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Energiepartnerschaft
DEUTSCHLAND - CHINA

FACTSHEET

THE LOGISTICS OF HYDROGEN

One challenge numerous countries face in the transition towards a fully renewable energy system is that locations with ideal preconditions for the production of renewable electricity and locations with industrial centers with a high demand for energy or feedstock are far apart. Hydrogen and its derivatives are a means to bridge that gap but each path has its unique advantages and disadvantages.

Hydrogen Characteristics

Hydrogen is colourless in its pure form. Its density is ρ = 0.0899 kg/m^3 at 0 °C and 1.013 bar (normal state). This low density leads to a low volumetric energy density of only 3 kWh (LHV)/m^3 at atmospheric pressure which makes certain transport modes of hydrogen inefficient. Compressed to 700 bar, the energy rises to 1200 kWh (LHV)/m^3. The chemical storage forms have an energy density of up to 9700 kWh/m^3.

There are numerous ideas for alternative ways of transporting hydrogen like transporting hydrogen in its liquid form; storing it in ammonia or methanol or temporarily binding it in so-called Liquid Organic Hydrogen Carriers (LOHC).

Each of these options has different advantages and disadvantages depending on the distance of transport, local infrastructure and end-use. Modes of transport furthermore vary regarding the technology readiness level, economic feasibility and safety.

Pipeline transport

Transporting hydrogen via pipelines is the cheapest and most energy efficient mode of transport at scale for short to medium transport distances. The comparatively low energy density of gaseous hydrogen is made up for by the higher

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flow velocity, which leads to similar energy transport per unit of time as natural gas. The operational pressure range for hydrogen pipelines is usually 50–200 bar.

There are pure hydrogen pipelines in operation meaning the technology is generally tested and deployed. Yet, these pipelines operate solely on local or regional scale usually for connecting a producer with a consumer or a hub of consumers. The hydrogen pipeline network on continental scale as envisioned in Europe and elsewhere does not exist yet.

The price of pipelines increases in proportion to the distance, but the costs per transported unit decrease sharply the larger the diameter, since, for example, a double diameter results in double costs, but can transport four times the quantity. This makes pipelines particularly useful for distances up to 3000 km, and even up to 8000 km in the case of retrofits of existing pipelines.

For transport modes in which the low energy density of gaseous hydrogen makes the transport inefficient, uneconomical or less useful, hydrogen can be converted. However, these conversion steps result in a loss of energy. The most relevant ones will be presented in the following.

Liquid Hydrogen

Liquefying hydrogen drastically increases energy density to 2417 kWh (LHV)/m^3. However, the required temperature for liquefaction is –253°C.

Since liquid hydrogen is rarely used, it is usually converted back into its gaseous form, which means a loss of energy. The required energy for liquefaction is about 12 kWh/kg. This process has an overall efficiency of 30 % to 33 %. Furthermore, liquid hydrogen is demanding for the deployed materials, as they have to withstand cryogenic conditions at –253°C.

This makes liquid hydrogen interesting for short distances up to 4000 km, as a longer distance would require more ships to maintain a constant flow. Since pipelines are already most efficient at this distance, liquid hydrogen could become relevant where pipelines are not possible, such as on islands like Japan . Yet, besides the low energy efficiency and the low technology readiness level of liquid hydrogen tankers, the problem of boil-off remains, as current tanks have a boil-off rate of 1–5 % per day, making large-scale deployment unlikely or dependent on technological innovation.

LOHC

Liquid organic hydrogen carriers (LOHC) are an approach to hydrogen transport and storage. LOHC refer to organic compounds, which can store and release hydrogen.

Hydrogen is bonded to the hydrogen-poor molecule exothermically, i.e., with the release of energy, in a process called hydrogenation. Later, the hydrogen can be recovered endothermically, i.e. by adding heat, in a process called dehydrogenation.

The advantage of LOHC compared to pure hydrogen is that they are easy to store. Yet, most LOHC are still in the development phase. The disadvantages besides the low Technology Readiness Level (TRL) is the low roundtrip energy efficiency of 30–40 %, which can be increased if heat recovery is in place. Furthermore, the hydrogen-poor part of the LOHC has to be transported back meaning that there is no one-way transport, but a cycle must be created, leading to economic inefficiencies. The optimal distance cannot yet be determined due to the low TRL and therefore unclear cost estimates. Nevertheless, in comparison to pipeline transport, LOHC will most likely not be competitive. As a result, LOHC application is considered more suitable for ship-based transport over distances exceeding 3000 km.

Ammonia

Ammonia (NH_3) is a hydrogen-rich compound that is particularly relevant for the production of fertilizers. For more than 100 years, it has been produced using the Haber-Bosch process, making it a globally traded good and resulting in established infrastructure.

Ammonia is liquefied at –33 °C at atmospheric pressure, but at a pressure of 9 bar the liquefaction temperature is 20 °C. The most common transport method deploys a combination of these two approaches.

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Liquid ammonia has a significantly higher hydrogen content than liquid hydrogen. Liquid ammonia at 1 bar and –33 °C contains about 120 kg H_2/m^3 compared to about 70 kg H_2/m^3 for liquid hydrogen at 1 bar and –253 °C.

The disadvantages of ammonia are the toxicity and therefore required safety levels for transport, as well as the low roundtrip energy efficiency of 13–34 %. Yet, due to the high TRL and less demanding properties, ammonia is promising especially for long-distance transport.

Methanol

Methanol (CH_4OH) is another widely discussed candidate for transporting and storing hydrogen. Methanol is liquid at room temperature. The volumetric energy density of methanol 4900 kWh/m³. It is a widely traded good with infrastructure in place. The roundtrip energy efficiency is 23–38 %.

Besides the existing infrastructure and the liquefaction conditions, methanol is also significantly less harmful than ammonia. The disadvantage of methanol is the required carbon atoms, which if released, form the greenhouse gas CO_2. Furthermore, those carbon atoms need to be of renewable origin for the synthetic methanol to count as renewable. Yet, the advantageous properties suggest applications for long-distance hydrogen transport.

Legal information

Publisher:
Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH,
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Last updated: December 2023

This factsheet is published as part of the Sino-German Energy Transition Project (EnTrans). EnTrans is a component of the Sino-German Energy Partnership and provides advice to the Chinese government and associated energy policy think tanks.

The GIZ leads the project implementation in cooperation with the German Energy Agency (dena) and Agora Energiewende.

Initiated by

Federal Ministry for Economic Affairs and Climate Action

Implementing organisation

giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

In cooperation with

dena German Energy Agency