Hydrogen stored as an oil!

March 2020
With hydrogen becoming a fuel, global volumes will increase significantly taking hydrogen from a regional industrial gas to a globally traded commodity.
Differences in hydrogen production cost will transfer hydrogen to a globally traded commodity - creating demand for intercontinental large scale transport of hydrogen...

Cost differences in future hydrogen production will define transportation routes for hydrogen transport and create natural demand for large scale and long distance hydrogen transport.

Sources: IEA 2019, The future of hydrogen and *IEA 2019, Hydrogen: A renewable energy prospective (value PV costs 2050)
...but existing transport technologies are not suited for large-scale international transport and thus the transition of hydrogen to a fuel

Transport Condition / State
Hydrogen (H₂) / truck
Hazardous Material
Boil-Off
Energy required / kg H₂ (excl. transport)
Transport capex per truck / trailer

Compressed Gas
CGH₂

- 250 – 500 bar
- up to 350kg / up to 1,100kg
- 0%
- 2 – 6 kWh (electric)
- > EUR 0.4m / > EUR 1.0m

Cryogenic (Liquid)
LH₂

-253°C
- up to 3,300kg
- 1 - 3%
- 7 – 10 kWh (electric)
- > EUR 1.4m
Hydrogenious LOHC Technologies GmbH – a global technology leader for Liquid Organic Hydrogen Carriers

**Vision**
A hydrogen fueled society – truly sustainable and emission-free.

**Mission**
Hydrogenious LOHC and its partners are committed to deploy their resources to make the hydrogen-fueled society a reality.

- **70** Employees
- **>31** Patent families filed
- **10** Systems in field
- **2016** First system delivered
- **€ 20.5m** Last fundraising round

**Investors**
- VC fund of world leading platinum mining company
- Winkelmann Group
- German holding providing solutions for automotive and heat industry
- Vopak
- World leading oil terminal operator
- Mitsubisihi Corporation
- The trading division of Mitsubishi group

**Key Partners**
- CLARIANT
- MAN Energy Solutions
- Arkema
- HIERN
- Framatome
- Cavilon
- Frames
LOHC enable a safe and efficient transport of hydrogen at ambient conditions for industrial, mobility and energy end users...

Industrial Hydrogen Supplier
(e.g. steam methane reforming, etc.)

Industrial Hydrogen Consumer
(e.g. fuels, chemicals, fertilizers, metal refining, food, etc.)

Energy
(e.g. on-grid, off-grid)

Mobility
(e.g. cars, buses trucks, trains, ships, etc.)

Renewable Energies
(e.g. via electrolysis)

Hydrogenation
Exothermic (~ 250°C, 25 – 50 bar)

Dehydrogenation
Endothermic (~ 300°C, 1 – 3 bar)
... leading to benefits for both: the supplier as well as the hydrogen consumer

**Hydrogen Source**
- By-product hydrogen
- Green hydrogen

**Industrial Hydrogen Consumer / HRS**
- On-site storage & release
  - Unloaded (LOHC^-)
  - Loaded (LOHC^+)

**Hydrogenious LOHC’ Value Add**
- >20% lower TCO for large-scale settings
- Increased modes of transport – road, train, ship
- Lower prices from supplier possible
- Increased on-site safety
- Enhanced flexibility and back-up buffer storage
- No ADR qualification required for drivers
- Easy increase of on-site storage capacity possible
- Small footprint due to reduced safety zones and high storage density
Technology deep-dive: The LOHC technology is based on a reversible hydrogenation / dehydrogenation process

Dibenzyltoluene
- Non-explosive
- Diesel-like liquid
- Hardly flammable
- Liquid state until -39 °C
- Stored at ambient conditions
- Commercial heat transfer oil (3–5€/kg)

Perhydro-Dibenzyltoluene
- Same characteristics

1) One VLCC ship can carry up to 350,000 DWT which would be equivalent to 17,000 tH2
2) One train in Europe can pull up to 35 wagons which would be equivalent to 59 tH2
The StoragePLANT: A product offering for low cost / large scale hydrogen storage in LOHC to enable cost efficient distribution

<table>
<thead>
<tr>
<th></th>
<th>StoragePLANT 5tpd</th>
<th>StoragePLANT 12tpd</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen capacity</td>
<td>5 t/d // 210 kg(_{\text{H}_2})/h</td>
<td>12 t/d // 500 kg(_{\text{H}_2})/h</td>
</tr>
<tr>
<td>LOHC production</td>
<td>4,500 l/h</td>
<td>11,000 l/h</td>
</tr>
<tr>
<td>Heat production</td>
<td>1,900 kW(_{\text{th}})</td>
<td>4,500 kW(_{\text{th}})</td>
</tr>
<tr>
<td>Load range</td>
<td>50 – 100 %</td>
<td></td>
</tr>
<tr>
<td>Footprint</td>
<td>Skid-based</td>
<td></td>
</tr>
<tr>
<td>Inlet hydrogen stream</td>
<td>30 – 50 bar, 99.99 % purity</td>
<td></td>
</tr>
<tr>
<td>Inlet LOHC stream</td>
<td>(\geq 0.1) barg, (T \geq 15) °C</td>
<td></td>
</tr>
<tr>
<td>Power connection</td>
<td>400 V AC, 3 phase, 50 Hz</td>
<td></td>
</tr>
</tbody>
</table>

*under nominal load

Engineered and build in cooperation with:
The ReleasePLANT: LOHC release system designed at sweet spot scale

ReleasePLANT 1.5tpd

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen outlet</td>
<td>1.5 t/d // 65 kg\textsubscript{H₂}/h</td>
</tr>
<tr>
<td>LOHC demand\textsuperscript{*}</td>
<td>1,400 l/h</td>
</tr>
<tr>
<td>Heat demand\textsuperscript{*}</td>
<td>780 kW\textsubscript{th}</td>
</tr>
<tr>
<td>Load range</td>
<td>50 – 100 %</td>
</tr>
</tbody>
</table>

\textsuperscript{*} under nominal load

Footprint: Skid-based

Inlet LOHC stream: \( \geq 0.1 \text{ barg}, T \geq 15 \text{ °C} \)

Power connection: 400 V AC, 3 phase, 50 Hz

ReleasePLANT >5tpd starting 2022

LOHC underground tanks in portfolio
Hydrogenious LOHC’ mission is the establishment of a global LOHC infrastructure to enable a hydrogen fuelled society

**Sustainable hydrogen sourcing**
- **Renewable hydrogen**
  - Wind & hydro @ <3 ct./kWh
  - >5,000 h/year production

- **By product hydrogen**
  - Chlor-alkali electrolysis
  - Others

**Global hydrogen distribution**

1. **Ship Transport**
   - **International**
   - Use of existing oil tankers / fuel storage infrastructure
   - International trans-ocean transport

2. **Rail Transport**
   - **(inter)-national**
   - Multi-ton transport on existing infrastructure
   - Flexibility of rail network

3. **Road Transport**
   - **National / regional**
   - High capacity road delivery to distributed customers

**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
Hydrogenious LOHC has the first systems in the field since 2016

Fraunhofer IAO (Germany)
- ReleaseBox 33 with autarkic hydrogen heating (hydrogen burner) and 25 kW PEM-fuel cell (output 600V DC)
- Integration into a smart grid
- Delivery date: July 2016

United Hydrogen Systems (USA)
- StorageBox 100 and ReleaseBox 2.5 commissioned at UHG site in Charleston (Tennessee, USA) in Q1 2018
- Daily test operations of ReleaseBox 2.5
- Commercial testing of RB 2.5 at customer site ongoing. Valuable results of continuous operation and interaction with industry process are gained.
Hydrogenious LOHC has gathered a strong consortium for the first European LOHC-based HRS project ‘HySTOC’

Project description

• Design and build-up of StorageBOX 10 and ReleaseBOX 10 delivering hydrogen according to ISO 14 687-2
• 1st step: Performance testing of ReleaseBOX 10 at VTT test facility (energy balances, hydrogen purity)
• 2nd step: Connection of ReleaseBOX 10 to HRS in Woikoski
• Total funding: EUR 2.5m

Key Partners

Grant number: 779694
Hydrogenious LOHC will demonstrate large-scale hydrogen storage in LOHC at the H₂Mobility refuelling station in Erlangen in 2020

Project description

- Implementation of first German LOHC HRS in Erlangen
- Worldwide first 1.5 t hydrogen underground storage by LOHC
- Dehydrogenated with ReleaseBOX 10
- Delivering hydrogen according to ISO 14 687-2

Key Partners
Hydrogenious LOHC successfully placed LOHC in the Federal Program: “Real-World Laboratories”

**Project description**

- Hydrogenious LOHC connects a “Green H₂” production (PEM electrolysis) in Kaisersesch and a HRS in Essen
- For the project Hydrogenious LOHC will deliver Storage- and ReleaseBOX
- Sector coupling excess heat (PtG, StorageBOX) goes to heat grid of the city Kaisersesch
- Sector coupling: ReleaseBOX will provide hydrogen for public transport bus fleet

**Key Partners**

- innogy
- RWTH Aachen University
- ESSEN
- OFB Projektentwicklung
- VIESSMANN

**H₂ production with economic green electricity**

- 250 kg_H₂ Day

**High H₂ transport capacity by truck**

- 1,500 kg_H₂ Truck

PEM Electrolysis  →  LOHC-StorageUNIT  →  Heat integration  →  H₂-Logistik with LOHC  →  HRS  →  LOHC-ReleaseUNIT  →  LOHC-Tanks

LOHC-Tanks  →  Kaisersesch  →  around 180km  →  Essen  →  LOHC-Tanks
First target sized systems planned to implement first European LOHC network and to prove scale and economics

Project description

- Implementation of first LOHC network with CO2 neutral hydrogen
- Prove of technology and economics of large scale LOHC units and transportation
- StoragePLANT has higher capacity – acquisition of further customers planned
- Expansion with ship and rail transport planned

Key Partners

With larger storage capacities new customers for ReleaseUNITs can be gained

to be announced as part of market communication
Blue Danube: Hydrogen shipped with river ships from Romania and Bulgaria upwards the river Danube

Project description

• Offgrid green hydrogen production in Romania and Bulgaria with final development of 2 GW
• Transport via river Danube with LOHC and e-fuels
• Delivery to offtakers along the river with high hydrogen demand
• Danube Commission explicitly excluded the transport of LH2 and NH3

Key Partners

Verbund

elringklinger

SIEMENS

ÖBB

DB SCHENKER

Green hydrogen production in Romania and Bulgaria by wind and PV

Many potential hydrogen consumers are situated along the river Danube (refineries, steal production, chemical companies)

Transport in existing crude carrier ships for rivers

260tpd

51tpd

51tpd

1,800 MW electrolysis for hydrogen production

2,000 MW off-grid wind and solar energy production

80,000 tonnes of hydrogen for industry, power + mobility hubs (500 trucks / 100 HRS) along the Danube

40 hydrogen transport barges
Green Spider: Hydrogen production in Spain and large scale transport to Rotterdam by ship over the Atlantic ocean

Project description

• Central hydrogen production with 100 MW PV electrolysis in the region of Castillia y Léon supported by grid access
• Central 5tpd StoragePLANT as first development step
• Shipment to the port of Rotterdam
• Distribution to offtakers in the port and in the region
• Further transportation along the river Rhine in discussion

Key Partners

In Castillia y Léon a 100MW el. project in combination to a 5tpd StoragePLANT will be developed

Central storage of hydrogen in existing tank terminals at the port of Rotterdam

On-site release and further distribution of hydrogen by river ships, trains and trucks

Hydrogen will be shipped by crude carrier ships over the Atlantic Ocean to the port of Rotterdam
With Dragon: Fully integrated supply of electricity and heat by using LOHC as long time storage combined with solid oxide electrolysis and fuel-cells

**Project description**

- Local hydrogen production in old lignite plant by pv in Noth Macedonia
- Supply of local cities with electricity and heat
- LOHC for long term storage
- Sophisticated heat integration of solid oxide FC and EC with LOHC process will provide high efficiency

**Key Partners**

![SOLID POWER](image1)
![ΔΕΗ](image2)
![FP](image3)

- Central production of hydrogen by PV in combination with special developed solid oxide electrolysis placed in former lignite pit
- Daily and seasonal hydrogen storage with LOHC in conventional liquid tanks
- Released hydrogen is used for electricity production to supply local village
- Heat produced by solid oxide fuel-cell and LOHC storage process is used to supply local village
- Access hydrogen is injected in South Stream gas pipeline
We make hydrogen handling easy!