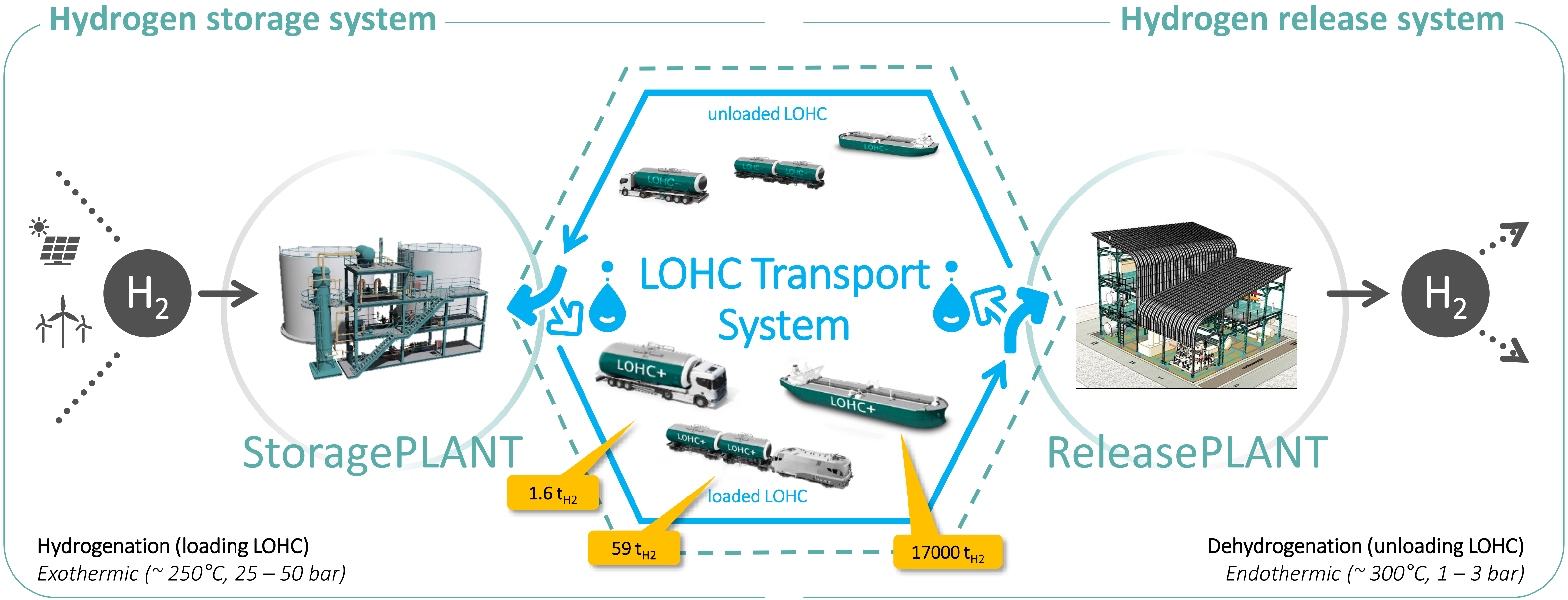
Significant hydrogen production cost delta[1]



Cost differences in future hydrogen production will define sourcing strategies and global distribution
Efficient, safe and flexible handling of H_2 to connect supply and demand across the globe

1) Source: IEA 2019, The future of hydrogen and *IEA 2019, Hydrogen: A renewable energy prospective (value PV costs 2050)

LOHC technology leverages the existing liquid-fuel infrastructure by transporting hydrogen in a liquid at ambient conditions



Safe:
Hardly flammable liquid

Efficient:
High energy density

Flexible:
Use of existing infrastructure

Hydrogenious LOHC' vision of a global hydrogen economy

Sustainable hydrogen sourcing

Renewable hydrogen

- Wind & hydro @ <3 ct/kWh
- Solar @ <2 ct/kWh
- >5.000 h/year production

By-product hydrogen

- Chlorine-alkali electrolysis
- Others

Hydrogen distribution

Globally Existing Infrastructure

1 Ship Transport
International

- Oil tankers & storage facilities
- Large scale

2 Rail Transport
(Inter)-national

- Efficient rail network
- Multi-ton transport

3 Road Transport
National / regional

- Bulk delivery
- High flexibility

Diversified demand sites

1 Pipeline hubs
International

- Green hydrogen from international sources for pipeline distribution

2 Large industry
International

- Large-scale industrial customers with renewable heat demand
- Green hydrogen as base chemical

3 HRS & medium scale industry
Distributed national

- High-capacity HRS
- Hydrogen as base chemical and utility

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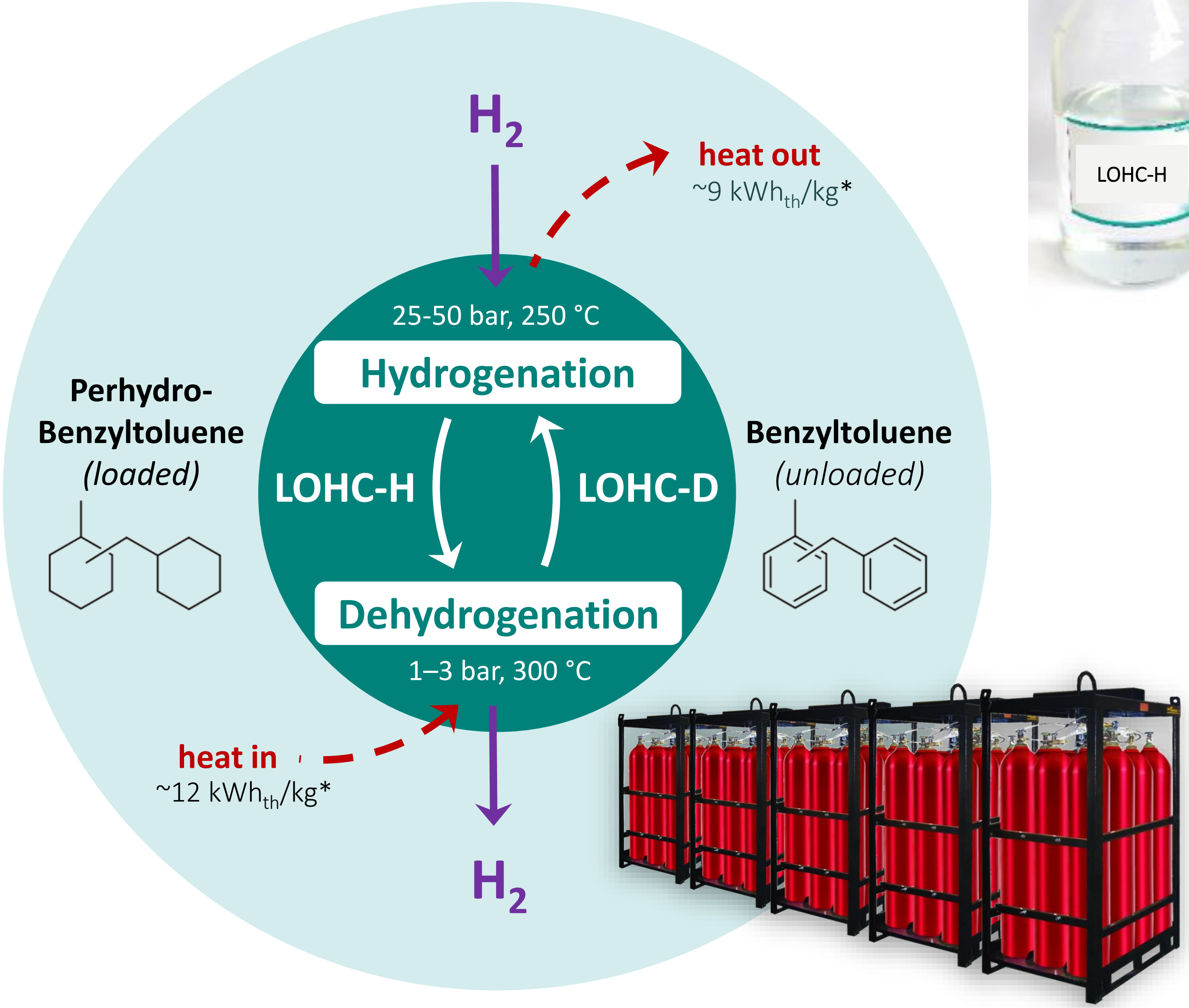
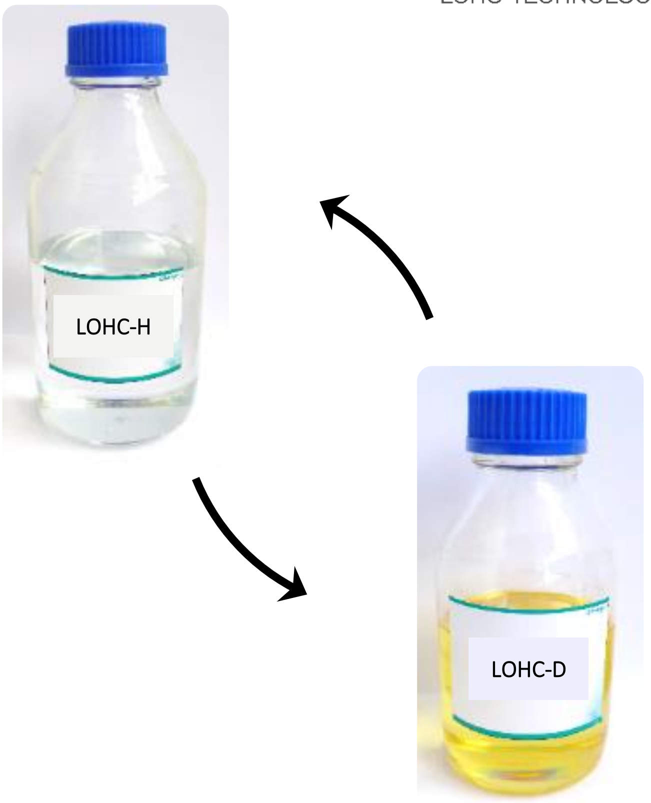
Hydrogenious’ LOHC technology utilizes a well known heat transfer fluid in a circular reaction scheme

(Perhydro-)Benzyltoluene

- Non-explosive
- Diesel-like liquid
- Hardly flammable
- Pour point < -30 °C
- Viscosity (dynamic)
  4.4 – 6.3 mPas; 20 °C
- Stored at ambient conditions
- 54 kg_{H2}/m^3_{LOHC} and 62 kg_{H2}/t_{LOHC}
- Commercially available product





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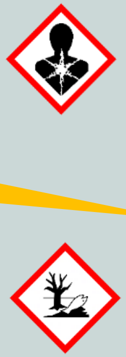
*technically usable heat – including scenario specific heat losses

BT has comparable eco toxic properties to today‘s energy carriers without their flammability and acute toxicity of NH3 and methanol

	DBT	BT	Toluene / MCH	(Marine) Diesel	Gasoline	Marine residual fuel	NH_3	Methanol	CGH_2 / LH_2
GHS symbol Further testing on behalf of ECHA currently ongoing									
Aquatic tox.	H410	H411	- / H411	H411	H411	H410	H400		
Carcinog./mutag.				H351/-	H350/340	H350/-			
Reproduct. tox.	H360FD	H360FD	H361		H361d	H361d			
Oral toxicity	H304	H304	H304	H304	H304			H301	
Contact toxicity		H315	H315				H314	H311	
Inhalat. toxicity							H331	H331	
Target organ tox.			H373	H373		H373		H370	

Hazard potential: HXX0 → HXX5

Handling hydrogen without its volatility and flammability is one of the major advantages of the LOHC technology

https://www.youtube.com/watch?v=9LnrNiHC_34

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StoragePLANT: LOHC Hydrogen Storage System

A scalable solution – applied process is state of the art in large scale hydrogenation at refineries

StoragePLANT 5 tpd

*StoragePLANT 5tpd incl. 2x750 m³ tanks

- Larger systems in development: up to 100-200 tpd

- Tank size and position can be defined flexibly depending on the project setting
- Tanks can also be included in scope of customer

	StoragePLANT 5tpd	StoragePLANT 20tpd
Hydrogen capacity[a]	5 t/d // 210 kg_{H2}/h	20 t/d // 835 kg_{H2}/h
LOHC output[a]	4,500 l/h	18,300 l/h
Heat production[a]	1,900 kW_{th}	7,500 kW_{th}
Load range	30 – 100 %	

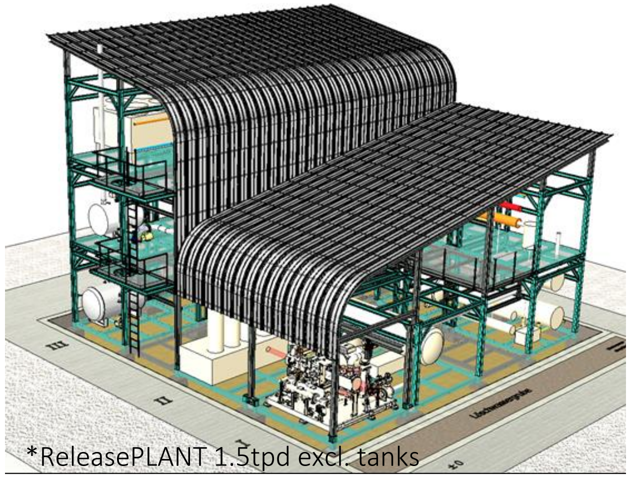
[a] under nominal load

Footprint	Skid-based
Inlet hydrogen stream	20 – 50 bar, 99.99 % purity
Inlet LOHC stream	≥ 0.1 barg
Power connection	400 V AC, 3 phase, 50 Hz

ReleasePLANT: LOHC Hydrogen Release System

Scalable centralized or on-site solution

ReleasePLANT 1.5tpd



*ReleasePLANT 1.5tpd excl. tanks

- Larger systems in development: up to 100 tpd
- Optimized footprint suitable for application at HRS

- LOHC underground tanks in portfolio
- Tank size and position can be defined flexibly depending on the project setting
- Tanks can also be included in scope of customer

	ReleasePLANT 1.5tpd
Hydrogen outlet[a]	1.5 t/d // 65 kg_{H2}/h
LOHC demand[a]	1,400 l/h
Heat demand[a]	780 kW_{th}
Load range	50 – 100 %

[a] under nominal load

Footprint	Skid-based
Inlet LOHC stream	≥ 0.1 barg
Power connection	400 V AC, 3 phase, 50 Hz

HRS Erlangen, Germany: LOHC-based Green Hydrogen Value Chain for H2 Mobility

Scheme: Solar Power – PEM Electrolyzer – LOHC Storage – Transport – LOHC Release - HRS

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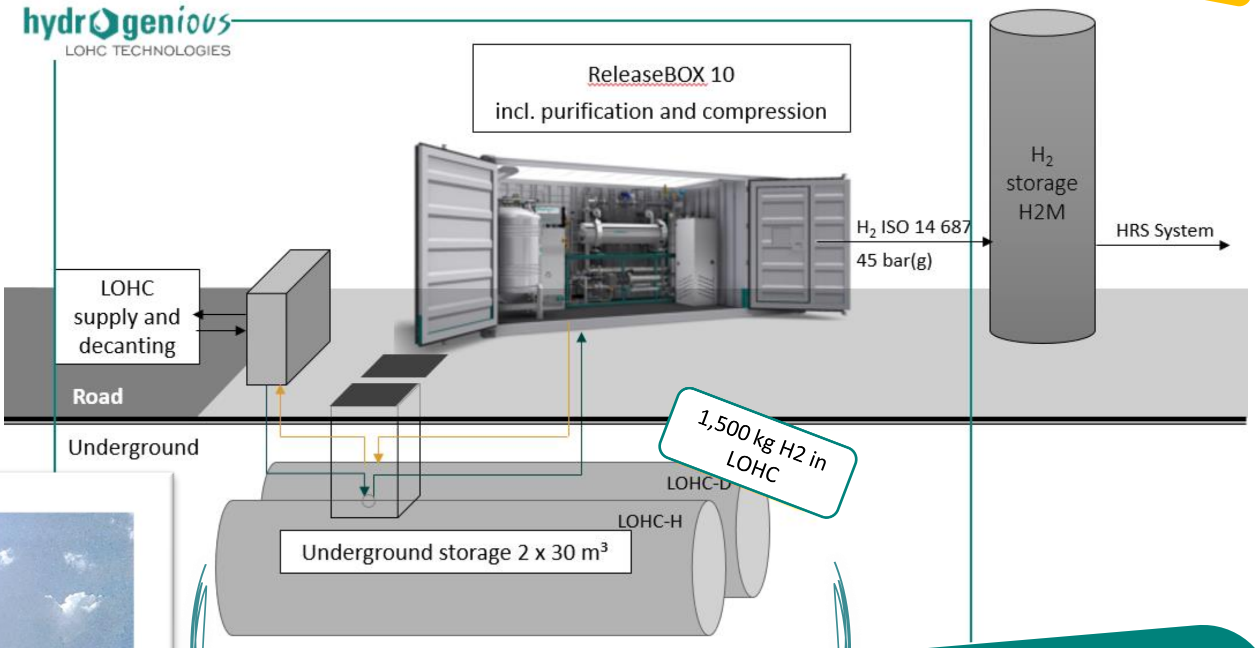
Project under construction

Project description

- Implementation of first Hydrogen Refueling station to be supplied via LOHC
- Opening in mid 2021 in Erlangen, supported by public funding (by State of Bavaria)
- Worldwide first underground storage of 1.5 tons of hydrogen via LOHC
- Hydrogen quality according to ISO 14 687-2



- ✓ Easy logistics
- ✓ Minimal footprint
- ✓ High safety due to absence of molecular hydrogen
- ✓ Large amounts of H2 stored on site

Key Partners

H_2 MOBILITY WASSERSTOFF TANKEN

Gefördert durch

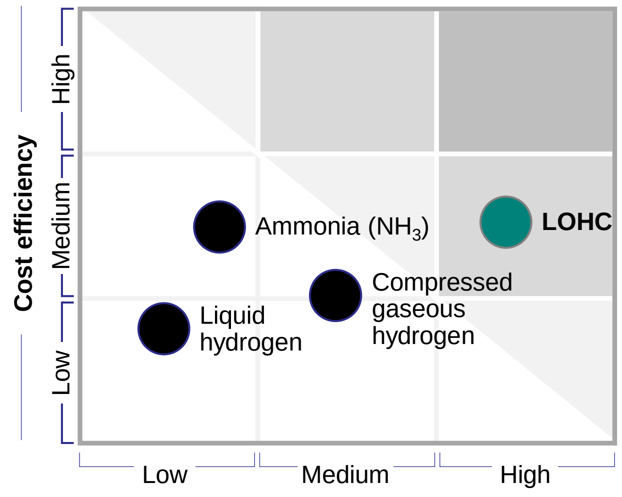
Bayerisches Staatsministerium für Wirtschaft, Landesentwicklung und Energie

Project Blue Danube: A pan-European supply chain for green hydrogen in the Danube region

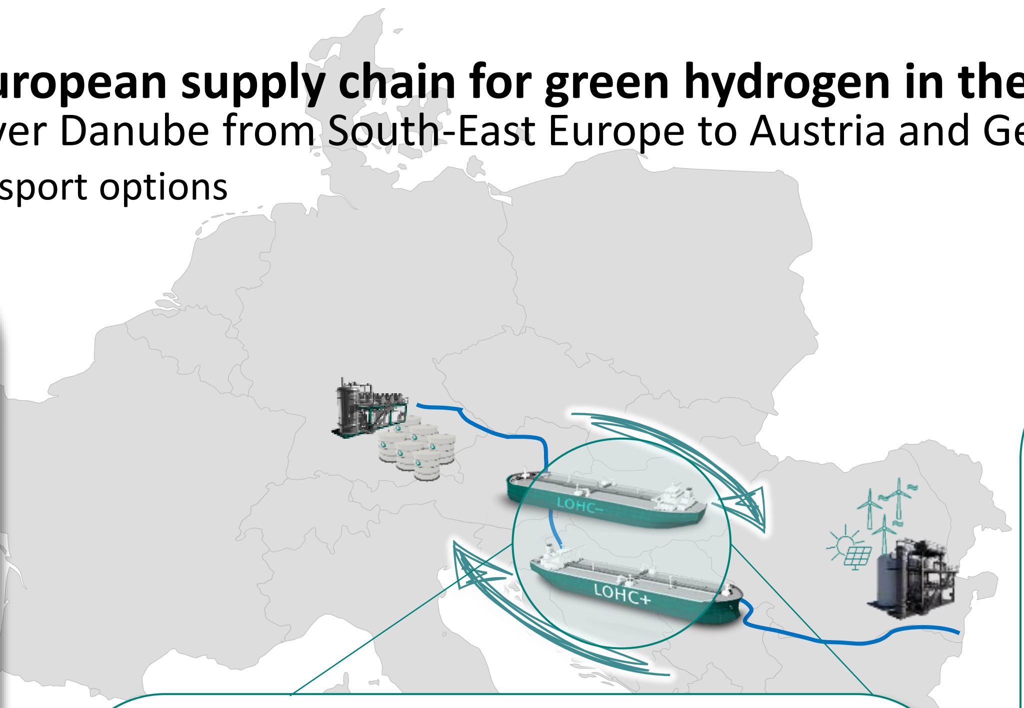
Hydrogen-LOHC distribution via river Danube from South-East Europe to Austria and Germany

Assessment of different hydrogen transport options

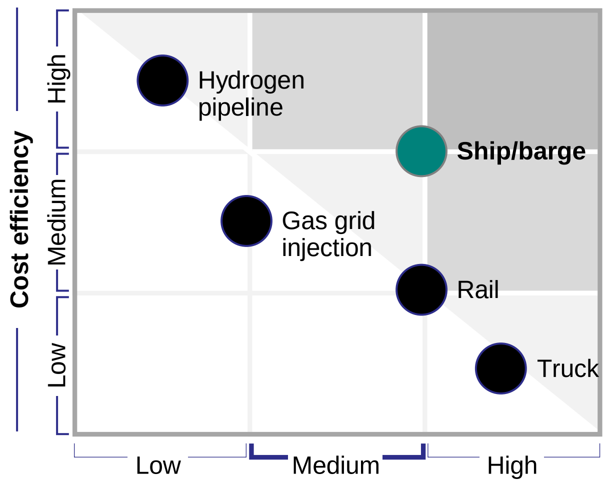
Conditioning*



Ease of implementation
(incl. safety/permitting, technology readiness, etc.)



Transport mode/infrastructure*



Ease of implementation
(incl. permitting, technology readiness, regulatory readiness, etc.)

Advantages of H2 transport in LOHC river ships

- Transport in existing infrastructure
- Usage of existing transport routes
- Large inland transport capacity
- Safe transport

Convoy on river Danube: 1 push-boat and 2 barges

186.000 kg_{H2}

Key Partners

Verbund
SIEMENS energy
bayernoil

*Source: Roland Berger

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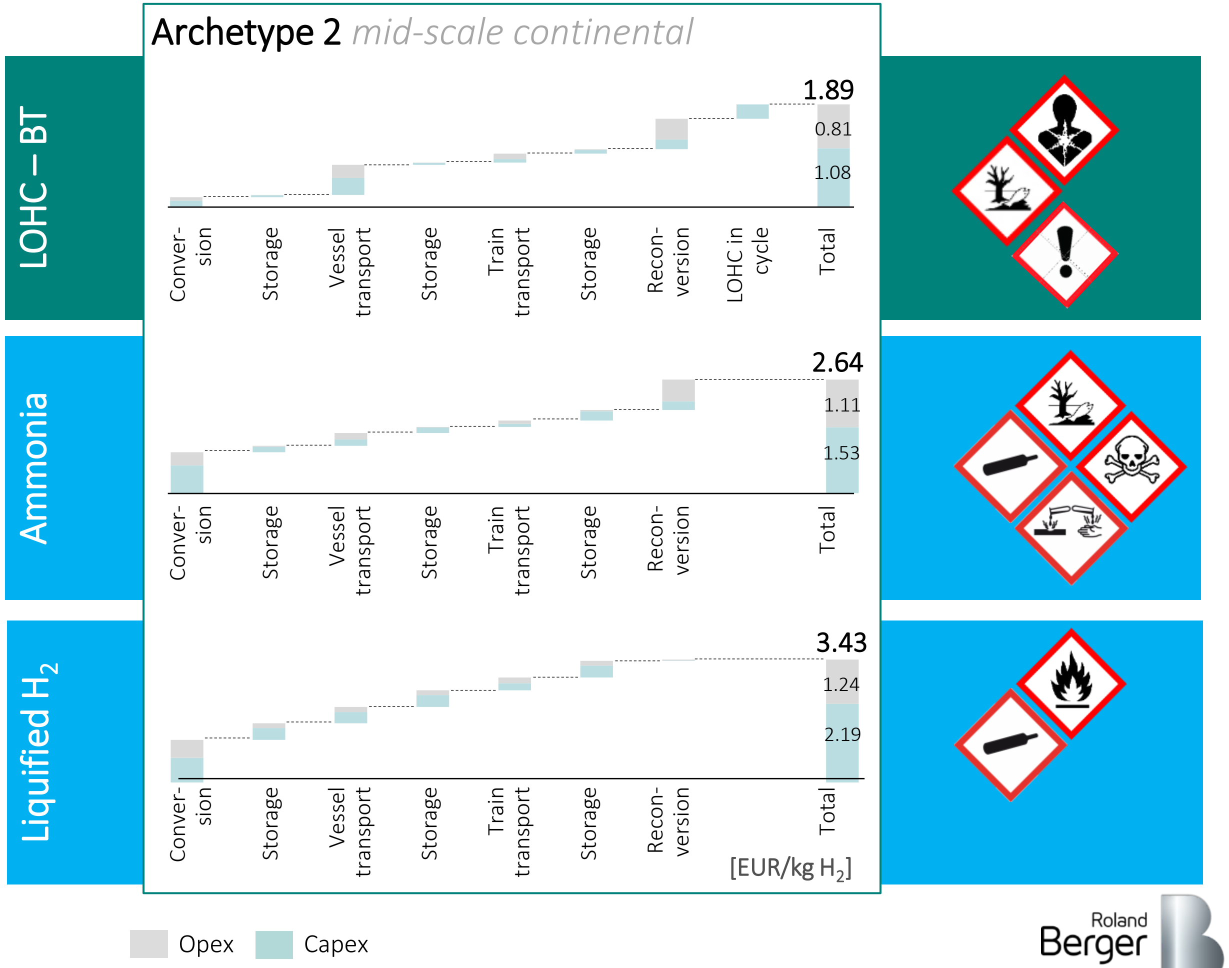
Improved cost competitiveness of LOHC technology in complex logistic chains

Archetype 2: Mid-scale continental – year 2035 –

- 20 tpd
- 20 tpd
- ~1,428 km via vessel + ~350 km via train
- ~12 days per roundtrip (vessel) + ~0.8 days (train)
- 1,570 m³ (vessel) + 2,700 m³ (train)
- 3 vessels + 30 wagons/train
- 23,000 m³ of storage capacity (total)
- 12,030 t LOHC in the system



Roland Berger

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Hydrogenious und Ostensjo Rederi have founded a Joint Venture in Norway for the development of LOHC-driven ships

Development and demonstration of a Multi-MW emission-free drivetrain on the basis of LOHC technology

Low cost hydrogen distribution
Use of existing fossil fuel infrastructure

Fast and familiar fueling process
Use of a liquid as a fuel

Low cost on-board storage
Use of existing fossil fuel storage tanks at ambient conditions

High safety
Minimal amount of molecular hydrogen

New Joint Venture

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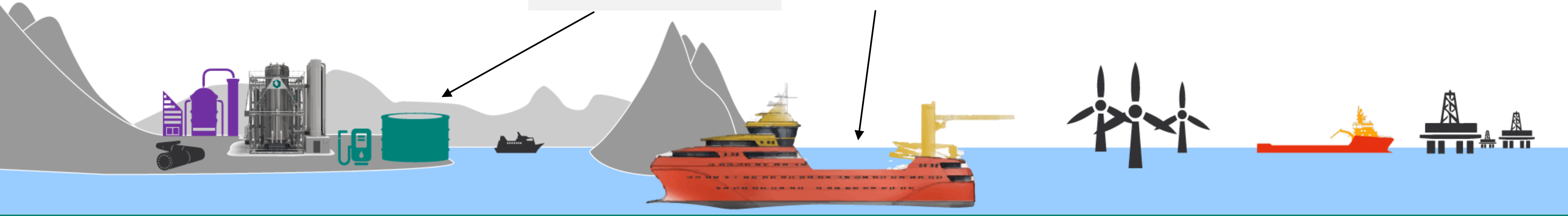
Østensjø Rederi

News

Hydrogenious LOHC Technologies and Østensjø Group Join Forces and Tread a Novel Path Towards Safe Zero-Emission Shipping

By FuelCellsWorks | July 2, 2021 | 7 min read (1186 words)



LOHC Technology enables safe & dense Handling of hydrogen onboard

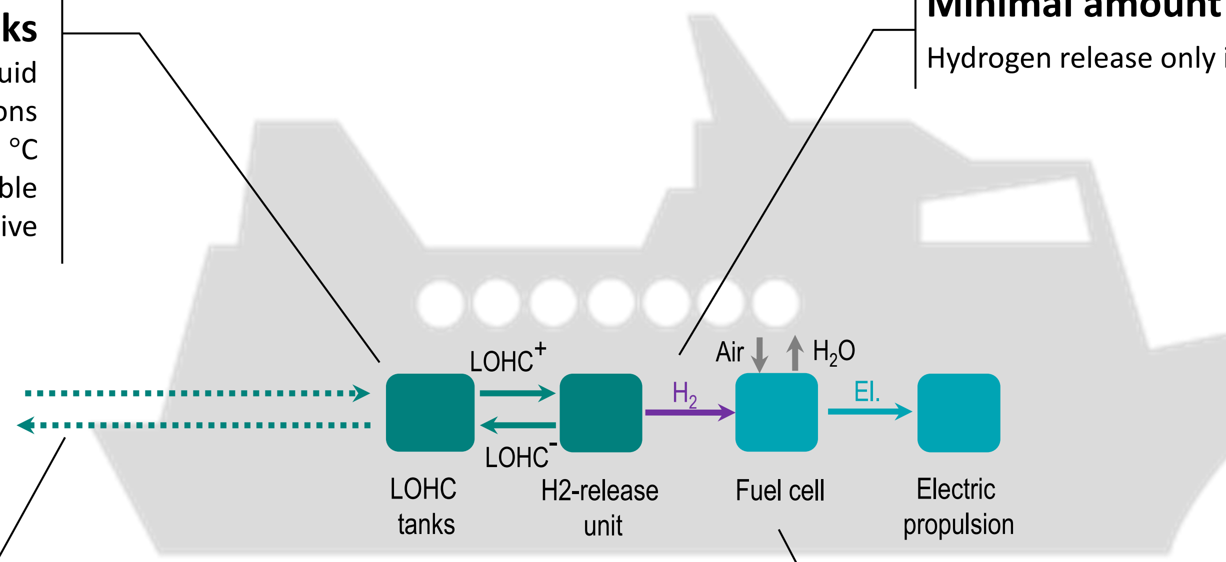
1 MW FC requires 60 kg/h; 350 m3 of LOHC is required for 14 days @ 1 ton H2 p.d.

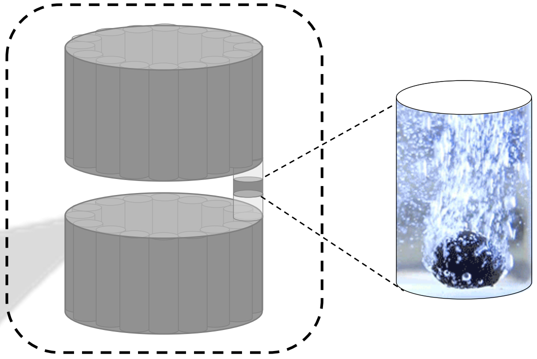
Conventional (existing) fuel tanks

Diesel-like liquid
Stored at ambient conditions
Liquid down to -35 °C
Hardly flammable
Non-explosive

Minimal amount of molecular hydrogen

Hydrogen release only in presence of catalyst and heat





Refueling by pumping a liquid

Fast refueling
Use of conventional pumps
Utilization of exising bunkering terminals
Cargo during refueling possible

H2 supply for different propulsion concepts

PEM-FC or SOFC (future)
Dual or single fuel ICE

We enable a safe and efficient hydrogen economy!

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