HONEYWELL LIQUID ORGANIC HYDROGEN CARRIER SOLUTION (LOHC)

Honeywell
UOP

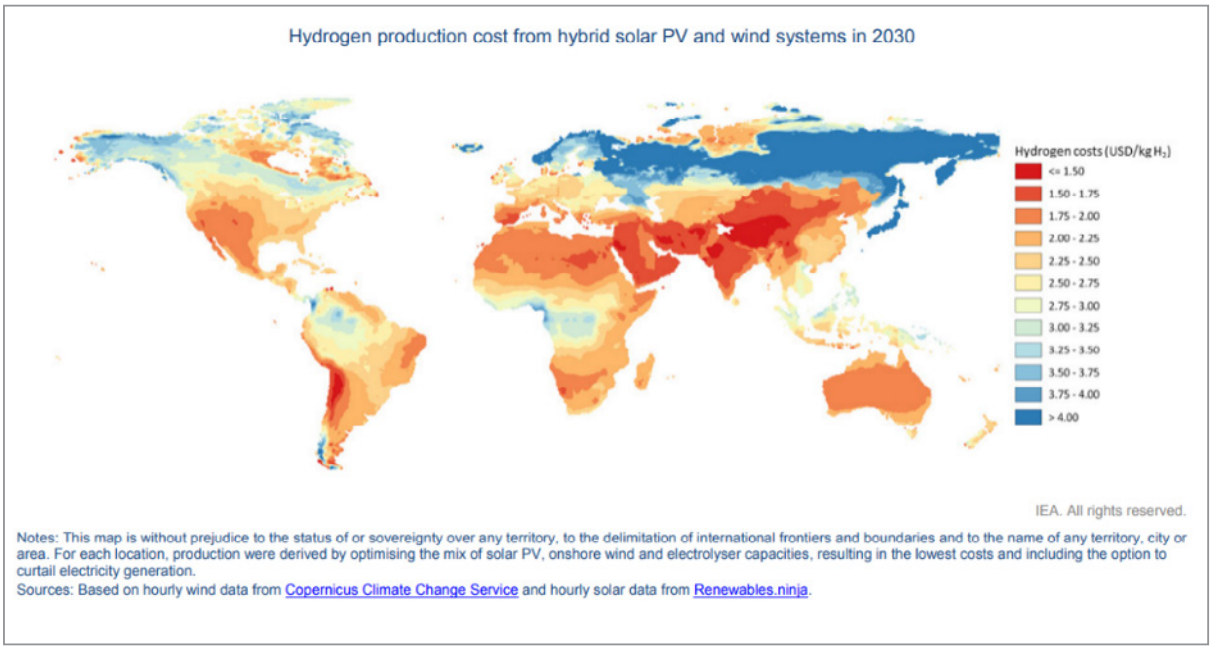
CONNECTING THE HYDROGEN VALUE CHAIN: LOW-COST HYDROGEN TRANSPORTATION

The lightest element is doing some heavy lifting in the move towards a carbon-neutral future. Hydrogen is the fuel of the future – ready to play a critical role in countries' and companies' efforts to reduce greenhouse gas emissions.

Capturing intermittent renewables energy production, providing fuel cell-powered transportation, or as an industrial feedstock, hydrogen is helping decarbonize economies. Dozens of countries worldwide have already adopted formal hydrogen strategies or are in the process of doing so. But while it's the universe's most common element, hydrogen production capacities and costs– particularly for green hydrogen – vary widely across the world.

In many territories, there's a significant mismatch between supply and demand.

Meeting growing requirements for hydrogen use across industries and the world will need cost-effective transportation solutions.



HYDROGEN TRANSPORT

Hydrogen is colourless, odourless, with low density and a high risk of leakage. The main transport options considered today involve organic carriers, ammonia and liquefied hydrogen.

	HONEYWELL LOHC (MCH)	LOHC (BT/DBT)	NH3	LIQUID H_2
Technology Readiness at commercial scale	🟢	🔴	🟡	🟢
Carrier availability	🟢	🔴	🟢	▬
Liquid at ambient Temperature and Pressure	🟢	🟢	🔴	🔴
Infrastructure	🟢	🟢	🟡	🟡
H_2 Purity	🟢	🟢	🟡	🟢
Retrofit options	🟢	🔴	🔴	🟡
Flammability	🟡	🟡	🟡	🔴
Health Hazard	🟡	🟡	🔴	🔴
Reconversion costs	🟡	🟡	🔴	🟢
Energy Density	🟡	🟡	🟢	🟡

Sources:

- The Future of Hydrogen, IEA, June 2019
- Determining the Production and Transport Cost for H_2 on a Global scale, Collis et al, 2022
- EU Commission assessment of hydrogen delivery options, EU Joint Research Centre, 2021
- Hydrogen Carrier Economics, KBR Advisory Consulting, 2021
- Hydrogen Insights, Hydrogen Council and McKinsey & Company, 2021
- Hydrogen transportation- The key to unlocking the clean hydrogen economy, Roland Berger, 2021
- Assessing opportunities and weaknesses of green hydrogen transport via LOHC through a detailed techno economic analysis, GASP and ENI, 2023
- An economic and greenhouse gas footprint assessment of international maritime transportation of hydrogen using LOHCs, CERENA and Copernicus institute of Sustainable Development, 2023

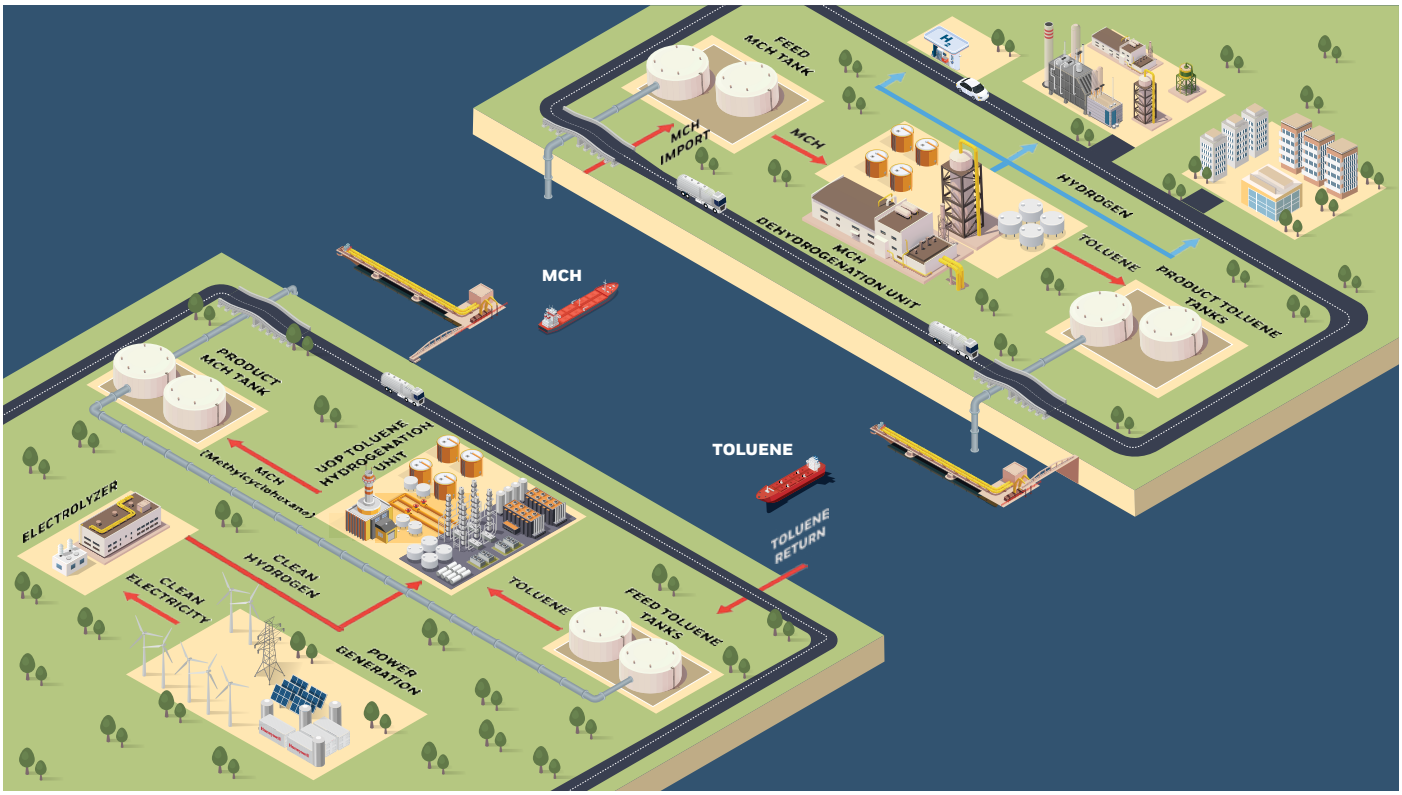
INTRODUCING HONEYWELL'S LIQUID ORGANIC HYDROGEN CARRIER

The Honeywell Liquid Organic Hydrogen Carrier (LOHC) solution is a lower cost method for long distance transportation of green and blue hydrogen. Using existing oil infrastructure for processing and storage, it's an economical option to unlock international hydrogen trading to power the energy transition.

LOHC is a cost-effective and comparatively safer carrier for clean hydrogen:

- Low capital cost using existing high capacity vessels and processing infrastructure
- Storage as a liquid under ambient pressure and temperature
- Non-toxic and less flammable than other solutions
- High storage density 48 kg H_2/m^3
- Low reconversion costs

Considering conversion, import and export, reconversion and distribution, LOHC is as cost-effective as ammonia (reference International Energy Agency calculations). LOHC economics become more attractive if there are existing underutilized refining assets that can be re-purposed for LOHC use [1].



[1] Cost of hydrogen transport for Honeywell LOHC is estimated based on Honeywell UOP's catalyst and LOHC technology performance. Cost of transport for other methods such as Liquid H_2 and NH_3 is based on "The Future of Hydrogen", IEA, June 2019.

BUILDING THE NEW HYDROGEN BUSINESS

The Honeywell LOHC solution is based on two proven Honeywell UOP technologies, specifically tailored for the export and import of green hydrogen.

The UOP Toluene Hydrogenation Process for hydrogen export builds on UOP's well-established BenSat™ and HB Unibon™ Processes. This process is able to achieve over 99.5% conversion and selectivity, using a commercially proven catalytic system and optimized process conditions and requiring extremely low fresh toluene make up. The catalyst system is extremely stable and has achieved over 10 years without need for regeneration in some commercial installations, and over 20 years of experience in operation at some sites, thus proving to be a low risk solution for hydrogen producers.

Technology highlights:

- A flow scheme with minimum hydrogen solution losses
- No continuous catalyst make-up or solid waste disposal issues
- Better exotherm management which makes the Toluene hydrogenation unit net steam neutral – critical for units not directly connected to a refining facility and without access to the OSBL utility system
- Large field experience, with over 45 commercial reference units using similar technology for benzene or aromatics processing
- >10-year catalyst life
- 7% lower cash cost of production [2]
- $9.3M higher NPV [2]

The UOP MCH Dehydrogenation Process for imports leverages the UOP Platforming™ process with catalytic and operating conditions specifically tuned for MCH feeds to achieve the highest conversion and selectivity towards toluene. The UOP Platforming process has over 1000 commercial reference units and over 70 years of commercial experience. For hydrogen importers, there is significant potential to retrofit existing fixed bed and continuous catalyst regeneration reforming units to dramatically reduce the overall investment cost for hydrogen transportation. The MCH Dehydrogenation Process is the most cost-effective technology for refiners importing hydrogen.

Technology highlights:

- Lower reconversion costs than ammonia or methanol
- High purity H_2 production
- Patented heat integration to maximize carbon efficiency and reduce hydrogen cannibalization boosting the net H_2 output by 10% compared to conventional flow schemes
- Proven technology with over 380 CCR and 610 fixed bed commercial reference units using similar technology for heavy naphtha processing
- 5% higher toluene selectivity [3]
- 10% higher H_2 yield [3]
- 30% lower cash cost of production [3]
- $12.9M higher NPV [3]

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[2] UOP Toluene Hydrogenation technology representations are based on a Honeywell UOP internal study that compared Toluene Saturation to industry standard methods for light aromatics hydrogenation including Honeywell UOP's own technology. This study was performed using Honeywell UOP developed simulation models.

[3] UOP MCH Dehydro technology representations are based on a Honeywell UOP internal study that compared MCH Dehydrogenation to industry standard methods for reforming including Honeywell UOP's own reforming technology. This study was performed using Honeywell UOP developed simulation models and UOP standard reforming catalyst.

OPTIMIZING OPTIONS TO BOOST RETURNS

The Honeywell LOHC solution provides significant potential for optimization of conversion, selectivity, capital investment, and operating costs at both the import and export locations.

Optimization of toluene and MCH product purities can minimize toluene make-up, and optimization of H_2 product purity provides the potential to eliminate additional equipment at the reconversion site.

It is possible to optimize feed rate, operating pressure, and heat recovery to provide customers solutions that leverage existing assets or maximize MCH processing.

Honeywell UOP can work as your technology licensor to evaluate retrofit options and optimize the entire value chain. Our technology will help you achieve the lowest possible cash cost of production with savings in the order of 8-10% when compared to alternative solutions.

WHY TOLUENE AS YOUR LOHC

Toluene is a stable organic liquid with high hydrogen carrying mass capacity and has significant advantages over other hydrocarbon carriers:

- Toluene has higher availability in the global market making the overall investment in initial inventory and make-up lower than other LOHCs.
- Toluene enables end users to leverage existing refining assets such as reforming units. Other heavier hydrocarbon carriers would require capital investment at both import and export locations.
- Different Toluene grades and purities can be processed within the Honeywell LOHC solution
- A lower boiling point hydrocarbon carrier such as Toluene enables wider options for reboiler heat input sources and overall heat integration.

WHY HONEYWELL?

A global player, Honeywell is helping create the hydrogen economy. It offers comprehensive solutions across the hydrogen value chain. From production and conversion, transmission and storage, to distribution and use, our solutions are already being used to make operations safer, more efficient and more reliable.

From hydrogen-ready systems, instruments and software to modular systems for local production and industrial control solutions for the biggest plants, our hydrogen solutions are trusted worldwide. UOP is a proven leader in hydrogen process technology, with over 1,000 hydrogen purification projects worldwide.

With worldwide coverage and local support, Honeywell offers the most comprehensive and advanced portfolio of technology and services for hydrogen today.

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