Hydrogen transport with Liquid Organic Hydrogen Carrier (LOHC) technology by Hydrogenious LOHC Technologies

Countries around the world are relying on imports of green hydrogen to meet their immense energy needs for power generation, mobility and industry, and to drive the decarbonization of these sectors.

At the same time, the properties of molecular hydrogen make it very difficult to store and transport, as it is highly volatile and explosive. The safe and cost-effective storage, transport and distribution of hydrogen is therefore a prerequisite for a sustainable hydrogen economy.

Technologies for Hydrogen transport

There are a number of technologies that in combination enable the transport of hydrogen in very large volumes and over long distances and multimodal routes, each with their own advantages and disadvantages.

Hydrogen stored in pressure tanks (CH2)

- Already used in transportation and power generation.
- Cost-effective only for comparatively short distances, and the energy required for compression is relatively high.

Hydrogen liquefied at -253°C (LH2)

- High storage density. Is being intensively researched and used in some applications (e.g. automotive, aerospace).
- Substantial energy and technical requirements and complex infrastructure.

Ammonia (NH3)

- Produced in large quantities worldwide and used in the fertilizer industry.
- Due to its high toxicity, ammonia is a hazardous material that is difficult and expensive to transport and store.
- Separating hydrogen from NH3 requires a lot of energy at high temperatures, and the cracking technology required for separation does not yet exist on a large industrial scale.

Pipeline-based transport of hydrogen

- Allows large amounts of energy to be transported relatively safely.
- New pipelines must be built or existing natural gas pipelines must be upgraded.
- New construction is associated with very high investment and a tendency toward negative social acceptance.

Liquid Organic Hydrogen Carrier (LOHC) Technology

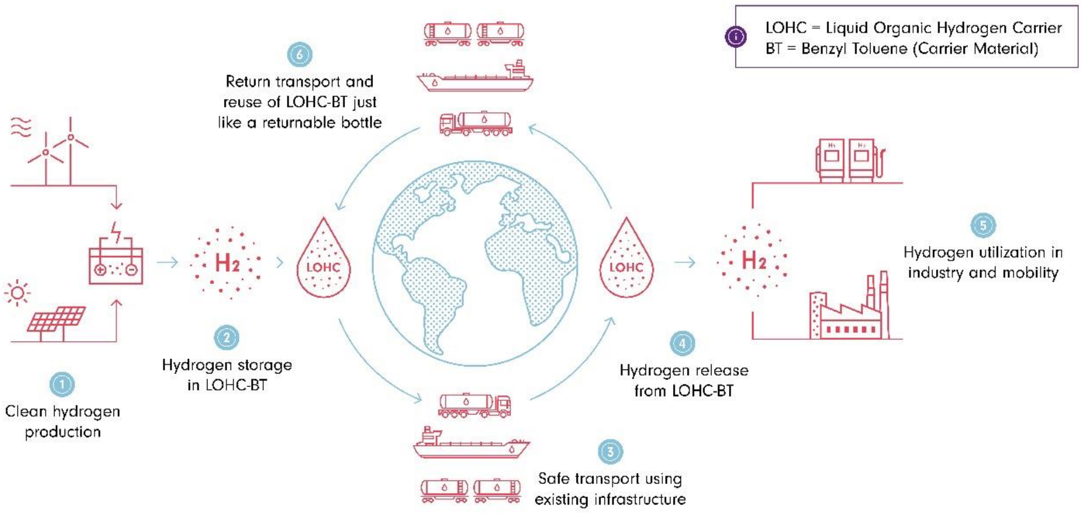
Another promising method for the storage and transport of hydrogen is the use of liquid organic hydrogen carriers (LOHC). Here, the hydrogen molecules are chemically bound to the LOHC via a catalytic process. The LOHC is then transported to the off-taker, where the hydrogen is released in a second chemical reaction. The carrier material is not consumed during this process and can be reused to transport hydrogen.

Why the LOHC technology by Hydrogenious is so compelling

There are a few possible LOHCs, such as carbazole, toluene/methylcyclohexane (MCH) or dibenzyltoluene. After many years of researching and testing the various LOHC technologies, Hydrogenious has opted for the thermal oil benzyltoluene (BT) as LOHC. BT has a hazard potential comparable to diesel, is already established in the industry as a heat transfer medium, has proven to be particularly robust at low temperatures and has many more positive properties as a hydrogen carrier:

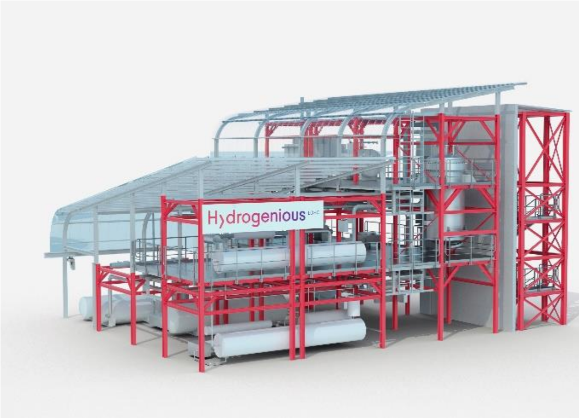
- **Safe:** LOHC-BT is hardly flammable (flash point at around 125 degrees Celsius)
- **Easy:** LOHC-BT can be handled under ambient pressure and temperatures
- **Cost-effective:** LOHC-BT can be stored and transported with conventional liquid fuel infrastructure (e.g. ship, barge, train or truck) over long distances in industrial scale
- **Reliable**: There is no loss of hydrogen (for example boil-off) even during longer storage periods and no molecular hydrogen released between hydrogenation and dehydrogenation.
- **Efficient:** The (volumetric) energy density is advantageous, as a transport container with LOHC can store about five times more energy compared to compressed hydrogen
- **Space-Saving:** In LOHC-BT, the hydrogen can be stored underground in a space-saving way, even in densely populated areas
- **Available:** BT has been widely used in industry as a heat transfer medium for decades. The market availability of the material is accordingly ensured

The LOHC-BT cycle in detail



1. In a hydrogenation plant (Storage Plant), the hydrogen molecules are chemically bonded to the LOHC benzyltoluene in a continuous process via a catalytic reaction. The hydrogenation is an exothermic process that releases approx. 9 kWh_{th}/kgH_2 of heat at approx. 250 °C, which can be used for further applications (sea water desalination, heating grids).
2. The LOHC-BT, which has been loaded with hydrogen molecules, is then transported to its destination via tanker truck, rail, barge or tanker ship. In a single cubic meter of LOHC-BT, up to 54 kilograms of hydrogen can be stored and transported without loss.
3. At the off-take site, the hydrogen molecules are released from the LOHC-BT in a dehydrogenation plant (Release Plant) via a catalytic reaction. This chemical process is endothermic, requiring approximately 11 kWh_{th}/kgH_2 of heat at approximately 300 °C. The hydrogen is released on demand with a high degree of purity, exceeding 99.9%.
4. The LOHC-BT can be reloaded and unloaded with hydrogen hundreds of times after the hydrogen has been released and is recyclable (deposit bottle principle).

LOHC Storage Plant



LOHC Release Plant

LOHC transport via conventional liquid fuel infrastructure

By enabling tank terminals, bulk carriers and tank trucks to transport large quantities of green hydrogen, LOHC-BT technology can make use of an already existing and proven liquid fuel infrastructure. Thus, LOHC-BT technology enables rapid access to regions with large renewable energy potential. It is particularly noteworthy that LOHC-BT technology is able to supply molecular hydrogen (not hydrogen derivatives), which is needed for many industrial processes such as refineries, steel or mobility.

By ship

- Hydrogen transport capacity per trip: up to **17,000 t** (VLCC*, 280,000 DWT**)
- Ideal for large scale hydrogen transport over long distances
- Import of low-cost green hydrogen to consumption markets

*VLCC = very large crude carrier
**DWT = Deadweight tonnage

By train & barge

- Hydrogen transport capacity per trip: up to **124 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 existing infrastructure for port and other energy hubs as well as ship, rail and train

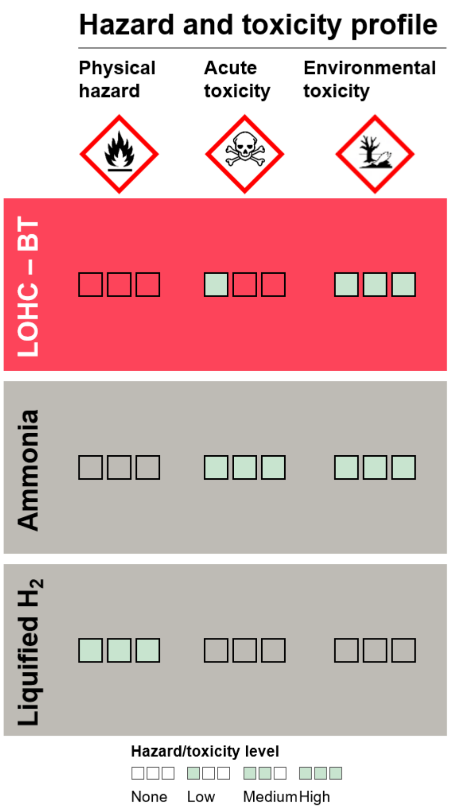
Cost-efficient hydrogen transport

Since the cost of hydrogen logistics is added to the final price of hydrogen, it is important to keep transportation and storage costs as low as possible. By relying on the well-established liquid fuel infrastructure, LOHC-BT technology is very cost efficient. This is also underlined by several studies that examine the competitiveness of LOHC and other hydrogen storage and transport technologies such as liquid hydrogen and ammonia.

See: Roland Berger: Hydrogen transportation | The key to unlocking the clean hydrogen economy

Safe and efficient hydrogen transport

The LOHC carrier material used by Hydrogenious is benzyltoluene (BT), a well-known industrial thermal oil. BT as a hydrogen carrier offers unique properties in terms of safety and ease of handling. The potential impact in the event of an accident can be compared to diesel, as both substances have similar properties in terms of toxicity, with BT additionally being flame retardant.



In addition, LOHC-BT technology does not produce molecular hydrogen during transportation and storage because the hydrogen is chemically bound to the carrier material. This simplifies, for example, cargo operations and refueling at ports.

Securing jobs in the transition to a hydrogen economy

One of the unique features of the LOHC-BT technology is that while it contributes to the transformation of the energy sector, it relies heavily on the existing infrastructure and technology of the oil and gas industry. This gives companies in the industry the opportunity to change their business models (e.g., tank terminal operators, tank truck manufacturers) and contribute their knowledge to the emerging hydrogen economy - creating a future for themselves and their employees.

High public acceptance

Society still has reservations about hydrogen, e.g. in terms of safety, because it is a relatively new energy carrier with which the population is not yet familiar. It is expected that the LOHC-BT technology can help to reduce these prejudices, as people are used to dealing with energy carriers in liquid form. Once the hydrogen is chemically bonded to the carrier material, there is no molecular hydrogen present throughout the LOHC BT supply chain.

Additional information / technological deep dive

A more detailed overview of the LOHC technology can be found in the following online publication (open access): *Distel, M.M., Margutti, J.M., Obermeier, J., Nuß, A., Baumeister, I., Hritsyshyna, M., Weiß, A. and Neubert, M. (2024), Large-Scale H2 Storage and Transport with Liquid Organic Hydrogen Carrier Technology: Insights into Current Project Developments and the Future Outlook. Energy Technol. 2301042.* https://doi.org/10.1002/ente.202301042

About Hydrogenious LOHC

Hydrogenious LOHC adds the missing link to high-performing hydrogen value chains globally. Based on its proprietary and proven Liquid Organic Hydrogen Carrier (LOHC) technology with benzyl toluene as carrier medium, Hydrogenious LOHC allows for superior, flexible hydrogen supply to consumers in industry and mobility across the globe, utilizing conventional liquid-fuel infrastructure. Founded in 2013, the portfolio of the market-leading pioneer and its joint venture companies today includes stationary and mobile (on-board) LOHC-based applications: Hydrogenious LOHC Technologies, headquartered in Erlangen/Germany, offers – within an EPC partnership with Bilfinger – (de-)hydrogenation turnkey plants, Operation & Maintenance and LOHC logistics services – ensuring safe, easy and efficient hydrogen storage, transport and distribution. Hydrogenious LOHC Maritime, established in 2021 jointly with Østensjø Group and located in Norway, develops an emission-free onboard propulsion system with a promising LOHC/fuel cell solution for the global shipping industry. With its >230 staff members and investors AP Ventures, Royal Vopak, Winkelmann Group, Mitsubishi Corporation, Covestro, JERA Americas, Temasek, Hyundai Motor Company, Chevron Technology Ventures and Pavilion Capital, Hydrogenious LOHC is a major enabler and accelerator for the energy transition.

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