Prospects for Green and Blue Hydrogen in the Mediterranean

Issues in development and interaction of gas and hydrogen transport networks
HYDROGEN AS A ZERO-EMISSION ENERGY CARRIER CAN HELP ACCELERATE THE ENERGY TRANSITION AND ACHIEVE NET-ZERO EMISSIONS

Sources of energy → Backbone of energy system → End uses

1. Enable large-scale efficient renewable energy integration
2. Distribute energy across sectors and regions
3. Act as a buffer to increase system resilience
4. Decarbonise transport
5. Decarbonise industry energy use
6. Serve as feedstock using captured carbon
7. Help decarbonise building heating

Source: Hydrogen Council, 2020
HYDROGEN CAN PLAY A KEY ROLE IN DECARBONIZING HARD-TO-ABATE SECTORS

### MOBILITY
- Fuelling infrastructure
- Public transport
- (Heavy) transport and (long-haul) traffic
- Shipping
- Air traffic (synfuels and direct H₂ use)

**Electrification may be possible but not with current technology**

### INDUSTRY
- Chemicals (e.g., ammonia synthesis, methanol)
- Refining (e.g., de-sulphurisation of liquid fuels)
- Steel making (blast furnace optimisation, direct reduction)

**No alternatives for deep decarbonization of industry**

### ELECTRICITY
- Storage (P2X)
- Generation (substitution of fossil fuels in fuel cell applications and thermal power stations)
- Integration of intermittent renewable electricity

**No alternatives for seasonal storage of energy**

### HEATING
- Space heating (boilers, fuel cell systems, heat pump support)
- Process heat generation (as part of CHP / fuel cell setups or boilers / burners)

**Electrification possible with heat pumps but not 100%**

Source: AFRY, 2020
FUTURE GLOBAL HYDROGEN DEMAND IS EXPECTED TO BOOM

In IEA’s Sustainable Development Scenario, global hydrogen production grows by a factor of seven to **520 Mt in 2070**, 98% of which is **low-carbon hydrogen**. Hydrogen use expands to all sectors and reaches a **share of 13% in final energy demand in 2070** (currently it is around 2%).

Source: EIA, 2020
HYDROGEN CAN BE PRODUCED FROM VARIOUS FEEDSTOCKS WITH DIFFERENT CO₂ INTENSITIES

- **Brown**
  - Derived from coal feedstocks w/CO₂ release into the atmosphere, e.g., gasification and steam reformation.

- **Grey**
  - Derived from oil and gas feedstocks w/CO₂ release into the atmosphere, e.g., steam methane reformation.

- **White**
  - Derived as by-product from industrial processes, e.g., chlorine production.

- **Blue**
  - Derived from fossil feedstocks but CO₂ emissions are captured, e.g., steam methane reformation w/carbon capture technology

- **Yellow**
  - Derived from water electrolysis using nuclear power without the production of CO₂ emissions

- **Turquoise**
  - Derived from fossil feedstocks but without the production of CO₂, e.g., methane pyrolysis

- **Green**
  - Derived from renewable electricity without CO₂ emissions, e.g., water electrolysis coupled to solar and wind generation

**Low-Carbon hydrogen**
The cost of hydrogen varies significantly across regions/countries, as it depends heavily on the prices and availability of energy inputs.

- Produced in countries with low-cost natural gas and coal resources
- China is the world’s largest hydrogen producer (1/3 of the world’s total, primarily from coal)

- Optimally produced in countries with low-cost natural gas and large-scale CO₂ storage (e.g., depleted gas fields, suitable rock formations)
- With enough scale, costs could average around US$1.20 per kg in 2025* in regions such as North America, Middle East and Russia.

- Optimally produced in countries with access to low-cost renewables
- Countries such as Chile, Australia, Morocco and Saudi Arabia with access to renewables from wind and solar at low LCOE - enabling high load factors for hydrogen production through electrolysis - could produce hydrogen at around US$1.90 per kg in 2025*

*Estimates by the Hydrogen Council, 2020
To develop an at-scale low-carbon hydrogen market quickly while lowering costs, a practical, agnostic position on blue and green hydrogen is required. Blue hydrogen offers the lowest-cost production pathway in the short term.
DISTINCT REGIONAL PRODUCTION POTENTIAL/COSTS CREATE THE OPPORTUNITY FOR INTERNATIONAL TRADE IN HYDROGEN

**EXPORTERS***
- ARGENTINA
- AUSTRALIA
- CANADA
- CHILE
- GCC
- MOROCCO

Countries with **abundant renewable and/or fossil and carbon capture and sequestration (CCS) resources** that are able to produce low-carbon hydrogen at competitive prices and in excess of domestic demand.

**IMPORTERS***
- FRANCE
- GERMANY
- INDIA
- JAPAN
- SINGAPORE
- SOUTH KOREA

Countries with **insufficient resources to meet own low-carbon hydrogen demand and/or production costs that are not competitive.**

**SELF-SUFFICIENT***
- CHINA
- NORWAY
- USA

Countries with **abundant renewable and/or fossil + CCS resources that meet own low-carbon hydrogen demand.**

*Not exhaustive list of countries.*
MEDITERRANEAN: STRONG LOW-CARBON HYDROGEN POTENTIAL, NEXT TO A DEMAND CENTER

EUROPE
Likely to be a high demand center

MEDITERRANEAN
Green and blue hydrogen potential varies within the region

### Overview of H2 distribution options

#### Costs

<table>
<thead>
<tr>
<th>Distribution</th>
<th>Transmission</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–50 km</td>
<td>51–100 km</td>
</tr>
<tr>
<td>Pipelines¹</td>
<td>Retrofitted</td>
</tr>
<tr>
<td></td>
<td>New</td>
</tr>
<tr>
<td>Shipping</td>
<td>LH₂</td>
</tr>
<tr>
<td></td>
<td>NH₃²</td>
</tr>
<tr>
<td>Trucking</td>
<td>LOHC²</td>
</tr>
<tr>
<td></td>
<td>LH₂ trucking</td>
</tr>
<tr>
<td></td>
<td>Gaseous trucking</td>
</tr>
</tbody>
</table>

1. Assuming high utilization
2. Including reconversion to H₂, LOHC cost dependent on benefits for last mile distribution and storage
3. Compressed gaseous hydrogen

THE OPTIMAL H2 TRANSPORT MODE VARIES BY DISTANCE, TERRAIN AND END USE

The cheapest hydrogen transport option depends on the distance to the market, the volumes to be transported and the products the consumer needs.

At shorter distances the cost of transportation makes up approximately 10% of the total delivery cost of hydrogen. At larger distances this increases to 30% of the total delivery cost of hydrogen.

For low/fluctuating demand or to bridge the development to a full pipeline network roll-out, trucking hydrogen – in gaseous or liquid form – is the most attractive option, costs of around USD 1.2/kg per 300km*.

Retrofitted pipelines can achieve very low H2 transportation costs (<USD 0.1/kg for up to 500km*), if existing pipeline networks are suitable for retrofitting, and H2 utilization rates are high. New pipelines are 60-90% more costly than retrofitting existing pipelines.

For longer distances (up to 5,000km), both new and retrofitted subsea transmission pipelines provide cheaper at scale transportation than shipping*; but are not relevant for all regions.

Mediterranean gas infrastructure brings gas from Azerbaijan, Egypt, Libya and Algeria to Europe, mostly though pipelines and some LNG. Infrastructure in the Eastern Med is used for regional consumption and re-export via LNG. Eastern Med gas can be competitive in Europe.
H2 BLENDING AS A FIRST STEP

Existing gas pipeline infrastructure around the Mediterranean can enable low-cost transportation, first by blending hydrogen in gas, and subsequently by repurposing the pipeline and finally new dedicated hydrogen pipelines.

Blending hydrogen into the existing natural gas pipeline networks has been proposed as a means of enabling low-cost H2 transport and assist market development. Blending 5%-15% hydrogen by volume in pipelines, pipeline compressors and gas storage is viable without significantly increasing risks to end-users. However, hydrogen blending does increase the risks of embrittlement and may result in lower operating pressure and lower capacity.

Blending to deliver pure hydrogen to markets is possible, using separation and purification technologies downstream to extract hydrogen from the natural gas blend close to the point of end use. Estimated extraction cost are in the range of $0.3–$1.3/kg.

Blending requires new pipeline certification and coordinated rules between upstream/downstream countries.

Source: CEPA, 2020
Gas pipelines retrofitted for hydrogen

- Existing natural gas pipelines need little modification to be fit for 100% hydrogen transport. Pipeline materials are generally fit for hydrogen transport. Repurposing includes purging to remove undesirable parts, monitoring for cracks, and potential replacements. Natural gas pipelines converted to hydrogen have to be operated at a lower pressure, unless internal coated.
- Capital cost of repurposing existing pipelines represents 10-40% of building new hydrogen pipelines. The cost difference depends on various factors, including diameter and pressure, quality of materials used, presence of connected equipment such as compressor stations, the pipeline’s overall condition, the existence of cracks, and the social costs of construction. Many of these factors are location-specific.
- Ease of retrofitting is higher for onshore than subsea transmission pipelines.

New hydrogen pipelines

- The energy density (calorific value) of hydrogen is a factor of three times lower than that of natural gas. To provide the same energetic content, the volume of hydrogen transported must be three times greater than in the case of natural gas.
- Moreover, due to its physical and chemical properties – low molar mass, large volume flow – greater efforts for compression are to be expected with hydrogen.

<table>
<thead>
<tr>
<th>Estimated levelized cost</th>
<th>€/kg/1000km</th>
</tr>
</thead>
<tbody>
<tr>
<td>New hydrogen infrastructure</td>
<td>0.20</td>
</tr>
<tr>
<td>Retrofitted gas infrastructure</td>
<td>0.11</td>
</tr>
</tbody>
</table>

Source: European Hydrogen Backbone, Lighthouse, 2021
H2 PIPELINE CHALLENGES: ENGINEERING AND SAFETY

Hydrogen has unique physical and chemical properties, which present benefits and engineering and safety challenges:

• Hydrogen is **14 times lighter than air** and **rises at a speed 6 times faster** than natural gas, which means that when released it rises and disperses quickly. It also means that **small leaks are hard to detect**;

• Hydrogen is also odorless, colorless, and tasteless making it undetectable by human senses. There is no known odorant light enough to “travel with” hydrogen. So, odorants are not used, and **hydrogen systems are designed with ventilation and leak detection**;

• Hydrogen **burns very differently than methane**. Combustion cannot occur in a hydrogen vessel or any contained location that contains only hydrogen – an oxidizer is required. **H2 pipeline ruptures always catch fire.** Although a hydrogen flame is just as hot as a hydrocarbon flame, the levels of heat emitted from the flame are lower. **This decreases the risk of secondary fires.**

• **Common specifications** for hydrogen purity must be defined for transport, otherwise pipelines will not be interoperable. The purity of hydrogen used in the network will be determined by **factors on the supply side, the demand side, as well as the suitability of retrofitted and new pipelines.**
Beyond pipelines, for longer distances, H2 suppliers can liquefy hydrogen (LH2), convert it to ammonia (NH3), or bind it to a liquid organic hydrogen carrier (LOHC). This process is costlier since it requires reconversion. LH2 is most efficient if the destination requires liquid or high-purity hydrogen, and has benefits if hydrogen needs to be distributed with trucks after landing at port. In contrast to NH3 and LOHC, LH2 does not require dehydrogenation or cracking to convert into gaseous hydrogen, which not only saves costs but also avoids purity concerns.

**Volumetric energy density of different fuels (MWh/m3)**

- Methanol
- Ammonia
- Liquid Hydrogen
- LOHC
- Hydrogen (70 bar)
- Hydrogen (1 bar)

**Levelized cost of hydrogen conversion in 2030 (euro/MWh H2 eq)**

- Compressed
- Liquid
- LOHC
- Ammonia
- Methanol

Source: Aurora Energy Research, 2021
The development of coastal hydrogen hubs with both hydrogen production and use, would promote economies of scale and reduce hydrogen transport and storage costs.

Conditions are favorable in the North Sea, Mediterranean south-eastern China, north-western India, the Gulf of Mexico or the Persian Gulf, etc.
A POSSIBLE PATHWAY...

If

Policies are introduced placing a cost on carbon emissions, making investment in decarbonization using hydrogen commercially attractive.

Market governance rules and institutions are introduced enabling hydrogen supply demand and price discovery and providing oversight over the monopolistic part of the value chain, thus giving confidence to investors.

Countries in the South and East of the Mediterranean accelerate investments in renewables/CCUS + natural gas capacity, enabling trade of surplus low-carbon hydrogen in the longer term.

Then

Low carbon hydrogen produced from natural gas can be developed at-scale in the short-term, helping create hydrogen markets in the region or in Europe and a transition towards renewables-based hydrogen.

Existing gas pipeline infrastructure around the Mediterranean can enable low-cost transportation, first by blending hydrogen in gas and subsequently by repurposing the pipeline and finally new dedicated hydrogen pipelines.