HYDROGEN COMES IN DIFFERENT 'PACKAGES'

The Netherlands and the European Union are preparing for huge imports of renewable energy. The population density and standard of living – and thus energy consumption – particularly of north-western Europe is so high that this region will not be able to produce enough renewable energy to meet all its demand. Europe will therefore continue to import energy even in a CO_2 neutral world. This energy will have to come primarily from regions that are sparsely populated and where there is lots of sunshine, lots of strong wind and/or hydro power available. That's where green energy can be generated relatively cheaply, which can then be used to produce green hydrogen. This kind of hydrogen can be imported in four or five different forms. It is impossible to predict or direct which of these forms will ultimately be the most important because it depends on too many different factors. At this stage, it's important to keep as many options open as possible and to stimulate development of a variety of technologies.

In order to develop and roll out the import of hydrogen, the European Parliament and the European Commission have decided that import and storage terminals are eligible for subsidies. The strategic vision of the previous Dutch government recognised the importance of importing hydrogen. The coalition agreement of Rutte IV indicates that this government has also put hydrogen and importing hydrogen at the top of the agenda. In anticipation of which, a working plan for a National Hydrogen Programme (NWP in Dutch) has already been presented to the House of Representatives. Here too the significance of importing hydrogen has been given special emphasis.

Rotterdam Port Authority expects that, by 2050, 18 million tons of hydrogen will be entering north-western Europe through the port, while simultaneously 2 million tons will be produced locally. A number of different businesses in the port are preparing to import hydrogen starting in 2025. In Rotterdam, an investment decision regarding construction of a hydrogen pipeline through the port area (HyTransPort), with connections for the different import terminals, is expected in the spring of 2022. The intention is to connect this Rotterdam pipeline to a national network in the future. In the meantime, preparations for construction of the Delta Corridor are underway on a number of new pipelines between Rotterdam, Chemelot and industry in Nordrhein-Westfalen for propane, butane, hydrogen, CO_2 and possibly also a hydrogen carrier like ammonia.

DIFFERENT HYDROGEN CARRIERS

Hydrogen can be transported in a variety of ways. In contrast with something like crude oil, which liquifies at normal temperatures, hydrogen has to be kept extremely cold (at -253 degrees) in order to liquify it. An alternative is 'loading' hydrogen onto another molecule, such as ammonia (NH_3), methanol or a Liquid Organic Hydrogen Carrier (LOHC), and then 'unloading' it. This requires energy and there are costs associated with the carrier. But many production countries are too far away to transport hydrogen through a pipeline as a gas. For import from southern Europe and north Africa, pipelines are an attractive option in the long term, if the volume is big enough. Additional costs include generating green energy, the most important cost item when producing green hydrogen, in countries with lots of sun or wind, and space which can be three times less than in north-western Europe. These generally outweigh the costs of liquifying or 'loading and unloading' the hydrogen, and transport.

ADVANTAGES AND DISADVANTAGES

The different ways that hydrogen can be transported and stored each have their advantages and disadvantages. Making liquid hydrogen will demand a lot of energy, new ships and infrastructure. This is offset by the fact that it then doesn't need to be 'loaded and unloaded'. Ammonia (NH_3) is a highly toxic substance and that means that many safety measures will be needed for the transport and storage of hydrogen in the carrier ammonia. This is offset by the fact that ammonia is a substance that industry already has lots of experience with and, just like hydrogen, is ready for immediate use in various production processes and as marine fuel. The last point also holds for methanol, but the disadvantage there is that the costs of unloading hydrogen from the methanol carrier are relatively high.

The disadvantage of LOHCs (like DBT and MCH) are that the carrier the hydrogen is bonded to has to be shipped back in order to pick up a new cargo of hydrogen. It also takes a lot of energy to unload it and these carriers also present challenges in the area of cost and safety. This is offset by the fact that existing infrastructure can be used and the carriers are relatively easy to handle, and/or there is a lot of experience in handling toxic substances. That makes them also relatively easy to transport to locations that are not hooked up to a pipeline.

In the coming years, practical experience will tell us which are the most attractive carriers. Technological developments, the level of cost reduction of the various technologies, the amounts that can be transported and the end use will all be determining factors. It would not be wise, as a society or an industry, to make a choice of one or two specific hydrogen carriers based on our current knowledge. The expectation is actually that different forms will be used because they all have their own characteristics. The combination of country of origin, destination or end use, available infrastructure and technological development will lead to a mix of hydrogen carriers. This mix will not be the same all over the world.

CONSTRUCTION TO 2030 AND BEYOND

In Rotterdam, both businesses and various inspection authorities have a great deal of knowledge and experience with toxic substances, including methanol, ammonia and some LOHCs. For the first few years, transhipment is expected to fit within the existing safety contours. If in the future substantial amounts of hydrogen are transhipped and stored in Rotterdam, then additional review of safety measures will be necessary. By that time, the technology for transhipment and storage of the different substances will have further developed, and safety will have to be safeguarded by taking measures such as limiting the size of storage tanks and applying all kinds of safety and security systems.

Schematic overview of the most important characteristics of different hydrogen carriers

	Liquid hydrogen (LH_2)	**Methanol**	**Ammonia** (NH_3)	**LOHC** (DBT)	**LOHC** (MCH)
Technological development (experience with 'loading' and 'unloading', storage, transport, etc.).	Little or no experience right now, but it is not very technically complex.	Broad experience with production, transport and storage.	Broad experience with production, transport and storage. Relatively easy to produce.	Scarcely any experience, but it is not very technically complex.	Experience with production, transport and storage.
Immediate application (without 'unloading') in production processes.	Transport fuel, blast furnaces, process industry, etc.	Chemistry, marine fuel.	Chemistry, marine fuel, artificial fertiliser.	None (always has to be unloaded).	None (always has to be unloaded).
Risks	Liquid hydrogen carries the risk of explosive combustion.	Limited	Highly toxic. Therefore most focus of environ-mental safety measures.	Limited	Limited
Costs of loading and unloading, storage, transport, etc.	Average	High (especially unloading).	Relatively low.	Average	Average
Volume / space needed for storage and 'unloading'.	Favourable	Reasonably favourable.	Reasonably favourable.	Not favourable.	Not favourable.
Availability of current infrastructure.	No infrastructure available.	Limited availability of infrastructure already in Rotterdam.	Limited availability of infrastructure already in Rotterdam.	Limited availability of infrastructure already in Rotterdam.	Limited availability of infrastructure already in Rotterdam.