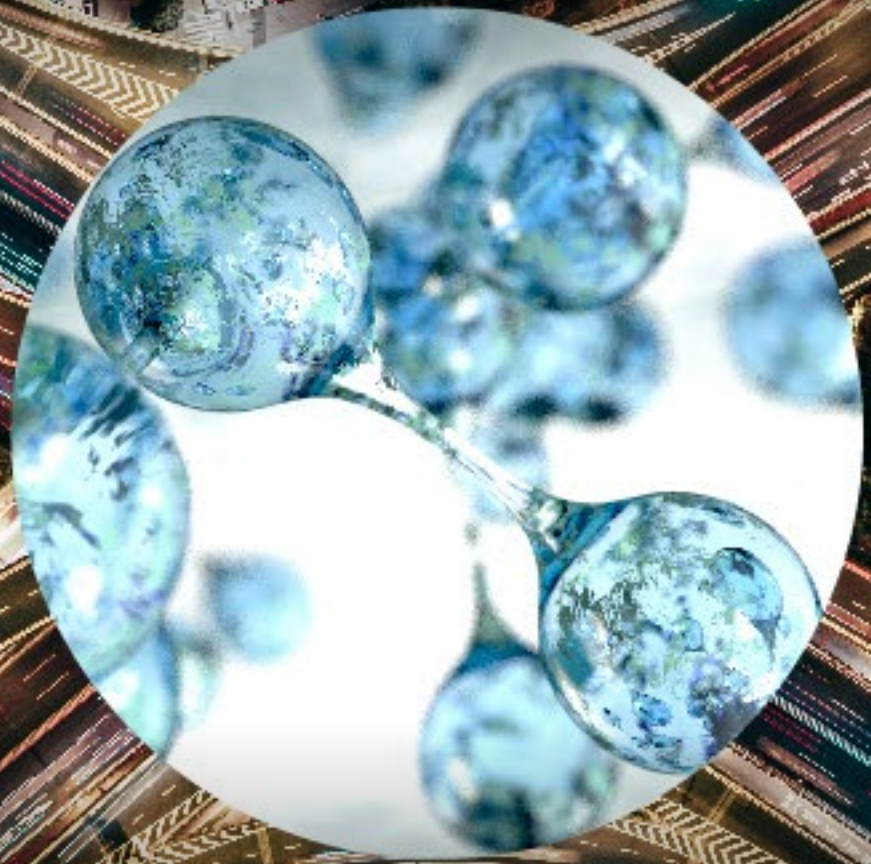
HONEYWELL UOP
INNOVATIVE SOLUTIONS TO SHAPE THE HYDROGEN ECONOMY



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14 December 2023

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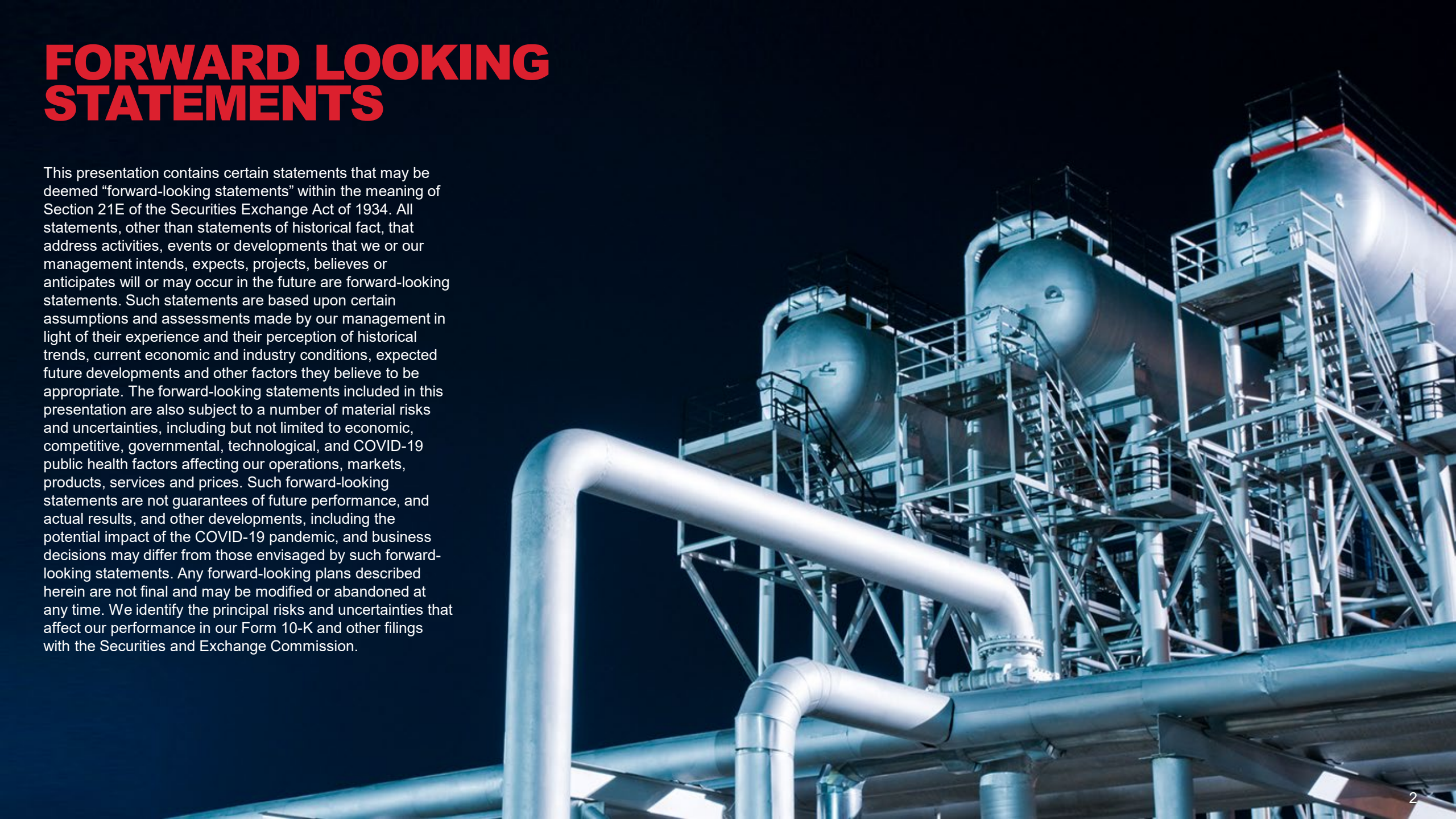

AGENDA

1. Global Hydrogen Outlook
2. Honeywell Hydrogen Portfolio
3. Low Carbon Blue H_2 ATR Solutions and H_2 Retrofit SMR Solutions
4. Blue Hydrogen Case Studies
5. Introducing Liquid Organic Hydrogen Carriers
6. Green H_2 Flows
7. Honeywell LOHC solution
8. Q&A

H_2 SOLUTIONS MARKET OUTLOOK

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GLOBAL HYDROGEN OUTLOOK THROUGH 2050

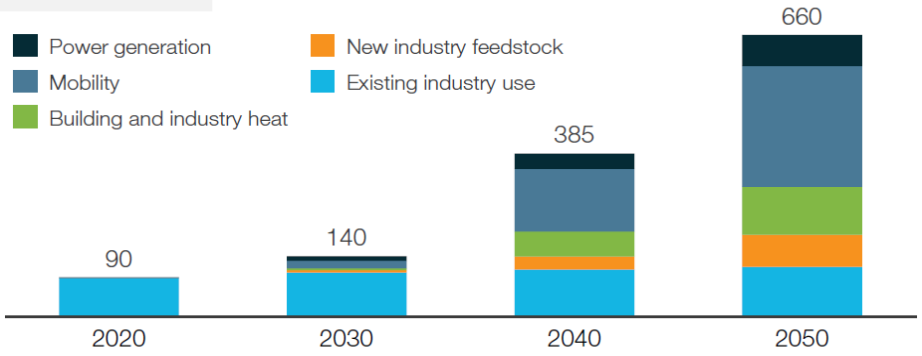
Demand

Global hydrogen demand by segment until 2050

660 MT
hydrogen required p.a. in 2050 for net-zero

22%
of global final energy demand[1]

Hydrogen end-use demand by segment, MT hydrogen p.a.

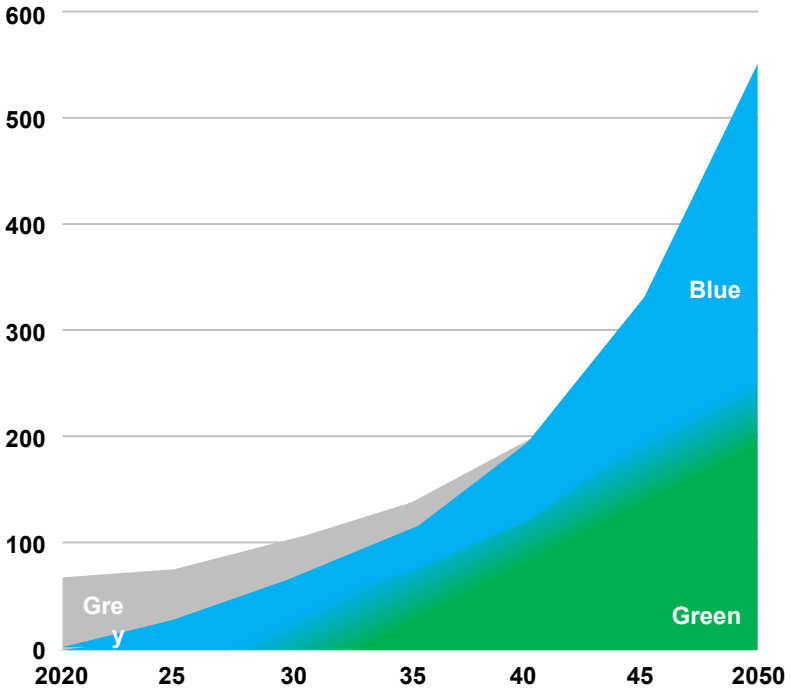


1. IEA net-zero scenario with 340 EJ final energy demand in 2050. HHV assumed. Excluding power.

[7] Clean hydrogen is in this publication defined as either renewable or low-carbon hydrogen; Renewable hydrogen refers to hydrogen produced from water electrolysis with renewable electricity, while low-carbon hydrogen refers to hydrogen produced from fossil fuel reforming with carbon sequestration.
[8] Assumes 35 GT anthropogenic emissions in 2050 in current trajectory.
[9] Considers the share 80 GT CO_2 abated from hydrogen in terms of cumulative emissions from 2021 to 2050, subtracting the remaining carbon budget of 420 GT.

Supply

H_2 Production Growth (Mt/yr)



SOURCE: Hydrogen Council, Decarbonization Pathways, 2021

22% of final energy demand

6Gt annual CO_2 abatement

$2.5tn annual sales (hydrogen and equipment)

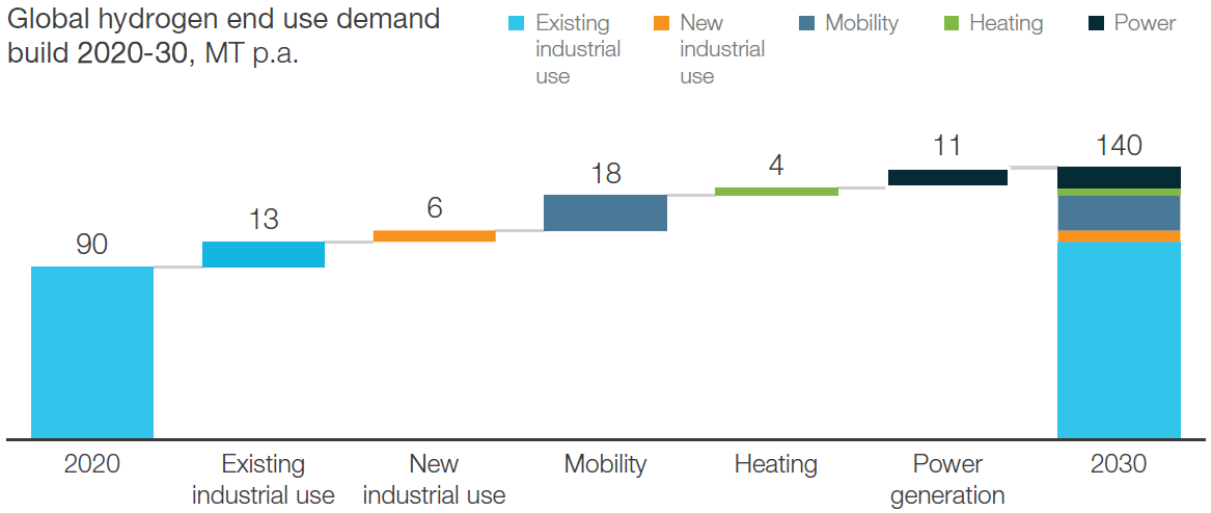
30m jobs created

In a decarbonized world, H_2 demand could grow up to ~10-fold

Source: Hydrogen Council: Scaling Up, McKinsey

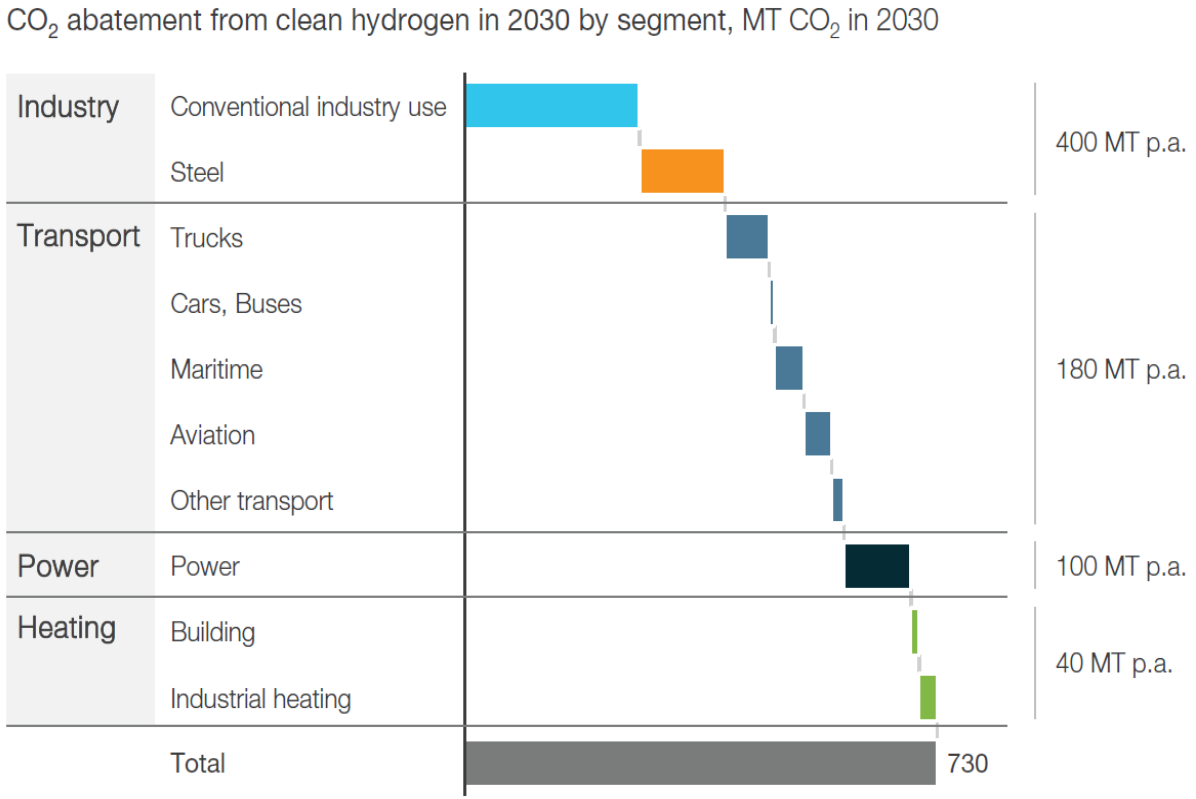
GLOBAL HYDROGEN OUTLOOK THROUGH 2030

Hydrogen End Use Demand



Moderate growth in hydrogen for ammonia, methanol, and refining	Steel production via the H2-DRI-EAF route grows significantly	Trucks largest sub-segment at ~40% of volume, followed by maritime & aviation (~20% each)	Early adoption of hydrogen for high-grade industry heat and blending with gas for building heat	Hydrogen adoption through ammonia blending with coal and pilots for pure hydrogen and blending in turbines

CO_2 Capture

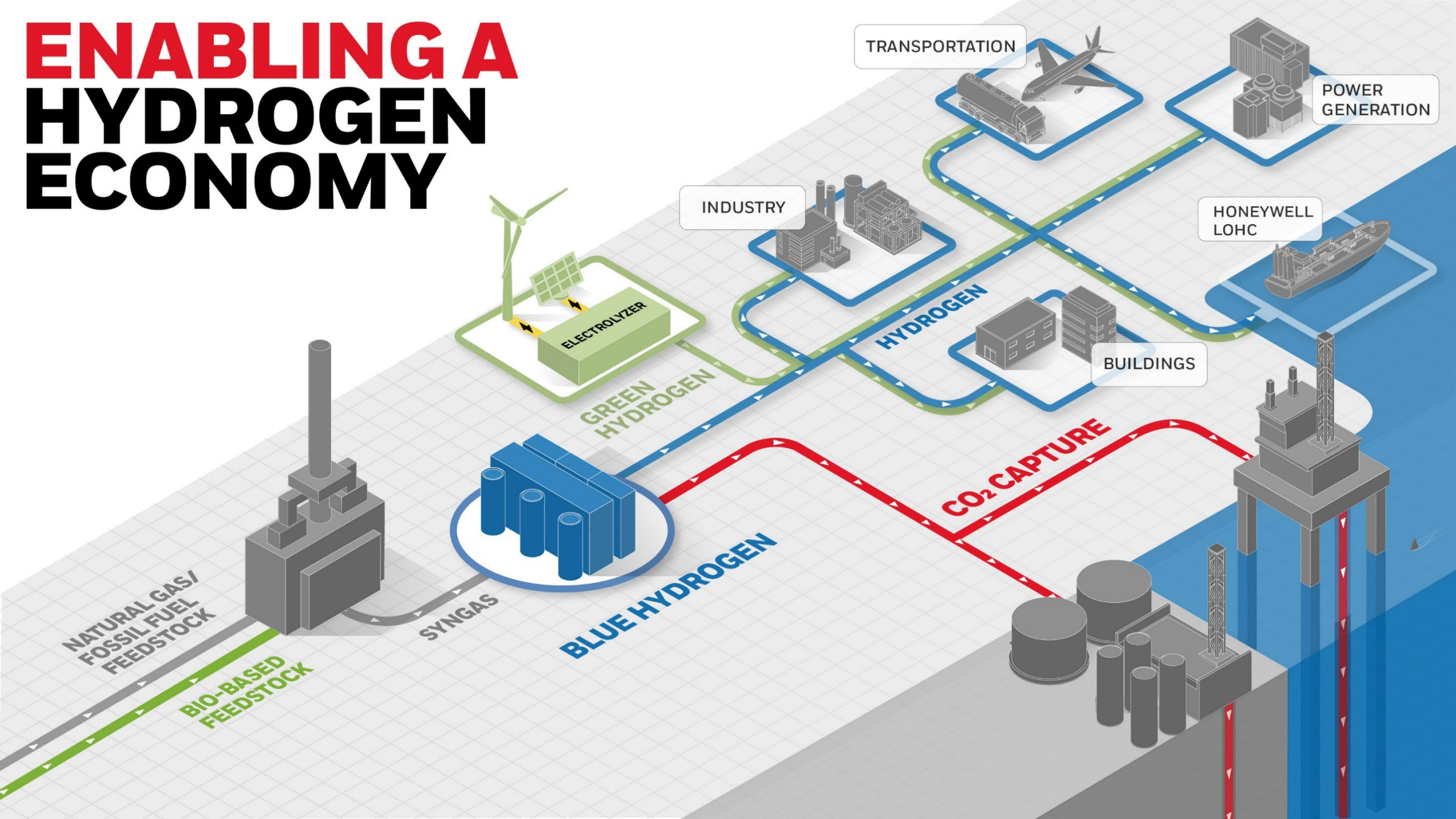


SOURCE: Hydrogen Council, Decarbonization Pathways, 2021

CO_2 capture critical to carbon neutral targets through 2030

Source: Hydrogen for Net Zero, 2021, Hydrogen Council

ENABLING A HYDROGEN ECONOMY



LOW CARBON H_2 ATR SOLUTIONS

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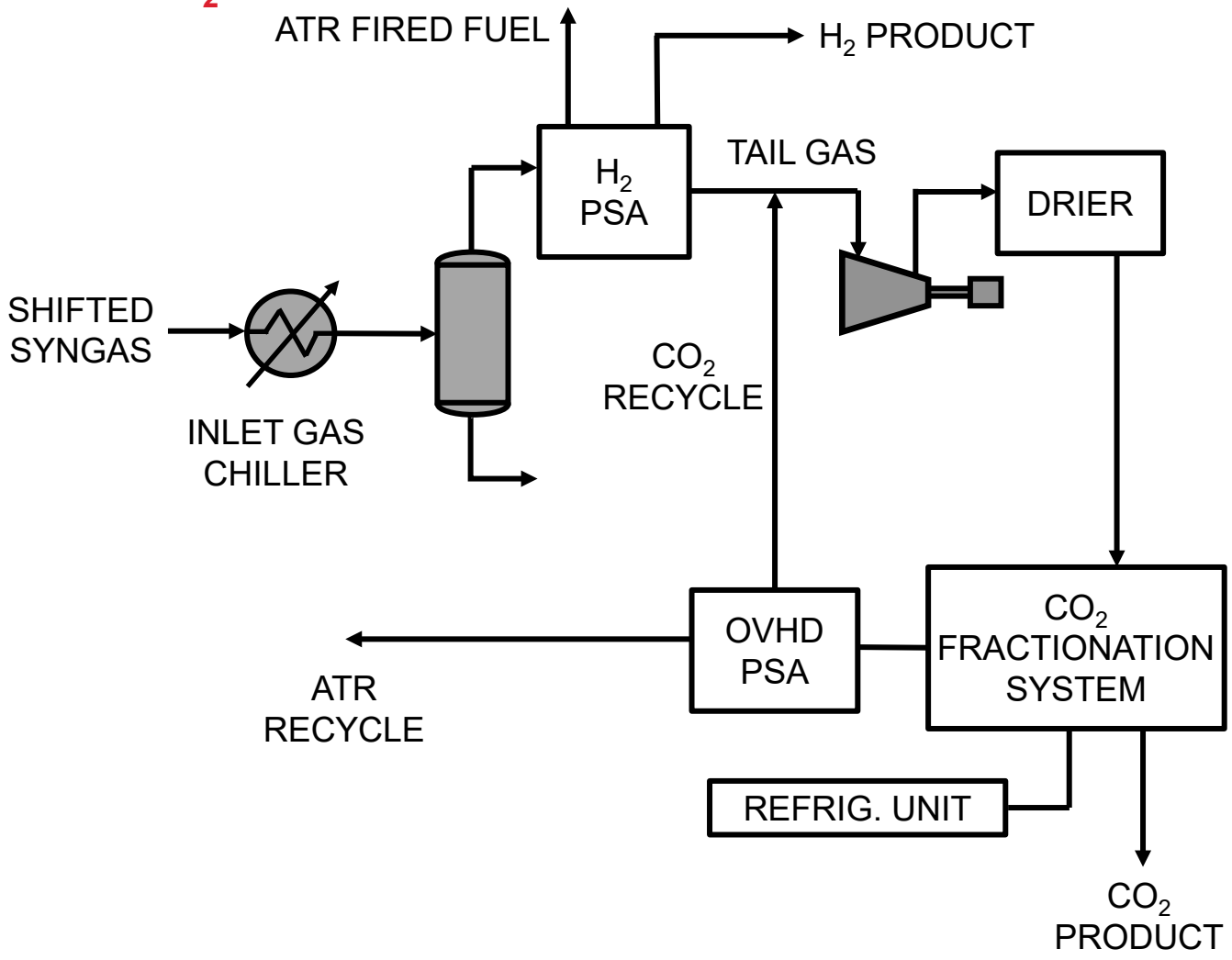
ATR RECYCLE LOW CARBON INTENSITY

UOP CO_2 FRACTIONATION SYSTEM



Off-gas Recycle to ATR Feed

- Low Carbon Emissions
- Higher Feedstock Efficiency

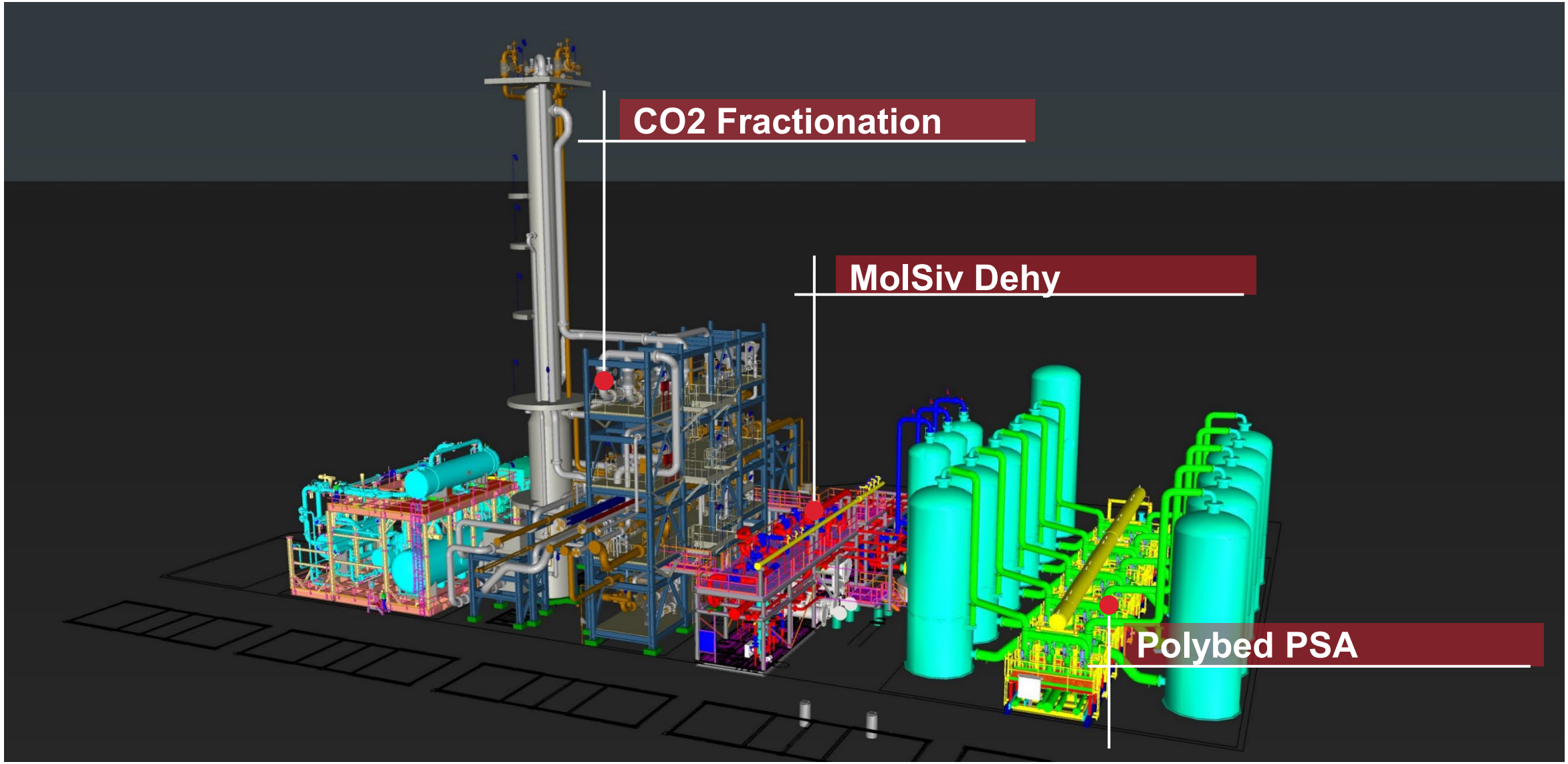
Scope 1 Emissions: <0.1 kg CO_2 / kg H_2*

Carbon-free fuel gas stream produced in H_2 PSA

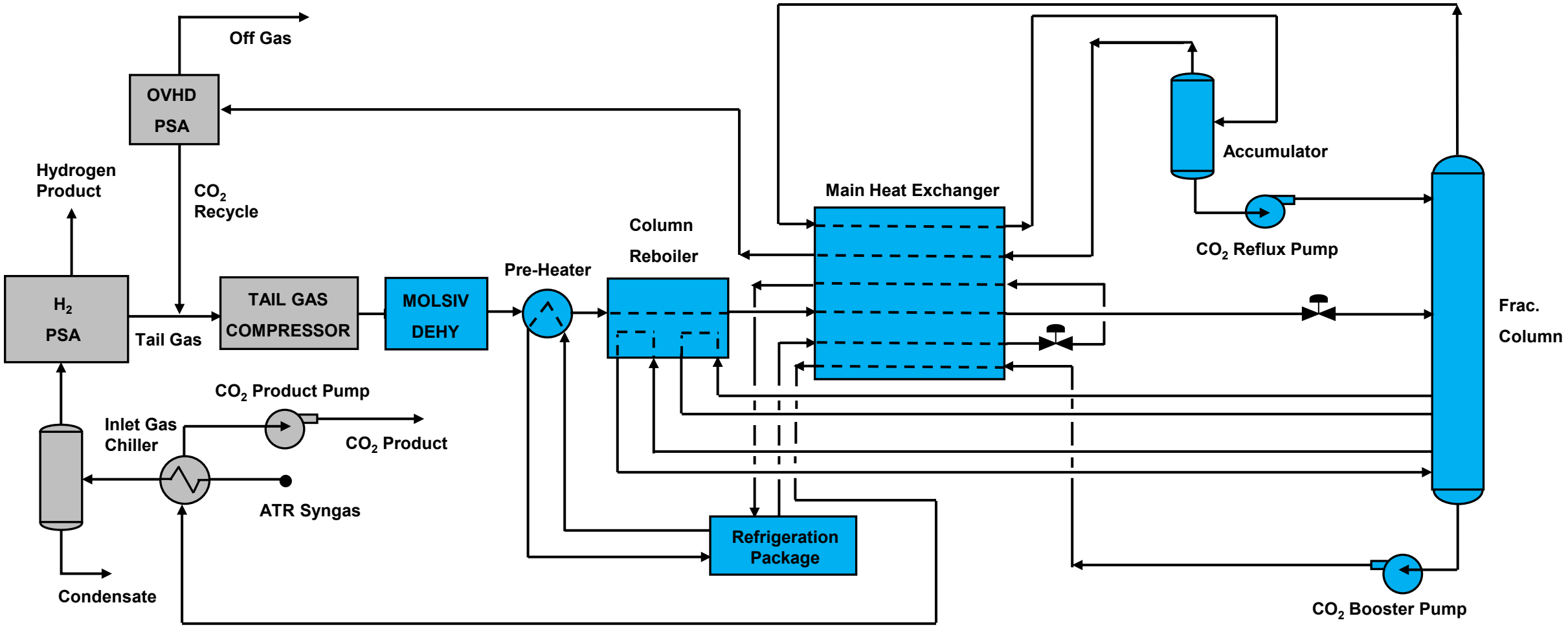
- Selective rejection of inerts
- Approximately 30 psi(g)
- Approximately 90 mol% H_2 and 10% N_2 + Argon

* With the evolving legislative environment, an integrated solution was identified with low carbon intensity as a key target. According to internal calculations, the result is a solution which will enable scope 1 emissions to be less than 0.1 kgCO2/kgH2 by carbon capture rates above 99%, supporting the eligibility for production tax credits within the IRA, meaning projects can access the support they need to be deployed rapidly.

CO_2 FRACTIONATION UNIT



CO_2 FRACTIONATION SYSTEM



VALUE PROPOSITION – INTEGRATION OF AUTO-THERMAL REFINING AND CRYOGENIC FRACTIONATION TECHNOLOGIES

- **Scope 1 emissions can be reduced to <0.1 kg of CO_2 per kg of H_2** by recycling Carbon molecules to the ATR and purging inerts. Overall carbon intensity will be driven by fugitive emissions upstream of the process and the carbon footprint of the electricity consumed from the grid
- **Lower Natural Gas consumption but more Electrical Power consumption.** Potential for Scope 2 emissions to be reduced over time as the grid power leverages renewable energy sources
- Scope 3 emissions driven by fugitive emissions upstream
- H_2 product is at 99.9+% purity*
- **No C and no inerts (Ar and N) to H_2 Product Stream** (C recycled, inerts purged in other streams)

- UOP's flow scheme has different battery limits, and this provides **more flexibility** to adapt to the needs of the Customer while optimizing performance
- **Liquid CO_2 product stream is inherent to process** and is ready for storage and shipping, and would save CAPEX and energy in case CO_2 needs to be compressed for high-dense pipeline transportation
- Reliability: **H_2 product supply can be delivered even when CO_2 capture system is shutdown**
- Equipment count of UOP Cryo fractionation system is about 2/3 that of an amine system, which helps **reduce Plot Area required and reduces maintenance requirements**

* With the evolving legislative environment, an integrated solution was identified with low carbon intensity as a key target. According to internal calculations, the result is a solution which will enable scope 1 emissions to be less than 0.1 kgCO2/kgH2 by carbon capture rates above 99%, supporting the eligibility for production tax credits within the IRA, meaning projects can access the support they need to be deployed rapidly.

LOW CARBON H_2 SMR RETROFIT SOLUTIONS

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SUMMARY OF OPTIONS

	Pre-Combustion			Post-Combustion
	UOP CO_2 Fractionation System on Tail Gas	**CO_2 Polybed PSA on Tail Gas**	**AmineGuard FS on Syngas**	**Advanced Solvent System on Flue Gas**
CO_2 Recovery from Stream	>99% Liquid product	90-98% Gas phase product	>99% Gas phase product	>95% Gas phase product
Overall CO_2 Capture	Depends on configuration of H_2 plant and % of total CO_2 in pre-combustion stream			95%+
Additional H_2 Yield	10-20%	NO	NO	NO
Ultra High CO_2 Purity	YES	NO	NO	NO
Steam Usage	NO	NO	YES	YES
Retrofit	Bolt-on	Bolt-on	May require main PSA retrofit	Bolt-on
Commercial Experience	YES, ref. units in similar applications	YES, ref. units in similar applications	Extensive	Exploring first commercial applications
Cost of CO_2 Captured*, $/MT	**20–40 (includes H_2 credit)**	**35–50**	**45–60**	**55-70**

*Cost of CO_2 captured includes operating costs, fixed costs, USGC basis annualized capital costs (10%/yr), and product value for additional H_2 production where applicable. Low end of range shown is for $3/GJ (LHV) and high end of range is for $6.6/GJ (LHV) natural gas price. CO_2 is provided as high-pressure product at plant battery limits and does not include CO_2 sequestration costs or any tax or credits for CO_2. Cost of CO_2 captured is subject to key variables - stream composition, CO_2 delivery requirement (pressure, purity, phase), utility price set, price of H_2, and geographic location; and is calculated based on internally developed models.

Best option depends on project requirements

LOW CARBON H_2 CASE STUDIES

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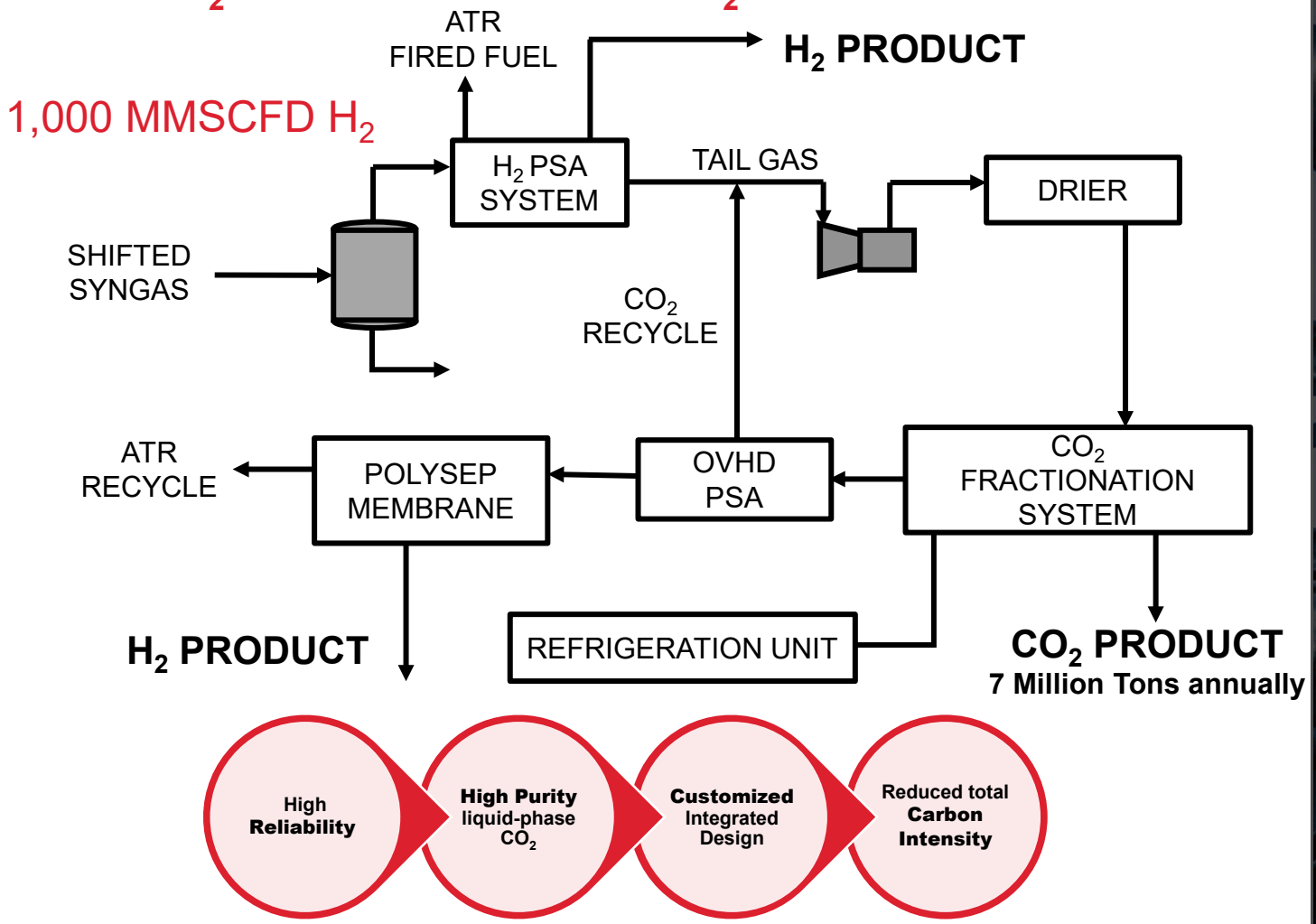
EXXONMOBIL CASE STUDY

UOP H_2 PURIFICATION AND CO_2 FRACTIONATION



CO_2 Fractionation System

- Enables the capture of about **7 million tons of CO_2 annually**, equivalent to the emission of 1.5 millions of automobiles for one year[1]
- **98% CO_2 emissions captured** across Low-Carbon Hydrogen production facility[2]

H_2 Purification

- **High Purity H_2 produced** from Pressure Swing Adsorption and Polysep™ Membrane technologies
- ExxonMobil's H_2 production project will enable **up to 30% of scope 1 and scope 2 emissions** reduced at their Baytown facility[3]

[1] Based on the EPA's GHG equivalency calculator comparing nearly 7 million tons of CO_2 per year with gasoline-powered passenger vehicles on the road.

[2] CO_2 equivalent emissions is a calculated value based on the combined carbon compounds emitted from the Hydrogen production and Carbon Capture equipment plus the combined carbon compounds in the H2 product.

[3] Based on press release issued Feb 15, 2023, announcing HON H2 tech in Exxon Baytown facility. Link

HONEYWELL IS WINNING WABASH VALLEY RESOURCES

Overview

UOP selected as technology provider for carbon capture and H_2 purification for clean H_2 production from gasifier at **Wabash Valley Resources (WVR)** in West Terra Haute, Indiana

Why it Matters

- One of the largest **CCS projects** (1.65 Mt/yr CO_2)
- Second US project to sequester CO_2 in permanent geologic storage
- **Demonstrates large-scale commercially viable clean H_2 and CCS project under current regulatory and policy framework**

Technology

Integration of Modular MOLSIV, Modular Ortloff CO_2 Fractionation System, Modular PSA

Solution Advantages

- Commercially proven technologies
- Lower Capex / Opex
- Faster modular execution
- Parallel on-site and module fabrication execution
- High-quality shop-fabricated equipment
- Efficiency: single supplier for technology and equipment allows for less handoff
- Bankability: well-recognized in the market for both technology licensing and modular equipment

One of the largest carbon capture and clean H_2 production facilities in the US to date

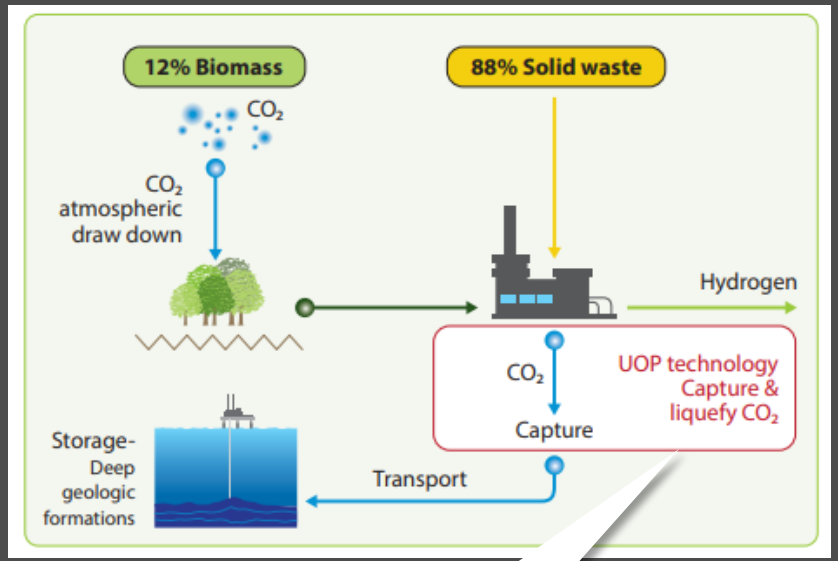


Figure 1: Overall flow scheme

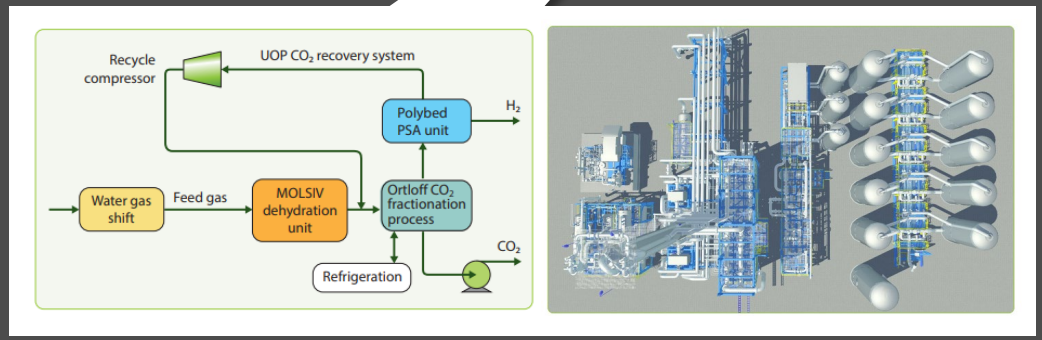


Figure 2: Honeywell CO_2 capture solution

LIQUID ORGANIC HYDROGEN CARRIER (LOHC)

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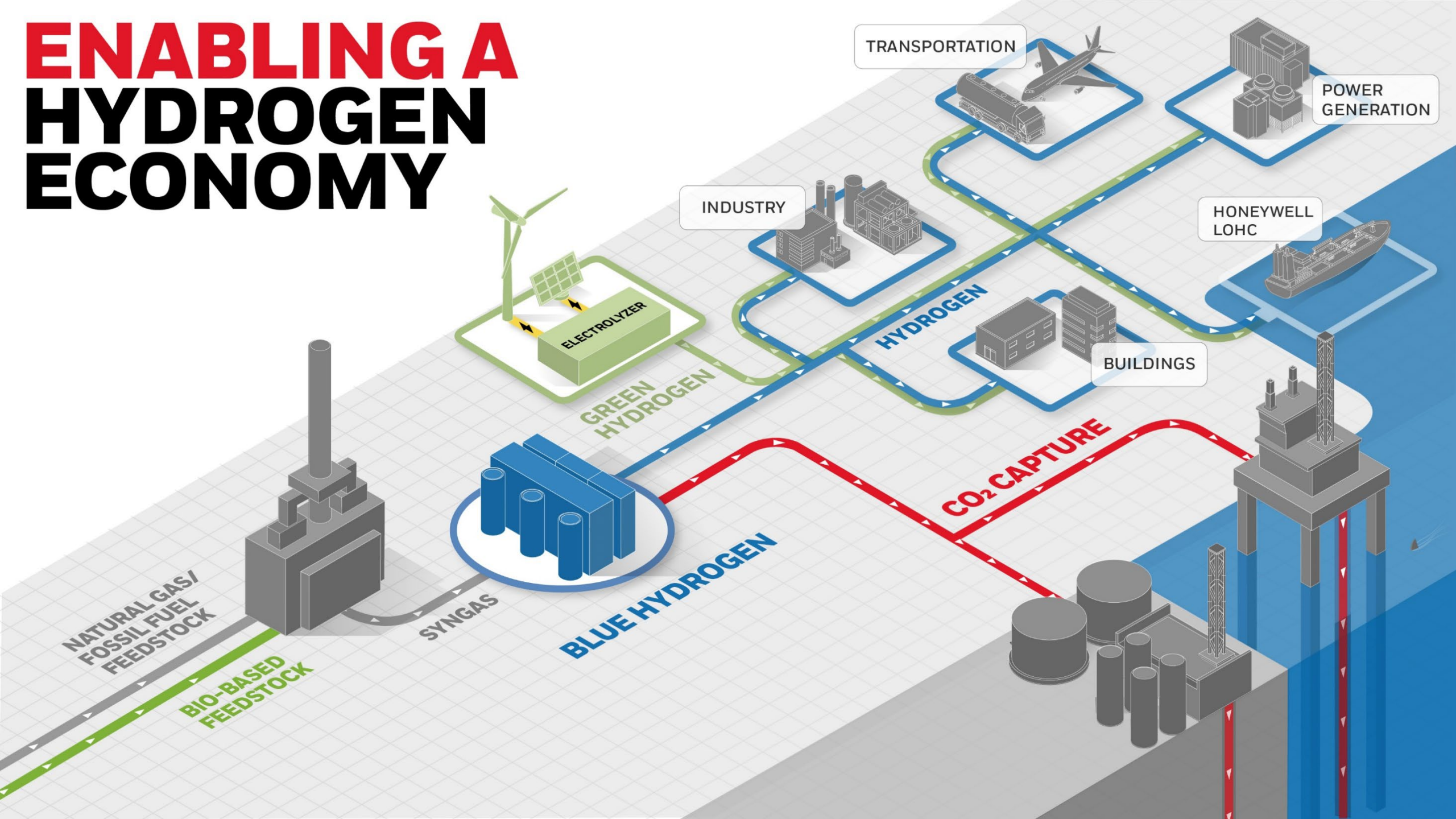
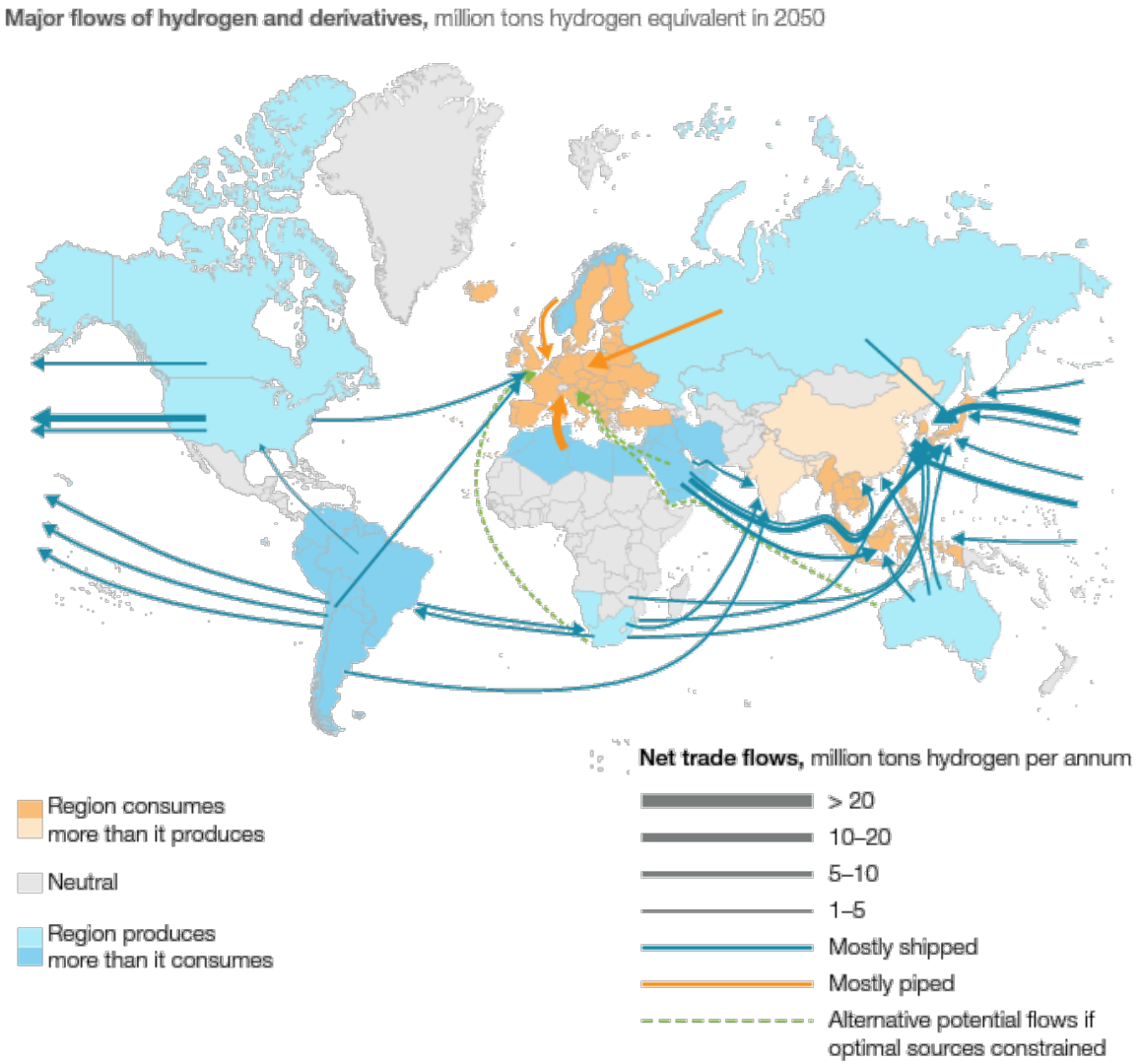
ENABLING A HYDROGEN ECONOMY



WHAT IS LOHC?

- Liquid Organic Hydrogen Carrier
- Stores hydrogen as liquid under ambient conditions.
- Enables high-capacity hydrogen transport
- Utilizes existing refinery and transportation infrastructure used today for fossil fuels
- Reduces the need of large-scale hydrogen storage

GREEN HYDROGEN FLOWS



LONG DISTANCE H_2 TRANSPORT DRIVERS:

- Supply and demand gap between regions
- Difference in cost of production of H_2 in some regions due to access to renewable resources

Hydrogen Council
McKinsey & Company, October 2022

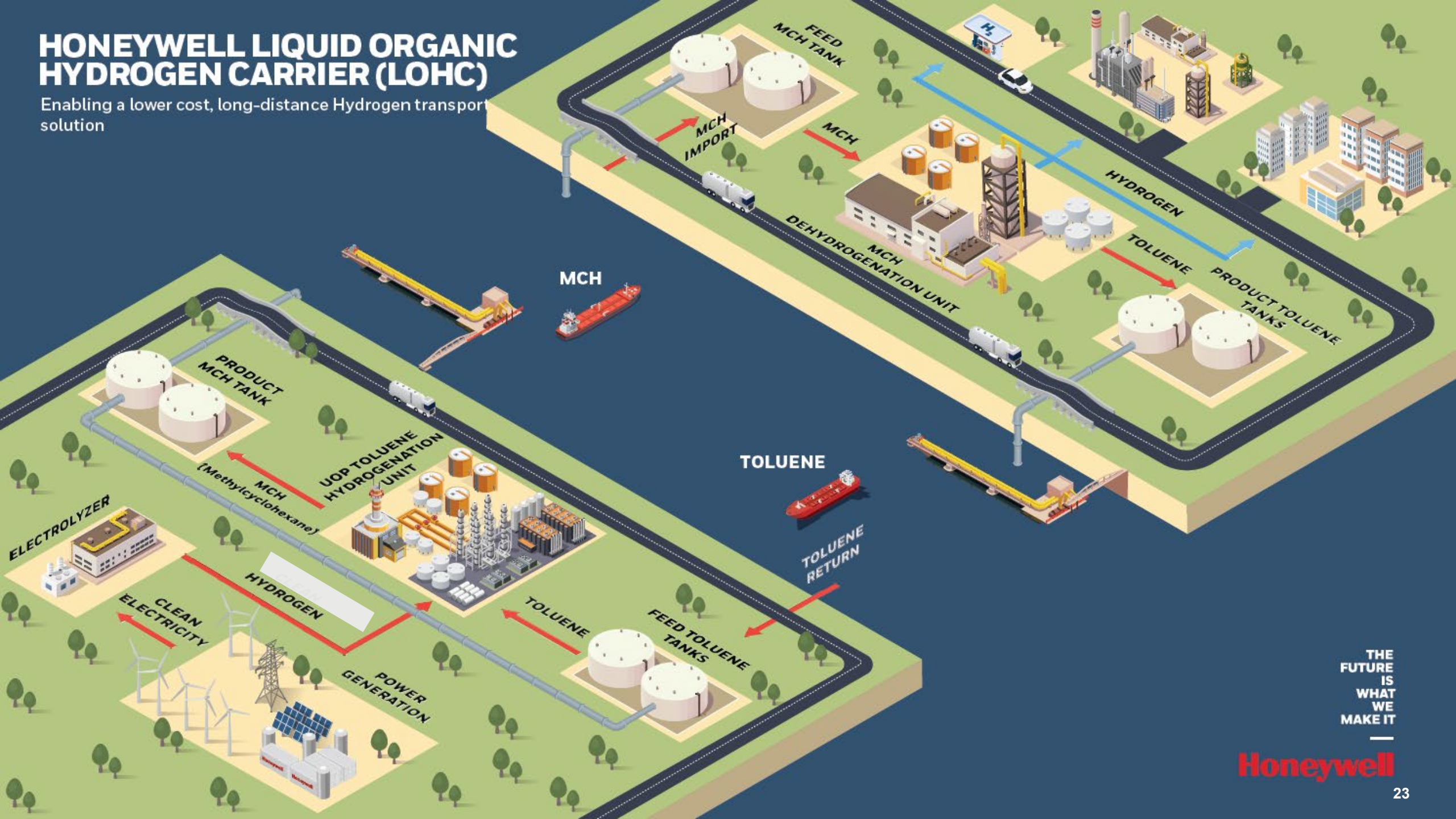
H_2 TRANSPORT OPTIONS

	Honeywell LOHC (MCH)	LOHC (BT/DBT)	NH_3	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 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

HONEYWELL LIQUID ORGANIC HYDROGEN CARRIER (LOHC)

Enabling a lower cost, long-distance Hydrogen transport solution



THE FUTURE IS WHAT WE MAKE IT

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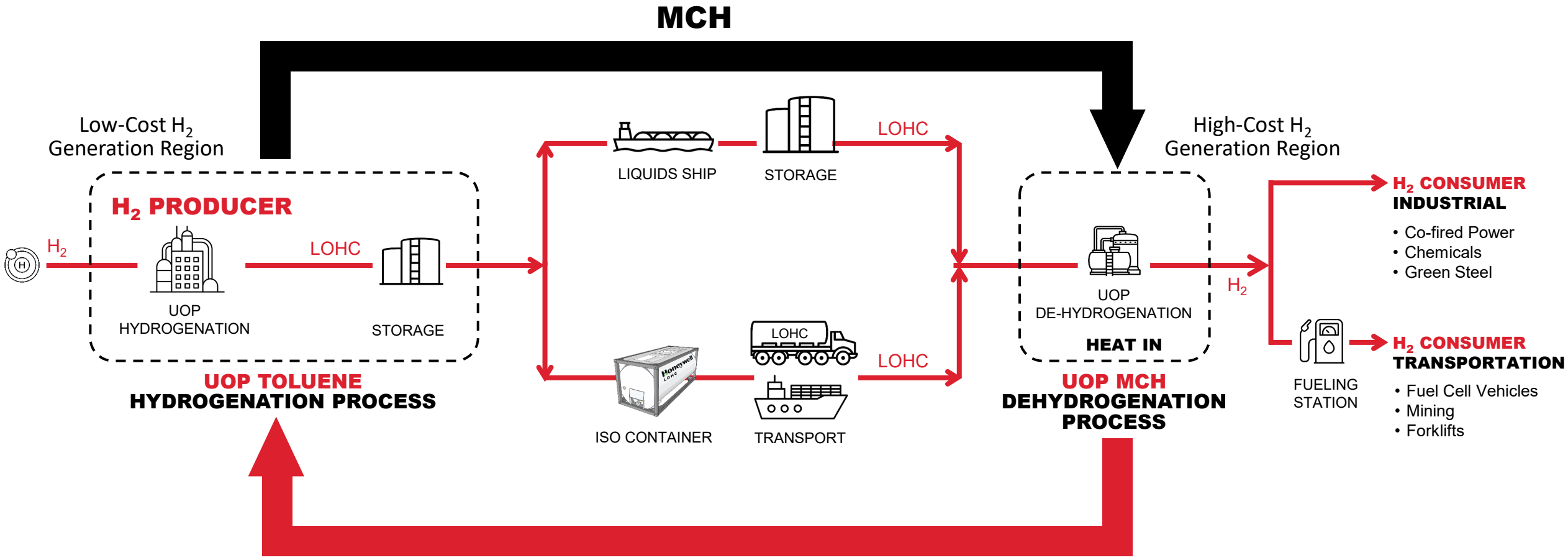
HONEYWELL LOHC SOLUTION
COMMERCIALLY PROVEN TECHNOLOGY AND CATALYST



UOP HYDROGENATION
45+ commercial reference units on similar technology for Benzene/Aromatics processing

UOP DE-HYDROGENATION
1000+ commercial reference units on similar technology for Heavy Naphtha processing

ADVANTAGES OF HONEYWELL LOHC

Commercially proven and ready to execute at large scale

- No need for a small-scale demonstration to prove the concept
- Costs/economics for commercial scale can be estimated with relative accuracy

Single source optimization for import and export

- Project risks are minimized
- Seamless project execution to implement grassroots and revamp design options
- Complete knowledge of both technologies, ownership of the catalyst supply chain

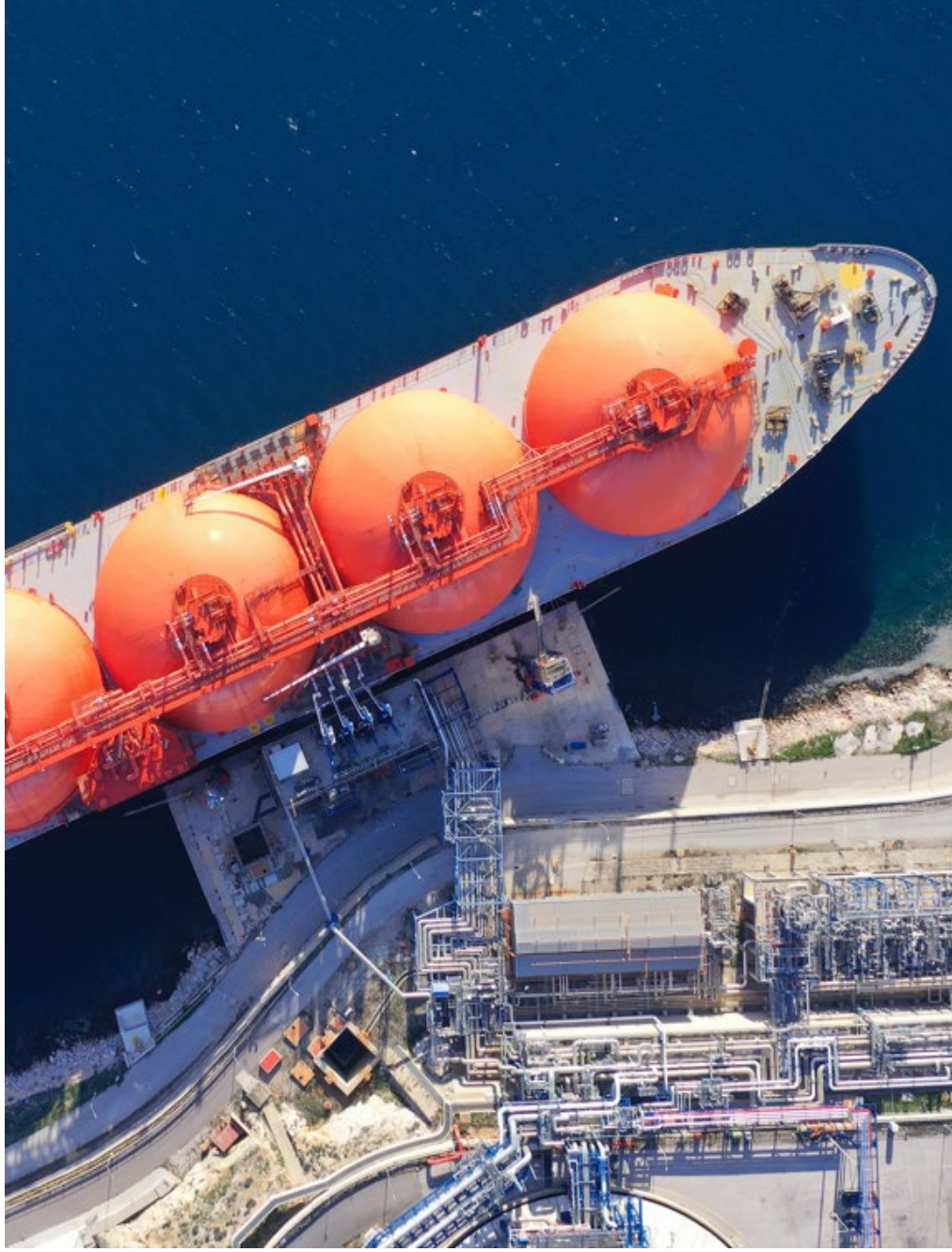
Maximum H_2 transported

- Highly selective reconversion to pure hydrogen
- Minimum loss of Hydrogen
- Independently evaluated by EPC contractors and multiple customers

Minimum carrier makeup

- High selectivity leads to minimum carrier consumption and makeup

No catalyst makeup



THANK YOU
FOR YOUR PARTICIPATION

QUESTIONS & ANSWERS