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The Concept and Role of Hydrogen in the Energy Transition

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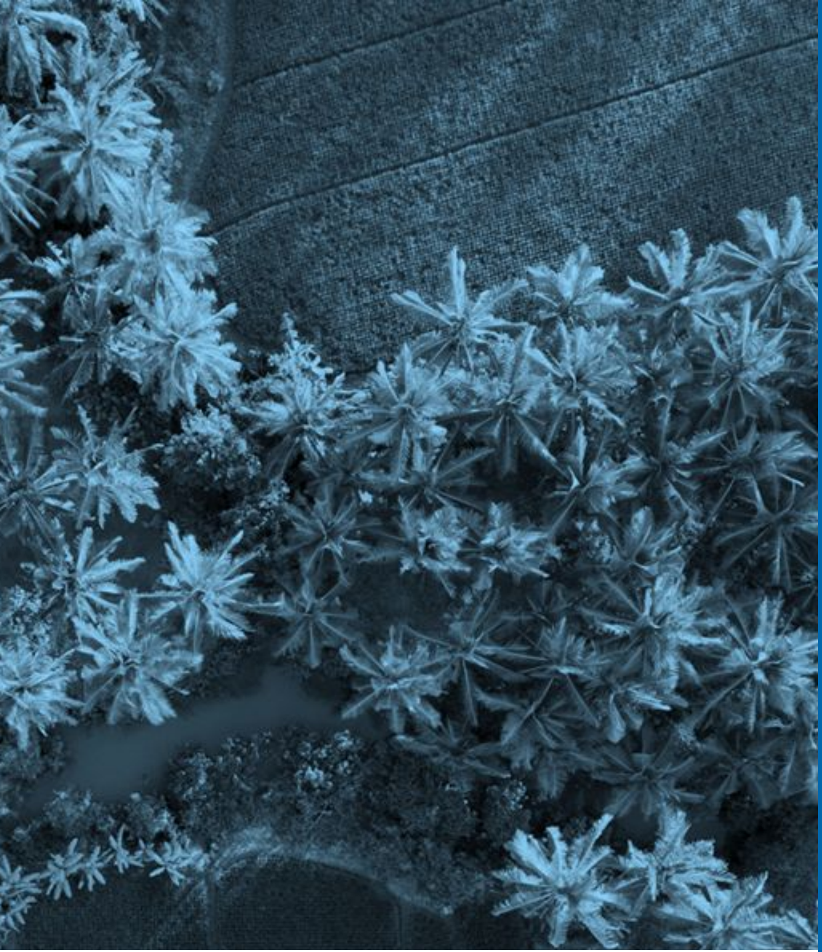

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Summary

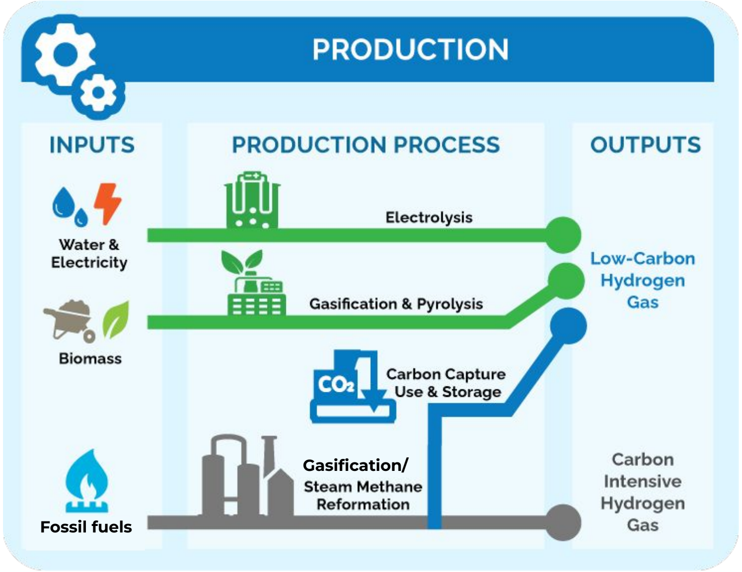
I. Hydrogen production methods, hydrogen distribution, and storage system technologies.
II. The role of hydrogen utilization in general in various sectors
III. Global green hydrogen growth trends,
IV. Driving factors and challenges in green hydrogen development

Towards Sustainable Societies

～ Hydrogen to be familiar with you ～

Source: Figarosensor, 2025

3 methods of hydrogen production based on the source

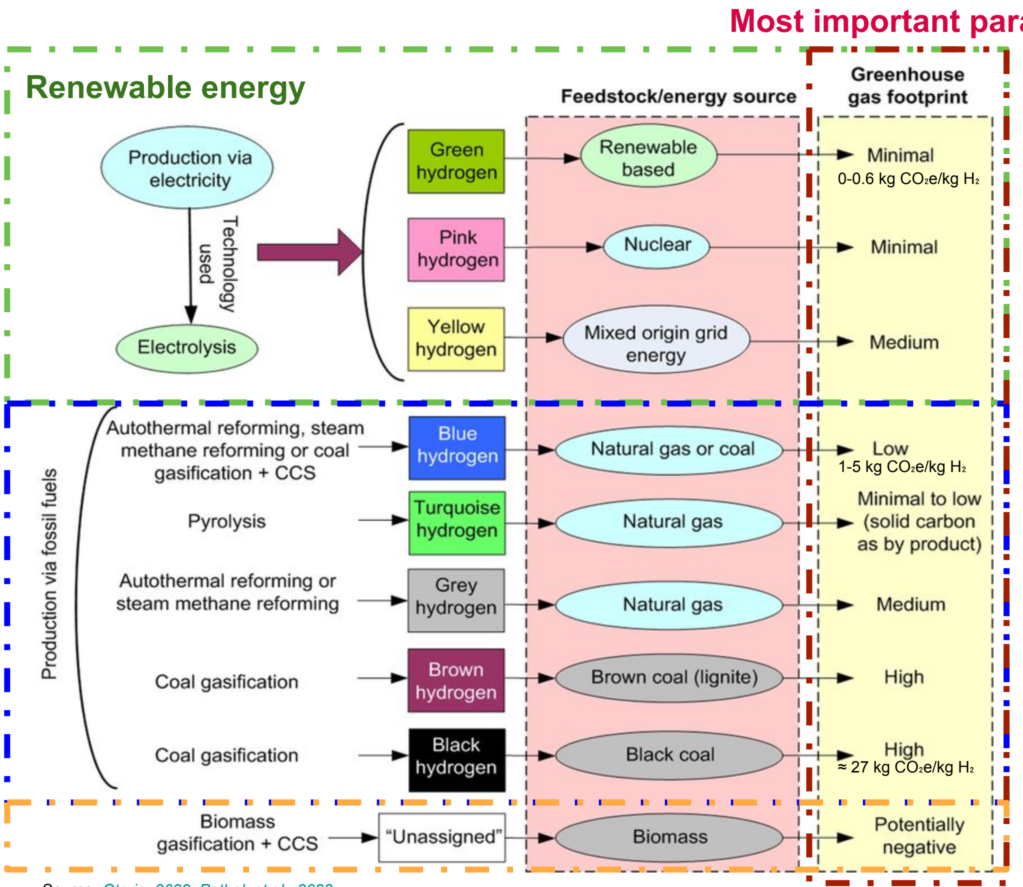


In simple terms, there are 3 methods of hydrogen production based on the type of resource.

- Renewable energy (with water electrolysis/splitting)
- Sustainable Biomass (Carbon neutral due to carbon offset applied)
- Fossil fuels

Source: Otario, 2022; Pathak et al., 2022

Hydrogen production by method and color identification



Source: Otario, 2022; Pathak et al., 2022

- Grey and blue hydrogen are reliant on fossil fuel supplies.
- CCS/CCUS technology is necessary to obtain blue hydrogen.
- Green hydrogen is reliant on renewable energy sources and water electrolysis.
- Biomass potentially negative with addition of BECCS

- But no less important in the taxonomy of the LCA/footprint of CO_2 emissions.

Hydrogen taxonomy by LCA/footprint of CO_2

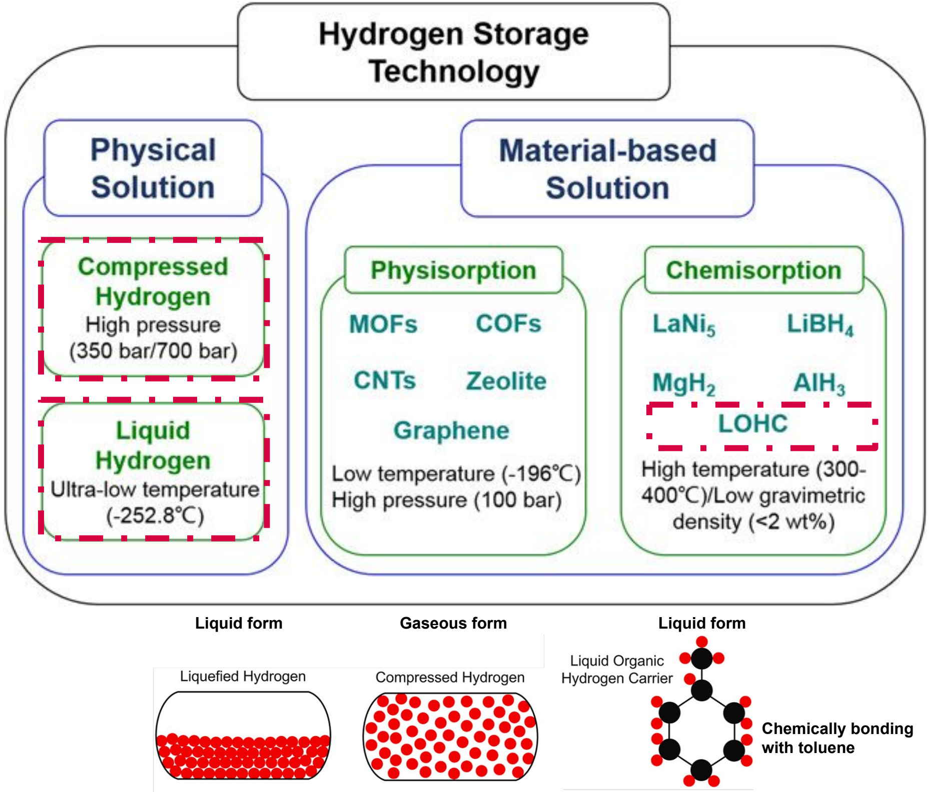
Clean hydrogen	
USA	4 kg CO_2e/kg hydrogen
UK	2.4 kg CO_2e/kg hydrogen
Japan	3.4 kg CO_2e/kg hydrogen
South Korea	4 kg CO_2e/kg hydrogen
EU	3.38 kg CO_2e/kg hydrogen 1 kg CO_2e/kg hydrogen by 2050
China	4.9 kg CO_2e/kg hydrogen

Renewable hydrogen	
Australia	0.6 kg CO_2e/kg hydrogen

Green hydrogen	
India	2 kg CO_2e/kg hydrogen
GH2	≤ 1 kg CO_2e/kg hydrogen

Source: *Adapted from* *US Department of Treasury, 2025*; *Agora, 2024*; *CMS, 2024*; *GH2, 2024*; *Clean Energy councils, 2024*; *PIB, 2024*; *EU, 2023*; *WEC, 2023*

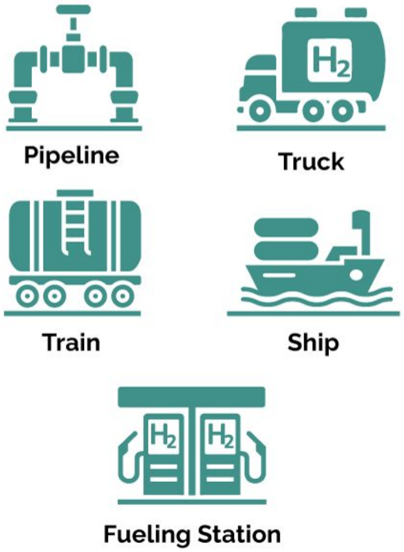
Hydrogen storage system

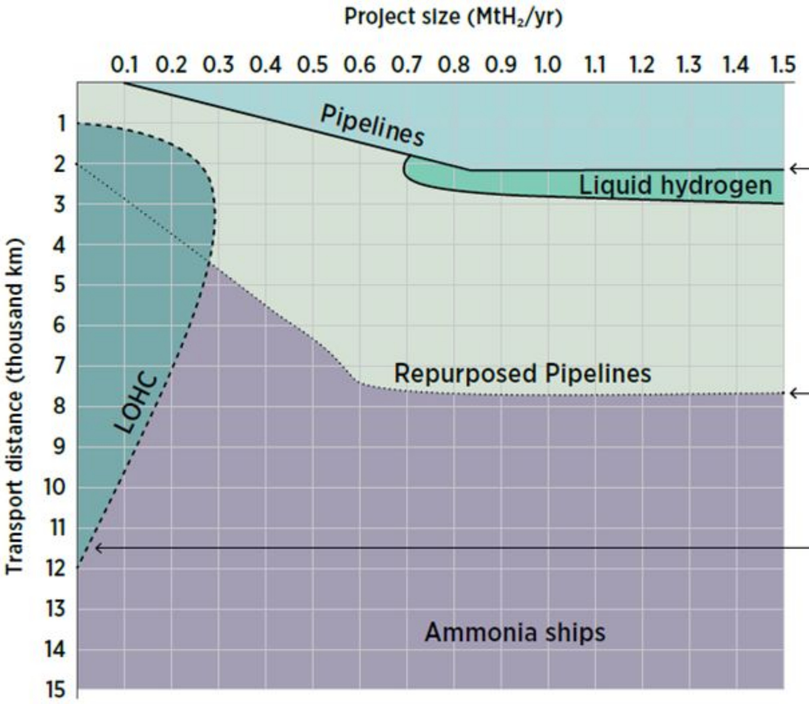


- Hydrogen distribution is highly dependent on how the hydrogen is stored.
- Hydrogen is most often transported in two forms:
  - Compressed gaseous pipeline, truck, train, and ship.
  - Liquid hydrogen by insulated pipelines or truck, train, and ship.
  - Liquid Organic Hydrogen Carrier (LOHC) transported using existing infrastructure like oil tankers or pipelines

Source: Liu et al., 2022; Hydrogeneurope, 2021; Usman, 2022; Umicore, 2025; Light house 2023

Most cost-effective hydrogen transmission method in 2050 by project size and distance - IRENA





Solid lines are the base case. Pipelines are attractive for short distances, liquid hydrogen has a niche role and ammonia shipping is the most attractive for most combinations

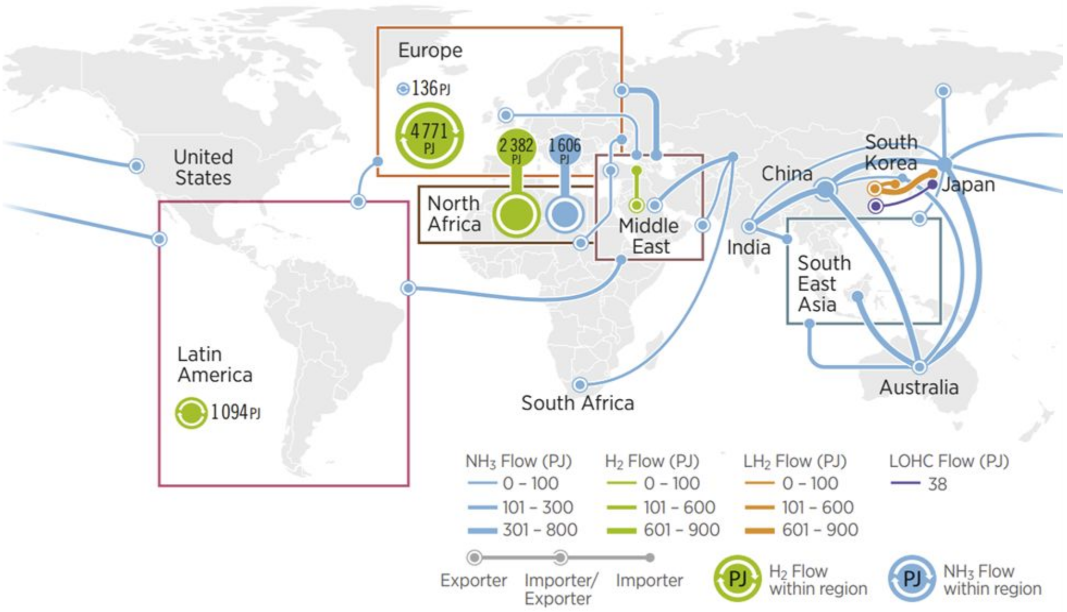
Dotted lines are for regions that have an existing network that can be repurposed to hydrogen, expanding significantly the area where pipelines are attractive

Dashed lines represent a case where innovation is slower and all the costs are higher. In this instance, LOHC can be attractive for smaller projects

Note: Liquid Organic Hydrogen Carriers (LOHCs)

Source: Otario, 2022; IRENA, 2025

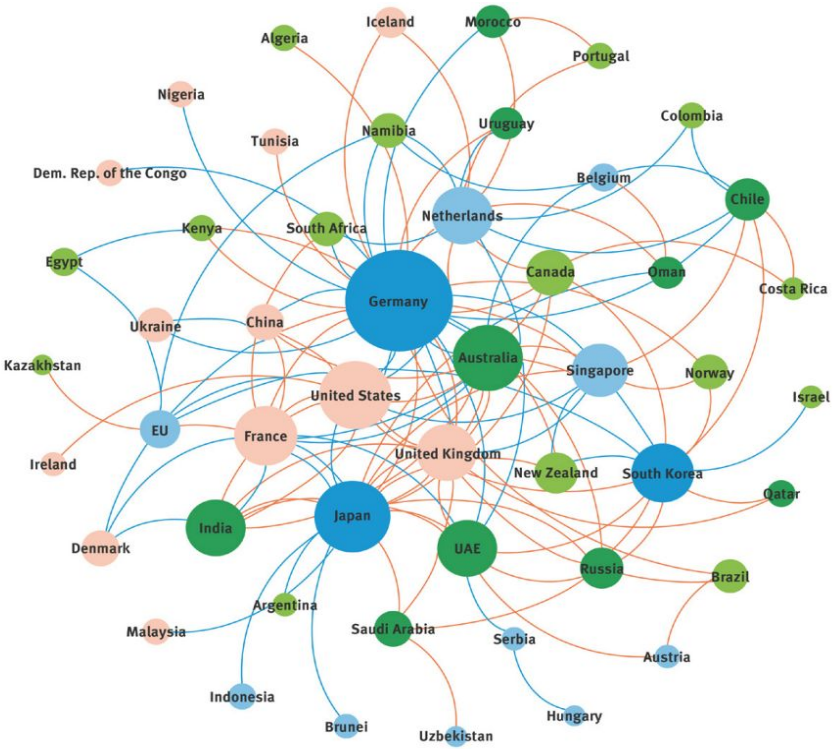
Projected hydrogen global trade flow in 2050

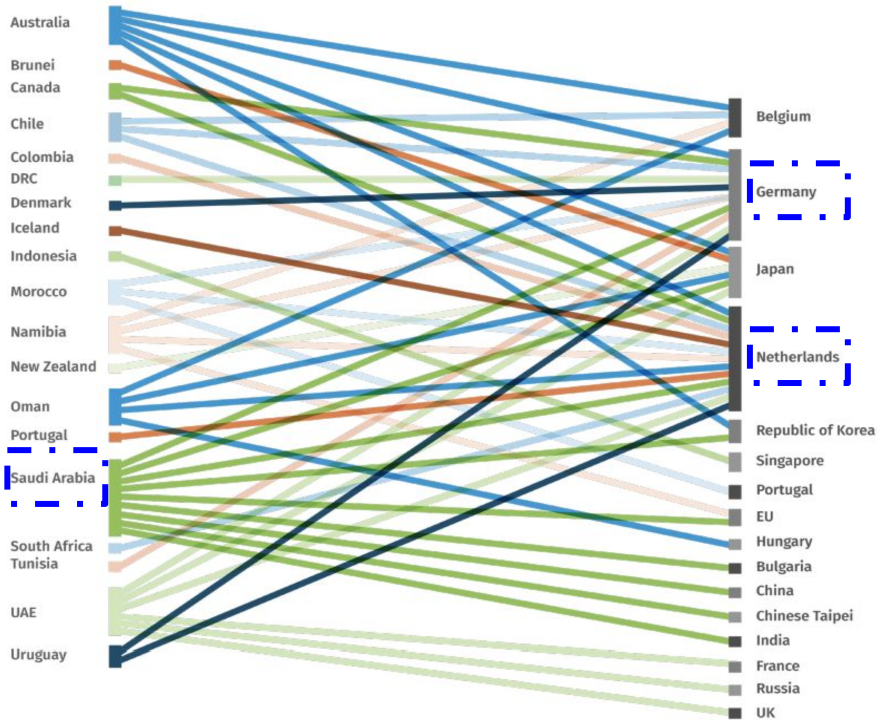


- 55% would travel by pipeline
- The remaining 45% would be shipped, predominantly as ammonia
- Ammonia is used directly without conversion to hydrogen
- Ammonia is preferred as it doesn't have carbon content

Source: IRENA, 2025

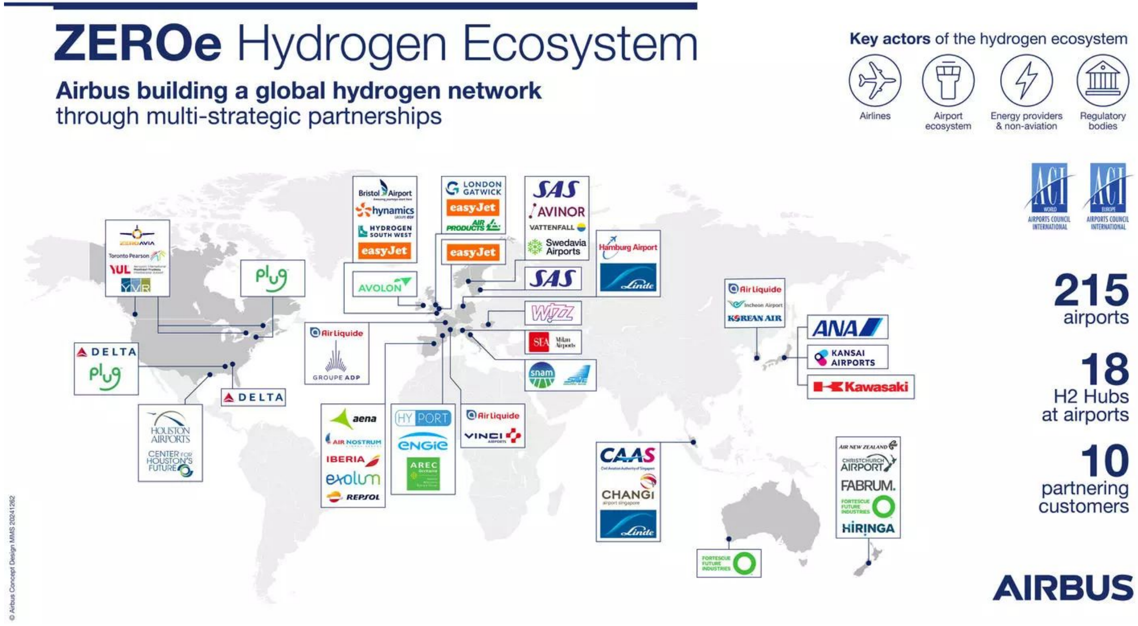
Visualization of the global hydrogen partnership network and Existing bilateral MoU as of October 2023

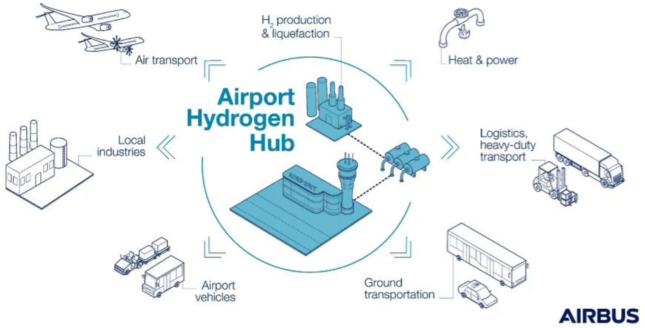




Source: IRENA, 2024

The hydrogen ecosystem is growing rapidly

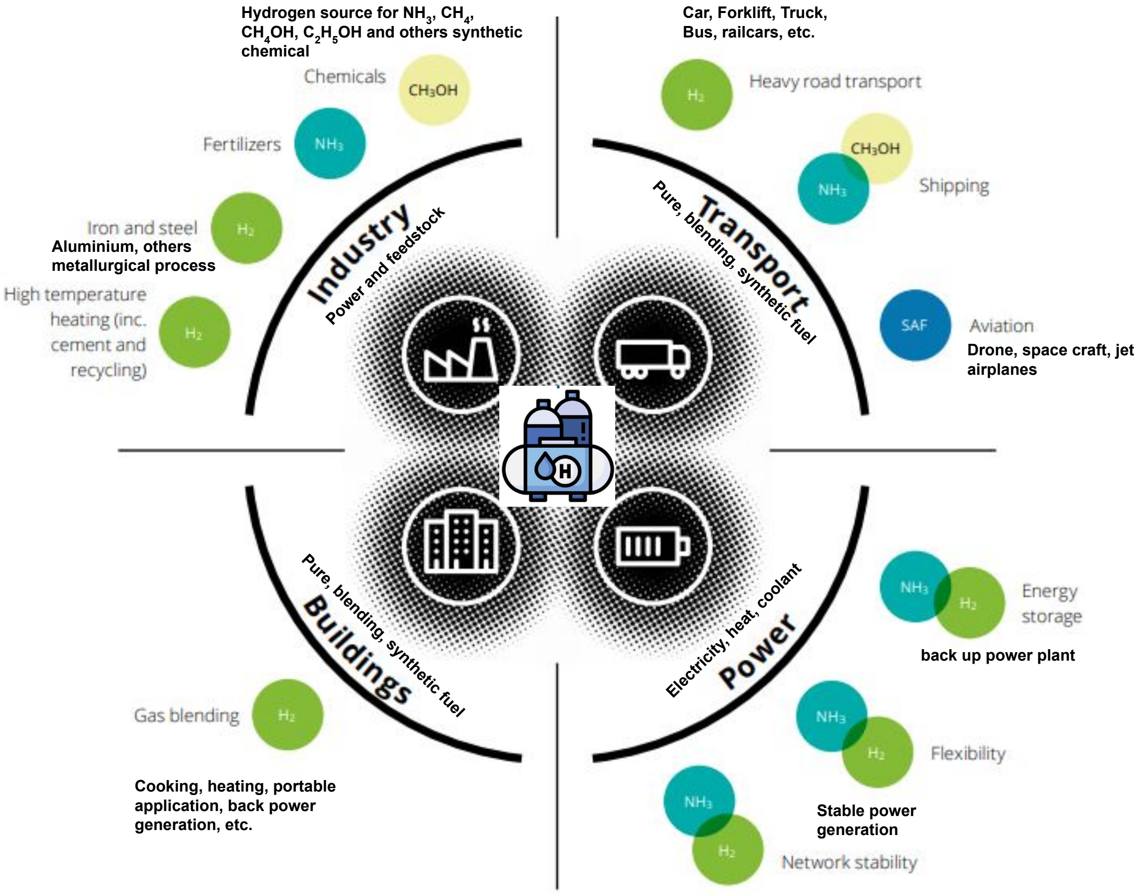




- Lower demand, hydrogen in liquid form by truck or ship
- High level demand by pipeline network

Source: Airbus, 2024

The role of hydrogen utilization



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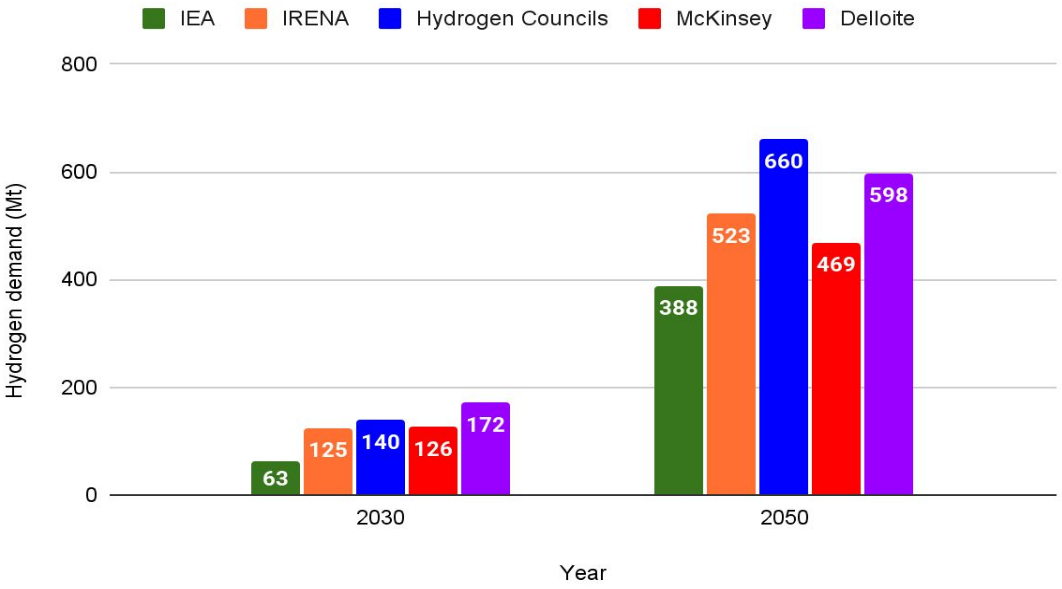
Hydrogen as clean fuel, energy storage, and feedstock

- Globally, almost 100,000 FCEVs had been registered globally by Q1 of 2025.
- USA, over 70,000 hydrogen FCEV forklifts by end of 2024
- EU, as 2023 required aircraft leaving the EU to use 1.2% by 2030 to 35% by 2050 of e-SAF derived from green H_2.
- EU and UK CBAM for hydrogen and industry commodities.
- South Korea, over 1 GW in cumulative fuel cells for power generation by 2023.
- Hydrogen-powered vessels are now available (pilot, commercial) in China, Lithuania, Norway, and Japan.

Source: adapted from *Deloitte, 2024*, *DOE, 2024*; *SNE, 2025*; *Fuel Cell Works, 2024-2025*; *Nippon-foundation, 2024*; *Global Times, 2024*; *IESR-ESS, 2024*

Trend of green hydrogen - Demand projection

Clean hydrogen demand projections

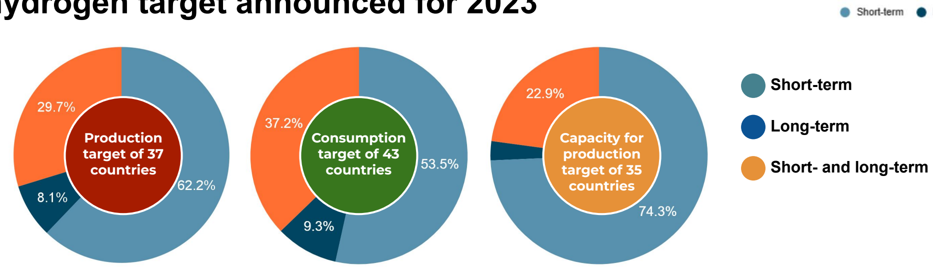


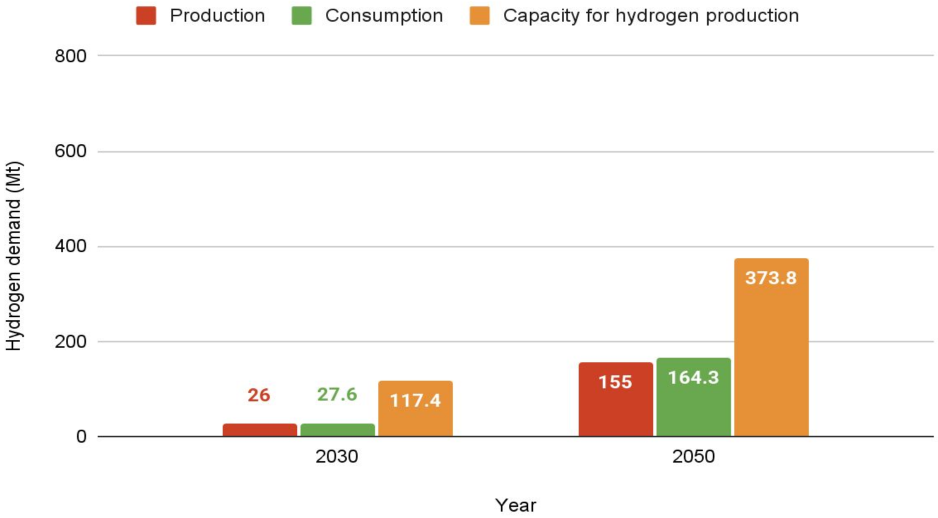
- The share of green hydrogen in clean hydrogen is estimated to reach 70-100% in 2050.
- Green hydrogen is preferred because it has high sustainability value, does not depend on CCS/CCUS and fossil fuels that have capacity/reserve limitations.
- However, it is still hampered by the high initial costs for renewable energy and electrolyzers.

Source: Deloitte, 2024; IEA, 2023; Hydrogen Councils, 2022; McKinsey, 2024

Announced target from countries' national hydrogen strategy

Clean hydrogen target announced for 2023





- Nearly 70% of capacity for production target comes from Middle East and North Africa (MENA).
- It is difficult to track the type of hydrogen.
- Still, not all countries have high enthusiasm, as seen from the number of countries that have short- and long-term targets.

- This number will increase as hydrogen strategies have been implemented by around 60 countries (including the EU) by Q4 of 2024

Source: Diadaptasi dari IRENA, 2024; Weltenergierat, 2025

Driving factor for green hydrogen development

Country's competitiveness and sustainability

	International			Domestic		
Driver	Paris agreement, NDC, Methane pledge, etc.	Regulations of green product and carbon limits for export: CBAM, SBTi, ESG, ISO, etc.	International carbon pricing and emissions trading system	Support the country's economy with green procurement, products, and services	Mitigation is needed due to climate change vulnerabilities	Healthy environment, ecology preservation, good lifestyle
Critical issue	International conventions and agreements	New green or carbon protection policy	Carbon pricing, and sustainable capital markets	Economy and Industry priorities	Material and energy supply vulnerabilities	Green lifestyle with low carbon emissions

Source: *adapted from many sources*

Challenge and key enabler for green hydrogen adoption

Challenges

1. Security: production, distribution, storage and use

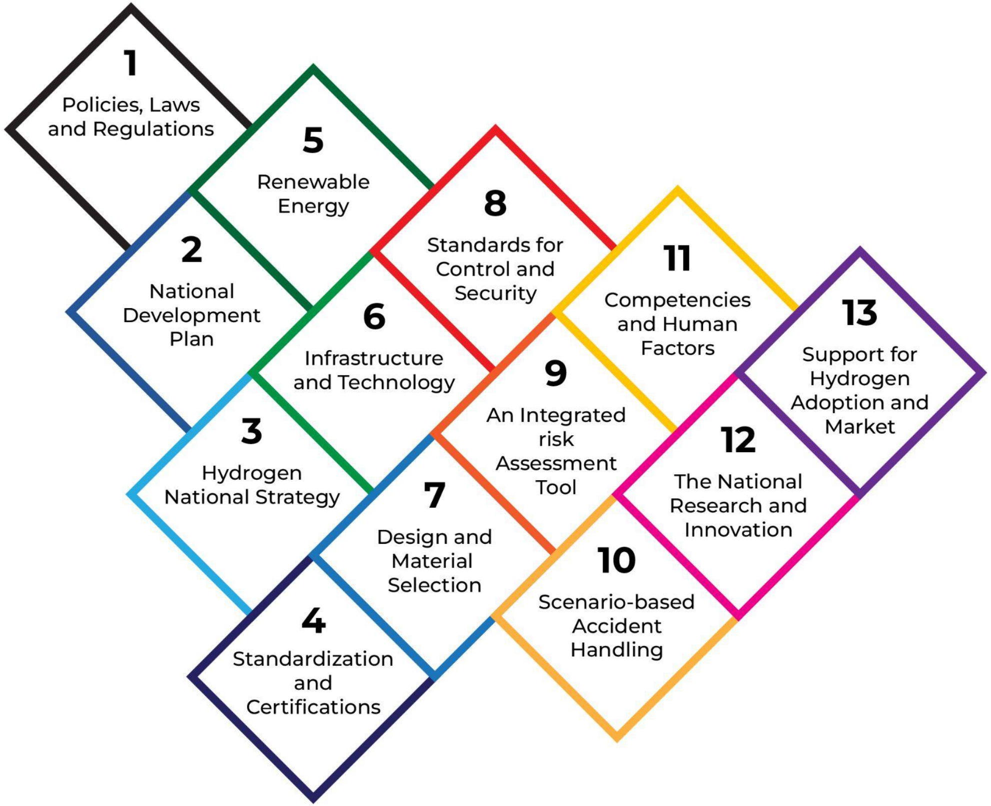
2. Environmental considerations: awareness

3. Economic feasibility and investment value

4. Energy needs and diversification

5. Technology infrastructure readiness

Key Enabler



Source: *IESR-IETO 2024*

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Thank You

Accelerating Low Carbon Energy Transition

Any follow up questions?

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