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# Sustainable hydrogen production and trade from remote and developing regions

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APERC Clean Hydrogen Workshop, 23rd April 2024

**IRENA Innovation and Technology Centre**

# Agenda

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» Introduction to IRENA
» The role of hydrogen in the energy transition
» Future hydrogen trade
» Key aspects of sustainable green hydrogen value chains from remote and developing regions

# 1 Introduction to IRENA

# Overview



- Established in 2011
- Headquarters in Masdar City, Abu Dhabi, UAE
- IRENA Innovation and Technology Centre – Bonn, Germany
- Permanent Observer to the United Nations – New York, USA

## Mandate

To promote the widespread adoption and sustainable use of **all forms of renewable energy** worldwide

Bioenergy | Geothermal Energy | Hydropower | Ocean Energy | Solar Energy | Wind Energy

# Growth in IRENA Membership

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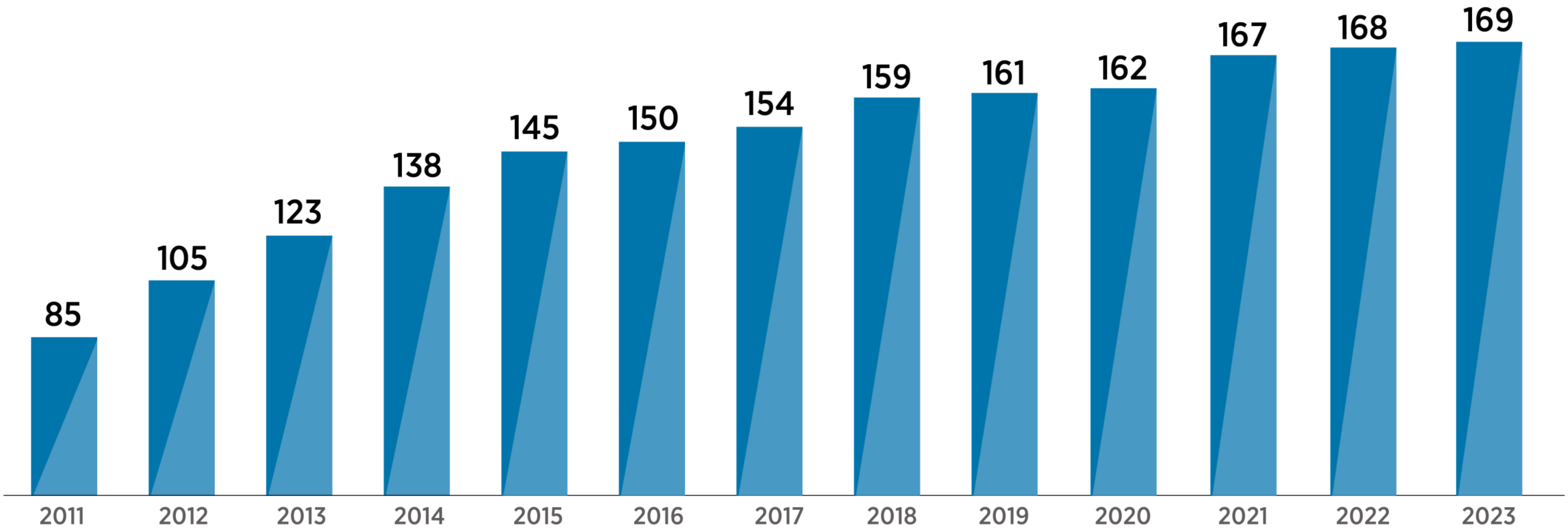
## 169 Members and 15 States in Accession



# IRENA provides up to date information on green hydrogen

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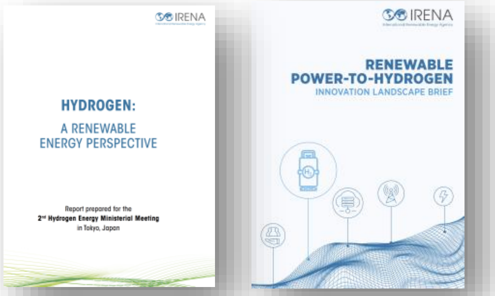
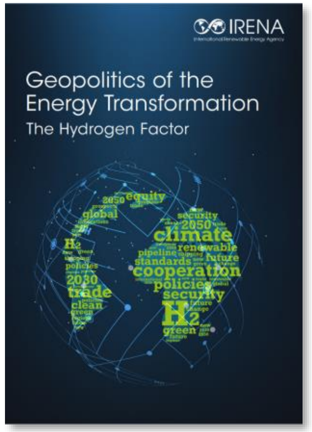
## Supply

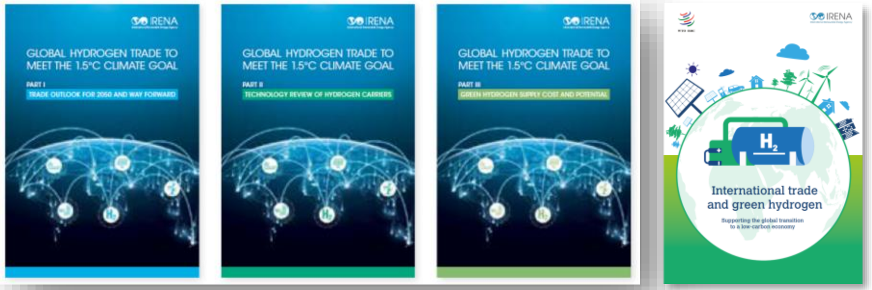

***Sector coupling***




## Trade








## Demand

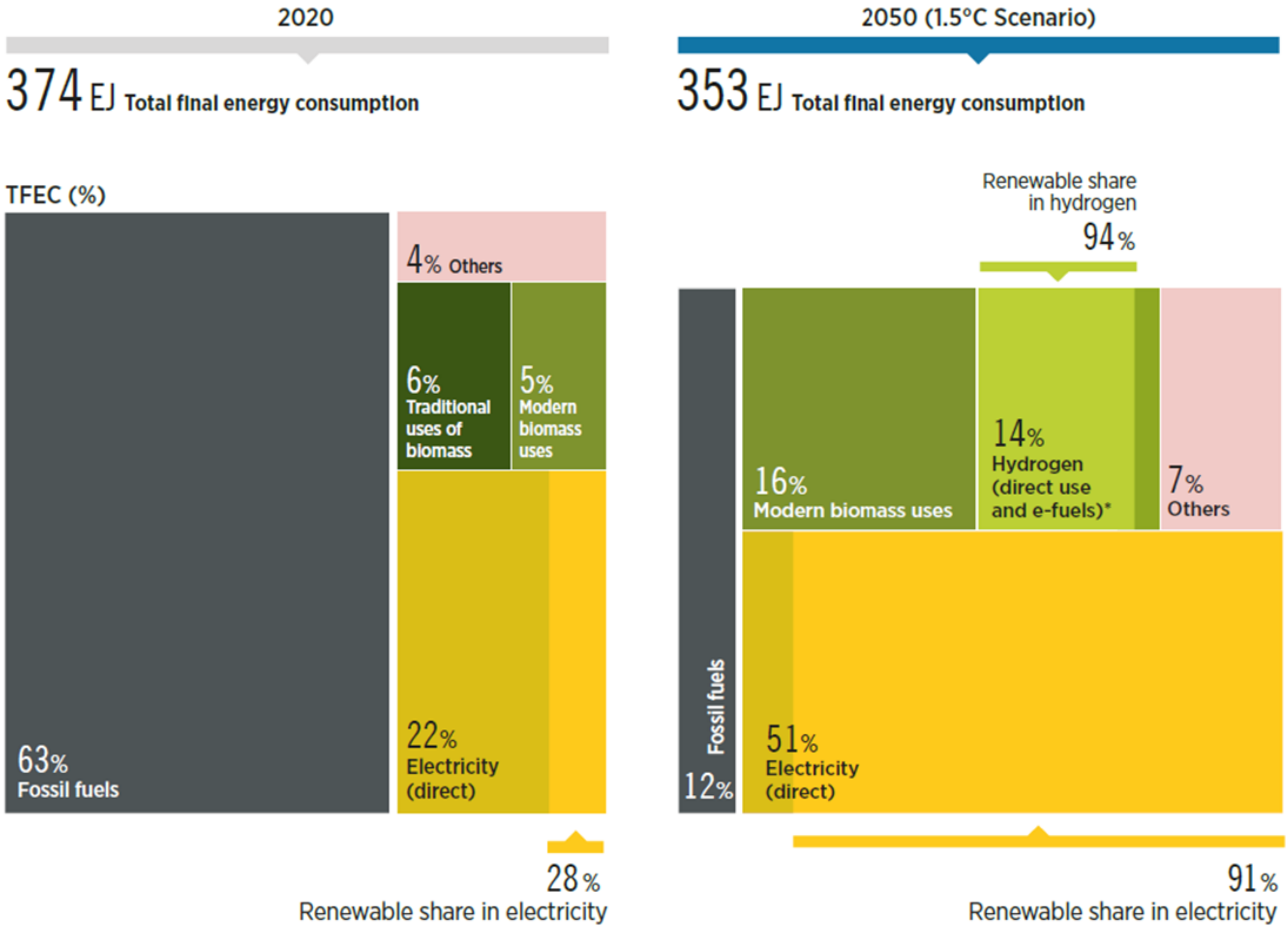


## Policies & cross cutting

# 2 The role of hydrogen in the energy transition

# Electricity will be the main energy carrier in 2050

**Breakdown of total final energy consumption by energy carrier between 2020 and 2050 under the 1.5-degree scenario**

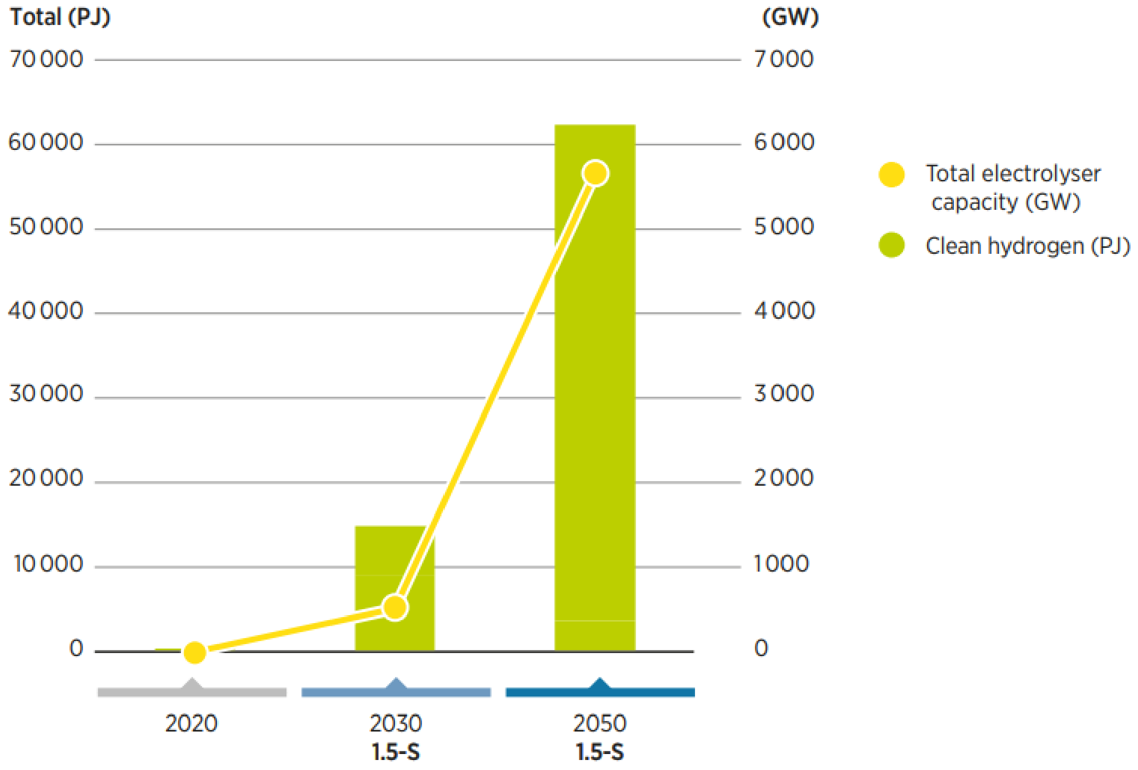



- The **global energy transition is off-track**
- Current plans are **not enough to limit the global temperature** increase below to 1.5°C.
- **Investments** in renewables must **quadruple.**
- By 2050 in a 1.5oC Scenario **electricity is the main energy carrier.**
- It has to **come from renewables.**
- ~ **50% direct use** and ~ **14% indirect use as green hydrogen and derivatives.**

Source: IRENA (2023), World Energy Transitions Outlook 2023: 1.5° C Pathway, International Renewable Energy Agency, Abu Dhabi.

# Scaling green hydrogen production will be a major challenge

**Global clean** hydrogen **supply in 2020, 2030 and 2050 in IRENA's 1.5° C Scenario.**




**Notes:** 1.5-S = 1.5°C Scenario; GW = gigawatt; PJ = petajoule.

- Most of **today's hydrogen production is fossil-derived** (mostly natural gas, but also coal)
- Most global hydrogen **production in 2050 should come from renewables**
- The electricity requirement for **green hydrogen in 2050 is comparable to today's global electricity consumption.**
- From **~ 1 GW to >5700 GW** electrolyser capacity by 2050.

Source: IRENA, 2023. World Energy Transitions Outlook 2023: 1.5° C Pathway, Volume 1

# We are transitioning to a world of abundant, cheap renewables

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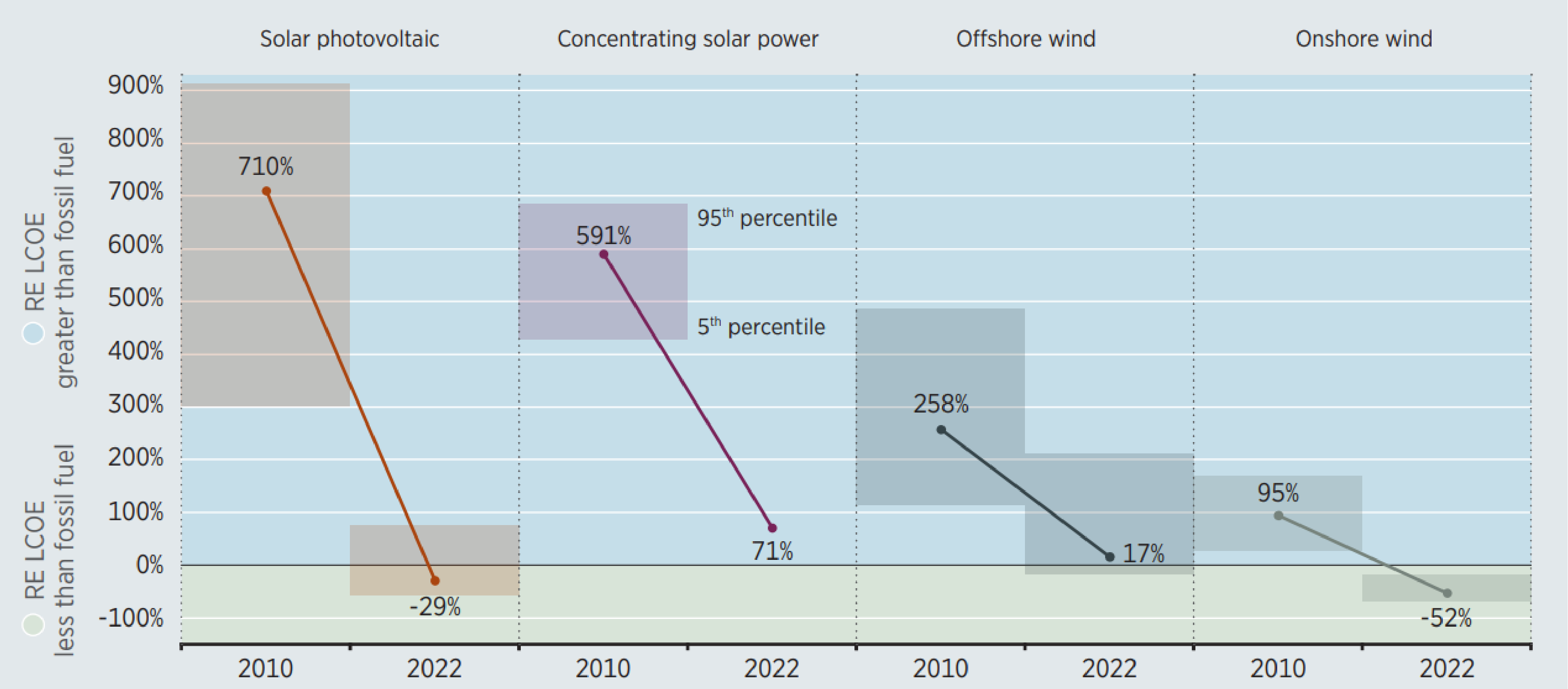
**Change in competitiveness of solar and wind by country based on global weighted average LCOE, 2010-2022:**




**Note:** The global weighted average LCOE data by technology and the fossil fuel LCOE data used to derive this chart is presented in detail in Chapter 1; RE = renewable energy.

Source: IRENA, (2023): Renewable Power Generation Costs in 2022.

# 3 Future hydrogen trade

# Renewables change how we trade energy

New trade flows in electricity, hydrogen, materials and clean technologies will emerge, differing significantly from traditional fossil fuel dependencies:

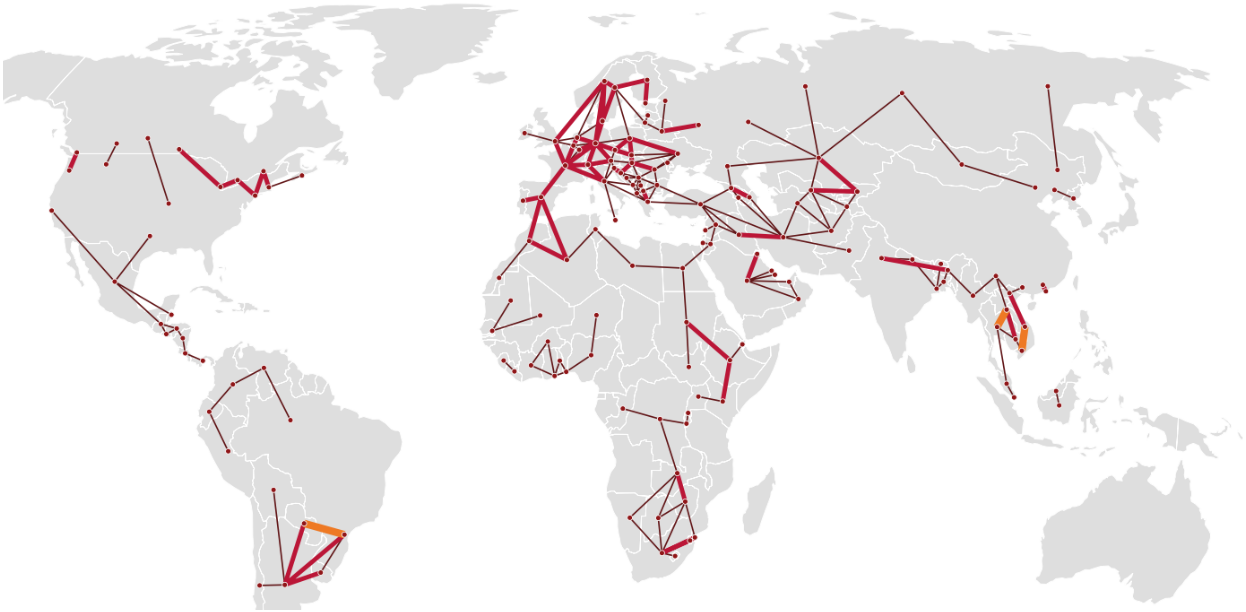
1. **Trade in renewable energy-related goods and technologies:** These include a wide range of goods and technologies, from solar PV panels and blades for wind turbines to smart meters, batteries and electrolysers.

2. **Electricity trade:** Will increase as additional interconnections make grids more stable and resilient. Electricity interconnections can be made between neighbouring countries, at a regional scale and possibly even inter-continentally.

3. **Trade in renewable energy fuels:** Such as green hydrogen, ammonia and methanol.

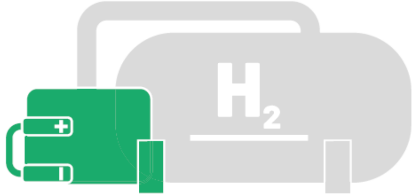
While renewable resources remain largely unaffected by geopolitical interruptions, harnessing them depends on availability of technologies and finance at scale.

**Existing electricity interconnectors (as of 1 February 2024)**



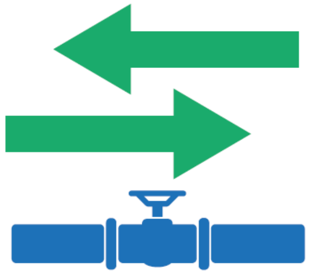
*This map is provided for illustration purposes only. Boundaries and names shown on this map do not imply any endorsement or acceptance by IRENA.*

Sources: IRENA (2024):Geopolitics of the energy transition: Energy security, IRENA (2019) A New World: The Geopolitics of the Energy Transformation

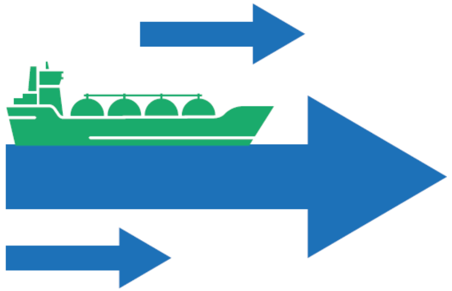


# GH2 trade projection by 2050 in a 1.5-degree aligned scenario

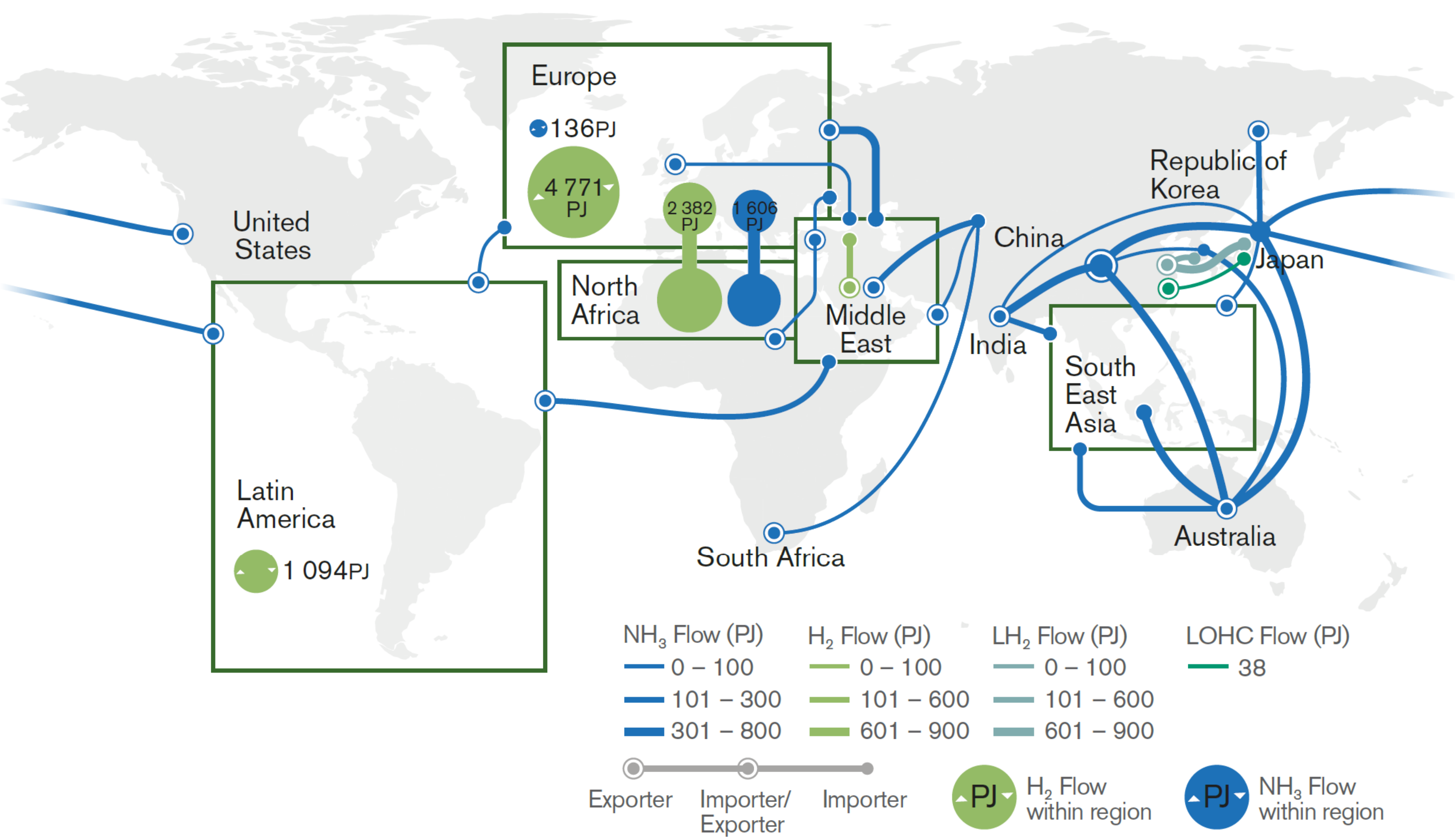
By 2050, international trade could satisfy about ¼ of the total global hydrogen demand in IRENA's 1.5°C scenario.



**55%** of this hydrogen would be traded via pipelines.



**45%** of this hydrogen would be shipped, predominantly as ammonia.




Source: WTO and IRENA (2023) International trade and green hydrogen: Supporting the global transition to a low-carbon

# Global trade needed across the whole green hydrogen value chain

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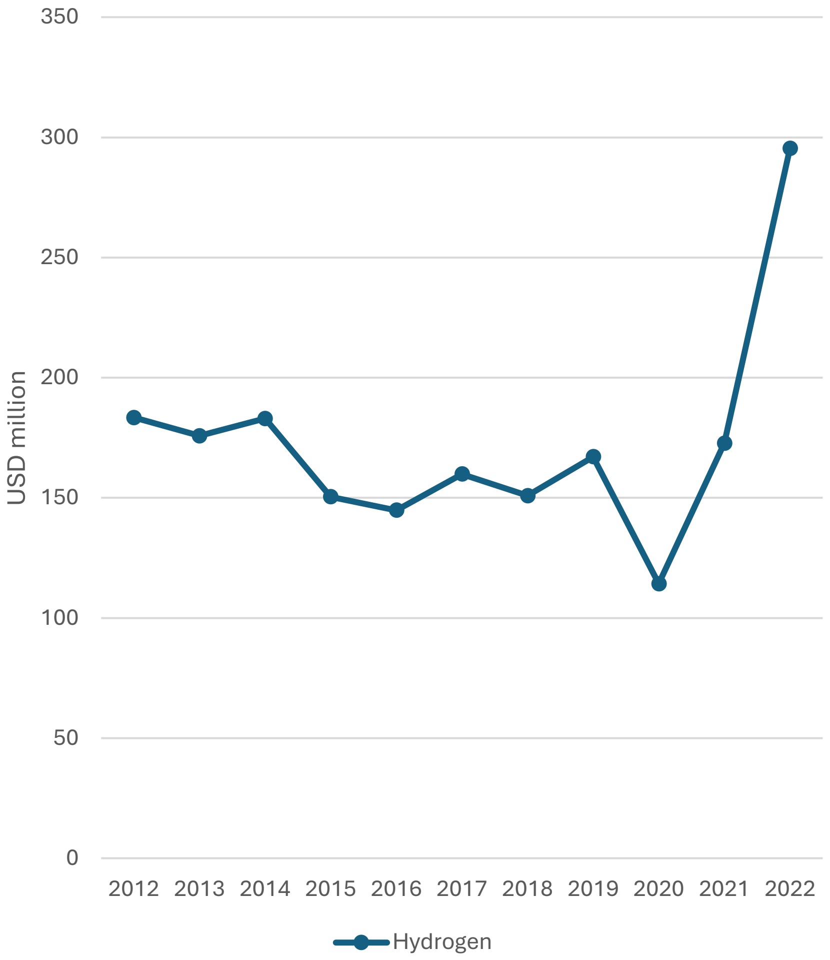
| | Renewable energy production | Hydrogen & hydrogen derivatives production | Transport, storage and reconversion | Use |
|---|---|---|---|---|
| Equipment | ▪ Renewable energy generation equipment, e.g., solar panels, wind turbines, etc.<br>▪ Electric equipment. | ▪ Electrolysers<br>▪ Compressors, valves, flow control, metering and related equipment.<br>▪ Ammonia, methanol, direct reduced iron production plants. | ▪ Piping and storage systems.<br>▪ Compressors, valves, flow control, metering and related equipment.<br>▪ Hydrogen, ammonia, methanol, hot briquetted iron transport vessels. | ▪ Ammonia, methanol, production plants.<br>▪ Direct reduction furnaces for iron production.<br>▪ Fuel cell systems.<br>▪ Hydrogen-ready (industrial) boilers<br>▪ Hydrogen-ready gas turbines for power generation.<br>▪ Ammonia, methanol and hydrogen storage equipment. |
| Services | ▪ Design<br>▪ Engineering<br>▪ Related construction<br>▪ Operation and management | | ▪ Transportation and storage services<br>▪ Related construction (e.g., port terminals) | ▪ Wholesale and retail (e.g., hydrogen stations)<br>▪ Marketing |
| | R&D, technical testing and analysis, consulting and training, various professional and business services | | | |

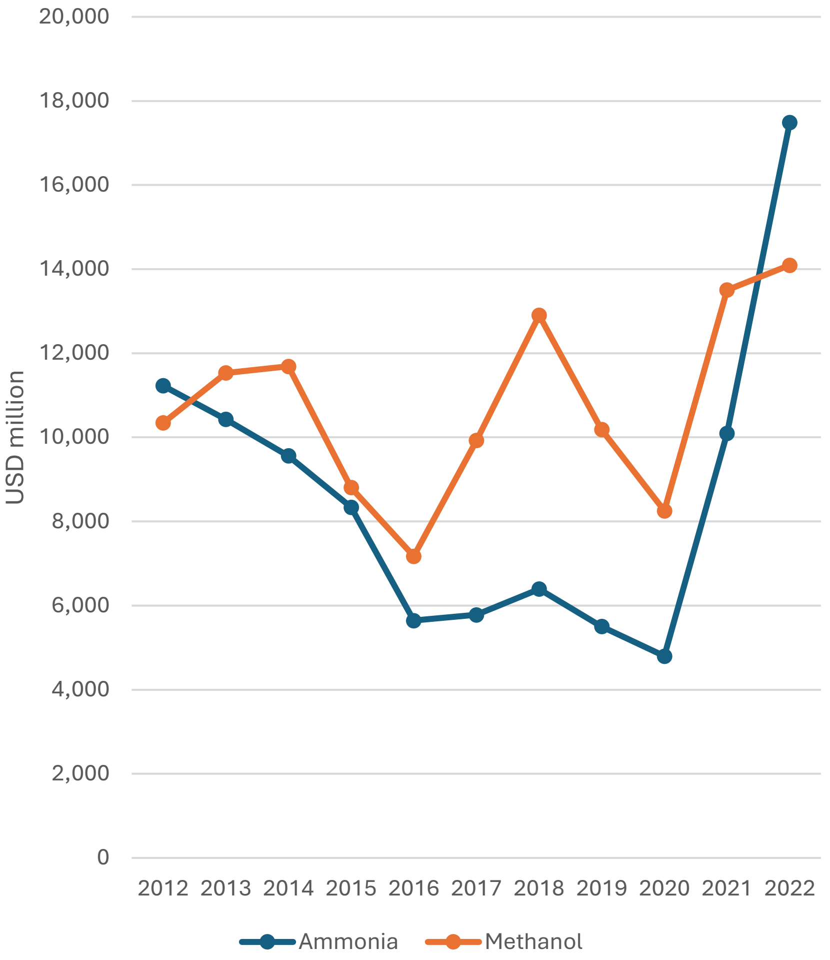
- While there is increasing attention on facilitating the trade of hydrogen and its derivatives a final products, a global GH2 economy requires **increased trade flows across the whole value chain**: *Renewable electricity supply, equipment (electrolysers, compressors, etc.), transport, storage and reconversion*


Source: WTO and IRENA (2023) International trade and green hydrogen: Supporting the global transition to a low-carbon economy

# Global imports in hydrogen and derivatives (ammonia and methanol)






- Trade of hydrogen and derivatives is **increasing since 2020**
- Current trade of **hydrogen is small compared to ammonia and methanol** – almost two orders of magnitude
- Hydrogen in the order of 300 USD millions, while **Ammonia and Methanol** in the order of **18 and 14 USD billions** respectively in 2022



Source: WTO and IRENA (2023) International trade and green hydrogen: Supporting the global transition to a low-carbon

# Geography of trade in hydrogen and derivatives: regional vs global

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### Top import markets for ammonia and top three suppliers, 2021

Source: WTO Secretariat Analytical Database based on data originally sourced from the WTO Integrated Database, UN Comtrade and the Trade Data Monitor.

| Importer | US$ million | Suppliers (percentage share in import market) |
|---|---|---|
| India | 1,577.5 | Saudi Arabia, Kingdom of (23), Qatar (22), Ukraine (13) |
| United States | 1,352.2 | Canada (48), Trinidad and Tobago (47), Algeria (1) |
| Morocco | 769.6 | Russian Federation (50), Trinidad and Tobago (36), Algeria (6) |
| Korea, Republic of | 746.7 | Indonesia (40), Saudi Arabia, Kingdom of (19), Trinidad and Tobago (12) |
| Belgium | 521.0 | Russian Federation (33), Trinidad and Tobago (24), Algeria (20) |

- **Trade in hydrogen** is currently concentrated in a few economies and largely **regional**.
- Current trade landscape for **ammonia** and **methanol** is **more global**.

### Top import markets for methanol and top three suppliers, 2021

Source: WTO Secretariat Analytical Database based on data originally sourced from the WTO Integrated Database, UN Comtrade and the Trade Data Monitor.

| Importer | US$ million | Suppliers (percentage share in import market) |
|---|---|---|
| China | 3,367.0 | United Arab Emirates (39), Oman (25), Saudi Arabia, Kingdom of (11) |
| India | 996.1 | Saudi Arabia, Kingdom of (31), Qatar (19), Oman (15) |
| Netherlands | 929.7 | Trinidad and Tobago (20), Equatorial Guinea (19), United States (13) |
| United States | 863.4 | Trinidad and Tobago (55), Canada (20), Equatorial Guinea (10) |
| Korea, Republic of | 791.7 | United States of America (38), Trinidad and Tobago (25), Oman (16) |

- Development of green hydrogen markets will lead to growth in trade in hydrogen and derivatives as well as affect the geography of trade.



Source: WTO and IRENA (2023) International trade and green hydrogen: Supporting the global transition to a low-carbon

# Summary - Five Key Actions to Foster Green Hydrogen Trade

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5. Increasing **international cooperation** through cross-borders dialogue and increased in joint capacity building programmes.

1. Addressing trade by **reducing tariffs and non-tariff barriers** on green hydrogen, electrolysers, derivatives and other products along the supply chain.


2. Developing **sound quality infrastructure** by adopting national measures based on international standards and engaging in international standardization.

4. Using **sustainable government procurement** by purchasing low-carbon goods and services and stimulating innovative solutions.

3. Implementing support policies via **targeted and non-discriminatory environmental subsidies** to help sustain growth in electrolyser capacity.

Source: WTO and IRENA (2023) International trade and green hydrogen: Supporting the global transition to a low-carbon economy

# 4 Key aspects of sustainable green hydrogen value chains from remote and developing regions

# Moving towards comprehensive sustainability

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## 01 ENVIRONMENT

- Emission intensity/ GHG footprint of hydrogen production
- Electricity supply
- Energy balance of hydrogen carriers for long-distance transportation
- Water demand and supply

## 02 ECONOMY

- Techno-economic potential
- Incentive schemes

## 03 GOVERNANCE

- Regulatory frameworks
- Hydrogen strategies and plans

## 04 BENEFITS FOR DEVELOPING COUNTRIES

- Energy access
- Jobs and skill development
- Industrial development

# Environmental aspects of hydrogen trade

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- The primary motivator behind the push for hydrogen - particularly renewable and clean hydrogen - is its potential to help achieve climate protection goals by replacing fossil fuels, especially in hard-to-decarbonize sectors.
- Countries and regions like the European Union have defined what they consider as renewable hydrogen or clean hydrogen, which is a significant step for both domestic producers and import products to the European Union.
- The EU has established the Carbon Border Adjustment Mechanism (CBAM) to prevent carbon leakage. It is further relevant for producers to qualify for and benefit from mechanisms like the European Hydrogen Bank auctions.
- However, it's not the whole story, as the environmental impact of large-scale infrastructure projects required to scale up hydrogen production will affect various aspects and must be taken into account also to assess the local impact of those projects.

# There will be a multi-carrier future

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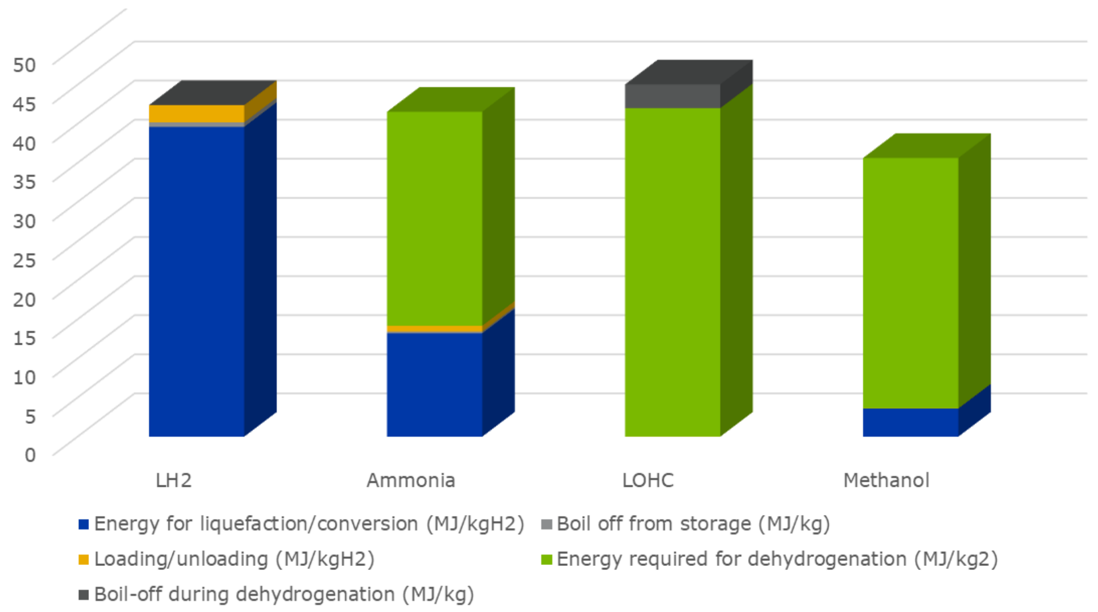
| | Ammonia | Liquid Hydrogen | LOHC | Methanol |
|---|---|---|---|---|
| Infrastructure for export | • Already produced at large-scale and traded globally. Liquefied, it can then be transported by a chemical tanker.<br>• Direct use as a feedstock (for chemical industry) possible without major infrastructure modification.<br>• Used as a hydrogen carrier, it needs to be reconverted to H2 via cracker.<br>• Large-scale cracking still to be proven. | • Can be transported by ship using specially modified isolation tanks.<br>• Distribution from the landing port may follow by trailer. This allows direct delivery to customers.<br>• Alternatively, the liquid hydrogen can be reconverted to gas and fed into grid infrastructure. | • Can be transported as oil is today using existing infrastructure, making it suitable for multi-modal transport.<br>• Can make use of existing fleet of<br>• An example of LOHC is toluene, which is converted to methylcyclohexane (MCH) when reacted with hydrogen.<br>• For transport, the toluene is “hydrogenated”, placed in chemical tanks, and transported to the destination. Once received, it can be “dehydrogenated” to release the hydrogen, while the toluene can be sent back for reuse. | • The liquid methanol is first stored in storage tanks at the port and then loaded onto chemical tankers.<br>• At the port of destination, the methanol can be transported via existing distribution routes for chemical raw materials (including trailer and rail transport).<br>• The infrastructure for importing chemicals and thus methanol is available and could be used straight away. |
| Technical considerations | • High energy density and hydrogen content<br>• Carbon-free carrier<br>• Can be used directly in some applications (e.g. fertilizers, power generation, maritime fuel).<br>• Ammonia combustion generates NOx emissions which may require scrubbers | • High energy losses for liquefaction (30-36% today), which calls for larger energy supply<br>• Boil-off (0.05-0.25% per day) during shipping and storage | • High (25-35%) energy consumption for dehydrogenation (importing region)<br>• May require further purification of the hydrogen produced depending on the use, i.e. for fuel cells<br>• Hydrogen is produced at 1 bar, requiring compression<br>• Only 4-7% of the weight of the carrier is hydrogen<br>• No clear chemical compound that is the most attractive<br>• Carrier losses every cycle (0.1% per cycle) | • Methanol is a commonly used basic chemical raw material.<br>• It can potentially be used as an energy carrier to recover hydrogen at the destination. However, the dehydrogenation step is a complex, energy-intensive process.<br>• Methanol can be used directly as a fuel, avoiding the previous disadvantages.<br>• The carbon dioxide source (for example, from an industrial point source or capture from ambient air) is a critical factor in energy and cost efficiency. |

# There will be a multi-carrier future

**Energy consumption along the supply chain for selected carrier pathways.**

| | $H_2$ production | Conversion to liquid | Handling and Storage | International Shipping | Handling and storage | $H_2$ recovery | |
|---|---|---|---|---|---|---|---|
| **Liquid Hydrogen** | | 30-36% **36-43.2 $MJ/kgH_2$** | Energy + boil-off 2.21 $MJ/kgH_2$ | boil-off < 0.1% per day during 3.8 days +1 day 0.58 $MJ/kgH_2$ | Energy + boil-off 2.21 $MJ/kgH_2$ | Gasification 0 $MJ/kgH_2$ | Total **41-48.2 $MJ/kgH_2$** |
| **Ammonia** | | Haber-Bosch **11.3 - 15.1 $MJ/kgH_2$** | Energy + boil-off 0.74 $MJ/kgH_2$ | boil-off 0.04% per day during 3.8 days +1 day 0.23 $MJ/kgH_2$ | Energy + boil-off 0.74 $MJ/kgH_2$ | Cracking (4.2-11 kWh/kg) **15.1 - 39.6 $MJ/kgH_2$** | Total **28.1 – 56.4 $MJ/kgH_2$** |
| **LOHC** | | **0 $MJ/kgH_2$ 32 $MJ_{th}$ could be recovered** | Energy only 0.002 $MJ/kgH_2$ | No boil-off 0 $MJ/kgH_2$ | Energy only 0.002 $MJ/kgH_2$ | Dehydrogenation (30-40% of energy content) **36 - 48 $MJ/kgH_2$** | Total **39 - 51 $MJ/kgH_2$** |
| **Methanol** | | **3.6 $MJ/kgH_2$** | Energy + boil-off 0.02 $MJ/kgH_2$ | boil-off 0.00032-0.005% per day during 3.8 days +1 day < 0.003 $MJ/kgH_2$ | Energy + boil-off 0.02 $MJ/kgH_2$ | Cracking **32 $MJ/kgH_2$** | Total **35.6 $MJ/kgH_2$** |

**Energy cost of transporting hydrogen over different carriers (MJ/kgH2 delivered)**



# The green hydrogen sector offers job opportunities and requires a well-skilled workforce: Anticipated employment effects along the value chain in developing countries

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| | | |
|---|---|---|
| **Manufacturing of renewable energy equipment** | Strong employment effects | • High market concentration (especially of solar PV).<br>• Hydrogen technology patents (electrolysers and fuel cells).<br>• Some inputs are more accessible for local production (e.g. steel structures, wind towers, pumps, cables), while others such as PV cells, wind turbine components and blades are often technology-intensive and rely on imports |
| **Renewable generation and electrolysis** | Significant during construction but weak in plant operation (depending also on type of RE employed) | • Engaging in core activities requires substantial capital and scale. In most developing countries, FDI and imported technologies are expected to play a leading role. |
| **Conversion into derivates** | Significant during construction but weak in plant operation | • Capital- and scale-intensive, thus deterring new entrants. Core technologies are not mature. FDI and imported technologies are likely to play a leading role in most developing countries. |
| **Export (infrastructure)** | Substantial during the construction phase, but the potential for forward and backward linkages and technological learning is fairly limited | • High investments in ports, pipelines and storage capacities, as well as transport mode-specific investments (for ammonia synthesis, generation of LOHC and deepfreezing hydrogen).<br>• Most potential exporting countries will strongly depend on imports of industrial equipment, which may considerably reduce net export revenues.<br>• Tax exemptions are often granted to investors (which are typically permitted to operate in special economic zones), thereby reducing the host country's tax benefits. |
| **Decarbonization of domestic industries** | Strong employment effects | • High switching/start-up costs for clean technologies. Large subsidies for incumbent competitors.<br>• It may be difficult to attract domestic customers due to initial price differentials between conventionally produced and "green" products. |

# Key take-aways

- Renewable-based electrolytic hydrogen holds the lowest emission intensity and market uncertainty.
- Future major markets are anticipated to prefer renewable hydrogen and its derivatives. Producing renewable hydrogen increases access to import markets.
- Product value chains will vary by technology, efficiency, and consumption proximity, with all derivatives potentially being traded.
- Renewable hydrogen production can bring co-benefits like job creation, clean energy access, and green industry promotion.
- Strategic partnerships among suppliers, consumers, and tech providers are key to advancing technology and scaling production.
- Social acceptance and community involvement are crucial for the sustainable production of renewable hydrogen.

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# Thank you!