Hydrogen pipeline from the Gulf to Europe: use case and feasibility considerations

AFRY AND RINA JOINT DISCUSSION PAPER
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Proposition for Gulf-to-Europe hydrogen pipeline

A hydrogen pipeline from the Gulf to Europe appears feasible and could unlock the Gulf’s full potential as a low-cost Green H₂ source for Europe

- With its extraordinary potential of Renewable Energy Sources (RES) and Natural Gas, the Gulf region is set to become a global key producer of Green and Blue H₂ and derivatives
- It appears challenging but feasible to link the Gulf and Europe by a hydrogen pipeline from Qatar to Europe via Saudi Arabia, Egypt and the Mediterranean Sea
- A realistic pipeline setup could transport 100 TWh or 2.5 mn tonnes of hydrogen per year
- Transport capacity could be multiplied by building further pipelines of the same type
- H₂ transport cost could amount to around 1.2 EUR/kg H₂
- Gulf countries could deliver Green and Blue H₂ to the economic center of Europe at Levelized Costs of Delivered Hydrogen (LCODH) of around 2.7 EUR/kg from the 2030s and 2.3 EUR/kg in the longer term

H₂ pipeline can enable joint shaper role for Gulf and Europe in global H₂ market
Powerful hydrogen link between Gulf and Europe could provide bulk volumes of clean molecules for Europe and strengthen Gulf’s role in future energy and industry system

**LIKELY FUNDAMENTAL CHANGE OF THE ROLE OF GAS IN EUROPE’S ENERGY & INDUSTRY SYSTEM**

— Net Zero requires move from Natural Gas (NG) to low-carbon alternatives for energy and industry
— For Net Zero around mid-century, low-carbon H₂ supply volume needs to ramp up twice as fast as historical NG expansion over five decades – European RES will not be able to do this alone

**WAR AGAINST UKRAINE PRECLUDES RUSSIAN NATURAL GAS SUPPLIES TO EUROPE, LEAVING GAP OF APPROX. 100 BCM**

— Cut-off of is politically driven, not healable through reduction of Russian gas’ CO₂ load (e.g., by Russia Offering Blue H₂)
— Delivery gap is very difficult to cover with LNG. 150 bcm Russian deliveries to North-Western Europe 2021 vs. around 100 bcm free re-gasification capacity across EU, much of it clustered in South-Western Europe, limited pipeline capacity to North-East

**GULF COULD BENEFIT STRONGLY FROM LOW-COST HIGH-VOLUME GAS TRANSPORT OPTION TO EUROPE TO AVOID SALES AND INCOME DEPENDENCY ON APAC**

— Net Zero requirements require Europe to significantly reduce oil and natural gas imports from Gulf towards 2035 (EU target window for full de-carbonisation of energy sector, prohibition of combustion-engine vehicles)
— Japan may likely follow comparable path, for different reasons but with reduced Gulf imports as well
— China and India are among few countries with likely sizeable fossil fuel demand after 2035, lowering GCC countries’ sales potentials, bargaining power, income
— Europe pushes ship-borne H₂ imports – less efficient for bulk transport but may absorb heavyweight of subsidies and gas/H₂ company activity if Gulf does not present competitive and actionable pipeline project in very near future

Source: AFRY analysis
Routing (1/2): route from Gulf to EU border could run 3,400 km from Qatar to Greece via Yanbu, Neom, Gulf of Aqaba, Port Said area

INDICATIVE ROUTE TO EUROPE

**Pipeline**

**Compressor station**

**Gas field**

(Blue H₂ production)

Routing (2/2): from landfall in Greece, several routes of around 2,500 km can connect to different prospective H₂ usage clusters in Europe

POTENTIAL ONWARD ROUTES AND CONNECTIONS

**Framework conditions:**
- Unlocking of pipeline's value potential suggests end point at German border, can be boosted by connection to further H₂ demand clusters across South-Eastern Europe
- Adriatic Sea offers favourable seabed conditions for sub-sea continuation and landfall in Venice-Triest region
- Alps' south-north pipeline route via Gries Pass would be technically very difficult to expand for H₂
- Routing through Balkans and/or non-EU countries would increase complexity

Three main structural alternatives with comparable length but different complexity profiles
- Western route requires another 1,500km of sub-sea pipe-line, albeit in less depth, or joint use of projected SouthH₂ Corridor
- Eastern route would need more complex permitting and interest alignment due to more countries along the route

**WITHOUT PRECEDENT, COST ESTIMATES ASSUME WESTERN ROUTE**

Source: Entso-E, SouthH₂ Corridor, AFRY and Rina analysis

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Two 32” strands can transport roughly the same gas volume as one 48” strand; max compressor station spacing about 1,000 km – single strand on-shore lowers complexity and cost; double strand sub-sea is required to stay within pipe collapse limits at the expected laying depth; 200 barg entry pressure offers some degree of water entry protection in case of leaks

Source: AFRY and Rina analysis
To corroborate the potential of the presented approach, we recommend to conduct a Red Flag exercise followed by a pre-feasibility study.

**TOPIC SELECTION**
- Capacity matching with Green and Blue H₂ ramp-up in H₂ source countries
- Construction and permitting challenges in the countries along the route
- Political risks
- Pipeline connection potential to further H₂ source and offtake regions
- Technical integration concept for Green H₂ production zones that can feed into route
- Support and subsidy perspective
- Partnering
- Budget detailing
- Overall timelining/roadmapping
- Etc.

**RED FLAG CHECK AND INTEREST GATHERING**
- Physical limitations (e.g., topological obstacles, hazardous bathyspheric parameters)
- Limitations of asset availability or volume (especially tubes, compressors, laying vessels, and labour force)
- Strategic hazards (e.g., attack risks in route vicinity, adverse political opportunisms)
- Stress test of competitive advantage versus, e.g., NH₃ shipping
- Etc.

**PRE-FEASIBILITY STUDY**
- FEL Phase 1 along entire route

Since time is of essence for European Net Zero and successful Gulf role re-shaping, a timely Go-NoGo decision appears strategically important and a full pre-feasibility study should be conducted as early as possible.
Annex

Map view shows that Gulf-to-Europe pipeline connection hinges on technical feasibility of pipe link between Port Said area and Sicily (Italy) and/or Peloponnes (Greece)

CURRENT NATURAL GAS PIPELINE SYSTEM VIEW

GEOSTRATEGIC CONSIDERATIONS

— Two main entry areas into Europe from Gulf: Italy or Central Asian Pipeline Corridor / Austria
— Conceivable on-shore corridors run through conflict zones and/or countries that have political issues with their close neighbours over plausible corridor areas
— Eastern part of EastMed route would be complex due to conflicts of interest
— First and last legs of the pipeline route are pre-set
  — Doha perimeter to Port Said area via Red Sea coast
  — Peloponnes or Sicily to Northern Europe around Eastern Alps – large capacity Central Alps crossing unviable
— Link between Port Said area and Europe needs a route that is unsusceptible to conflicts of interest and adverse action

Source: Petroleum Journal, AFRY analysis
Two plausible route alternatives for H₂ pipeline from Egypt to Europe were chosen for red-flag checks and dimensioning considerations.

**KEY ROUTE ALTERNATIVES FROM GULF TO EUROPE**

- Port Said area as common jump-off area
- Orientation value for transport capacity: 2.5mn tonnes / 100 TWh H₂ p.a.²
- Novel parameter bundle for feasibility appraisal³
  - Materials' H₂ embrittlement immunity
  - H₂ tightness of materials, joints, fittings
  - Large water depths beyond 3,000m
  - Complex morphology with chasms and high gradients (up to 35° slope) – need to optimise route for minimisation of free-span correction works
  - Inside and outside pressures³
  - Long uninterrupted deep-sea distance³
  - Maintenance and average management / recovery at depth

**FRAMEWORK PARAMETERS**

- Appraisal of bathymorphology and seismic hazards shows relevant exposure of Northern part of Eastern route – preliminary view: challenging but feasible

**TECTONIC SITUATION VIEW**

- Active faults and subduction along Hellenic and Cyprus Arcs
- Variable soil conditions
- Salt tectonic under Egyptian waters

**SEISMIC ACTIVITY VIEW**

- Volcanic area across Aegean Sea, Sicily/Etna
- Relevant level of seismicity along the Northern part of the Eastern route alternative

1 Projects in italics; 2 TWh/a HHV, figure chosen for relevance in European context e.g. roughly equals Germany’s 2030 H₂ production target – can be multiplied by adding further strands if concept is considered attractive; 3 Many parameters were already achieved individually (e.g., NorthStream 1 1,224 km @ 220 bar entry pressure without interim compression, Turkstream 2,200m depth, Galini project 2,800m depth) but not yet all combined

Source: National Geographic, AFRY and Rina analysis
Proposed setup: single 48” strand onshore, twin 32” strands offshore, min. four compressor stations, max. distance between compressors approx. 1,000 km, 130-200 barg inlet pressure

### Dimensioning Considerations
- Recommendation: one onshore strand with 48 inch / 1,200 mm pipe, two offshore strands with 32 inch/800 mm nominal diameter
- H₂ pipelines should be large-diameter to allow high mass flows of very small/light molecule with minimal compressor power and associated minimised compression energy – typical large production pipes are 48 inch (approx. 1,200 mm)
- Uniform transport capacity along route requires offshore section capacity to match onshore section capacity
- Depth of more than 2,200 m in middle of offshore section limits maximum diameter to 32 inch, which has roughly half the cross-section of 48 inch
- All materials compliant with ASME B31.12 option B, X65 Steel grade recommended¹
- Minimised ovality & thickness imperfections and buckle arrestors to foster stability

### Pressure and Flow Rate Considerations
- Minimum H₂ flow for considered pipeline is 100 TWh HHV p.a. resp. 350 t per hour
- Input pressure assumed as 200 barg
- Maximum operating pressure 300 barg, set by pipeline material and maximum wall thickness
- Minimum practical compression pressure 200 barg, to achieve acceptable mass flow and avoid strand multiplication needs for target transport volume
- Maximum flow speed needs to be below erosional velocity for H₂ on steel, i.e. less than 49 m/s at 80 barg
- Pressure drop from initial 200 barg over 1,000 km is approx. 100 barg – Yanbu compressors are dimensioned for pressure lift of 100 barg, Port Said compressors for 170 barg

¹) Collapse wall thickness requirement as per API 5L Xseries PSL2; 2) X70 grade conceivable but needs to be carefully evaluated since it could impact on ductility issues and consequent H₂ embrittlement criticality; 3) Pressure containment verification according to DNV ST F101, upper limit as per ASME B31-12 Pl-1.3 – pipeline materials to be tested for pressures over 210 barg

Source: Rina analysis
Hydrogen transport to Europe would cost approx. 1.2 EUR/kg, resulting in LCODH\(^3\) of approx. 2.7 EUR/kg by 2030, with 2.3 EUR/kg perspective 2050.

**KEY BUSINESS CASE PARAMETERS**
- Pipeline system CAPEX: EUR 28 bn.
  - Gulf to Greece: EUR 18 bn.
  - Greece to Central Europe: EUR 10 bn.
- H\(_2\) mass flow: 2.55 mn tonnes p.a., corresponding to 100 TWh p.a. HHV
- Compressors: 44, thereof 6 reserve, 25 MW each
- Pipeline system run-time: 8,500 hours p.a.
- Green electricity price: 70 EUR/MWh
- Approximate H\(_2\) production costs in Gulf region:
  - Green H\(_2\): 2 EUR/kg today, 1.4 by 2030, 1.1 by 2050
  - Blue H\(_2\): 1.3 EUR/kg today, 1.1 from 2030
- Lifetime: pipes 40 years, compressors 20 years
- Cost of Capital\(^2\): 7%
- Construction time: 7 years
- Average capital binding during construction: 25%

**KEY BUSINESS CASE RESULTS**
- Annual pipeline system cost: EUR 30.5 bn p.a.
  - CAPEX annuity: 2.4
  - O&M and other fixed OPEX: 0.15
  - Electricity costs for compressors: 0.5
- H\(_2\) transport unit cost: 1.2 EUR/kg
- Levelised Cost Of Delivered Hydrogen (LCODH)\(^4\):
  - Green: 2.7 EUR/kg 2030, 2.3 EUR/kg 2050
  - Blue: 2.3 EUR/kg 2030 and beyond

H\(_2\) pipeline can make the Gulf a competitive source of bulk low-carbon H\(_2\) for Europe.

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1) Levelised Cost Of Delivered Hydrogen. 2) Assuming current KSA bond rates and typical return expectations of capital providers in the Gulf region. 3) Approximate value based on AFRY project results for shipping from Gulf to Italian ports – inland transport by rail not modelled, would come on top. 4) For HHV Source: IRENA, KAPSARC, AFRY and Rina analysis.
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