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

AFRY AND RINA JOINT DISCUSSION PAPER

Contents

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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 H_2 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 H_2** 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

— H_2 **transport cost** could amount to **around 1.2 EUR/kg H_2**

— Gulf countries could deliver Green and Blue H_2 to the economic center of Europe at **Levelised Costs of Delivered Hydrogen (LCODH) of around 2.7 EUR/kg from the 2030s and 2.3 EUR/kg in the longer term**

H_2 pipeline can enable joint shaper role for Gulf and Europe in global H_2 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 H_2 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' CO_2 load (e.g., by Russia Offering Blue H_2)
- 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

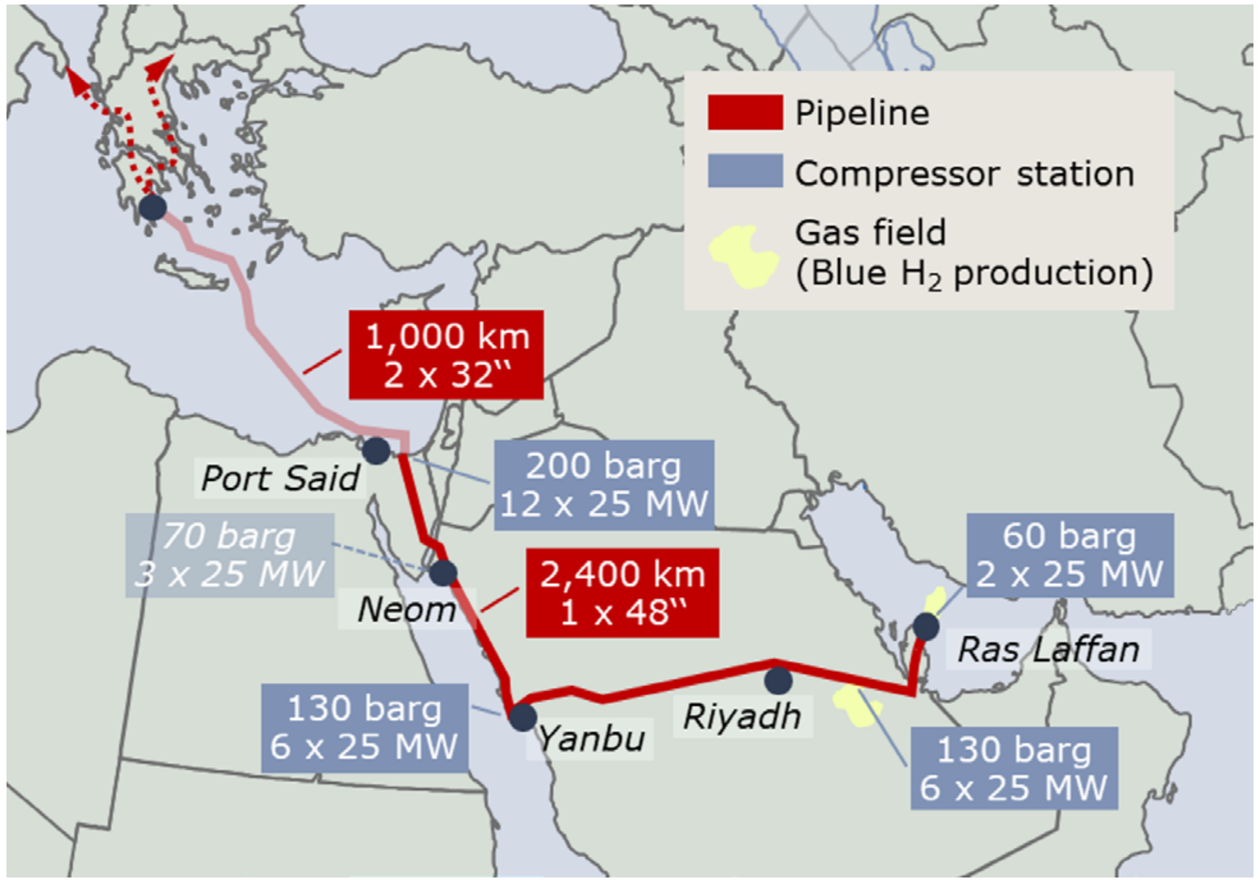
GULF COULD BENEFIT STRONGLY FROM LOW-COST HIGH-VOLUME GAS TRANSPORT OPTION TO EUROPE TO AVOID SALES AND INCOME DEPENDENCY ON APAC

- 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 H_2 imports – less efficient for bulk transport but may absorb heavyweight of subsidies and gas/H_2 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



ROUTING CONSIDERATIONS

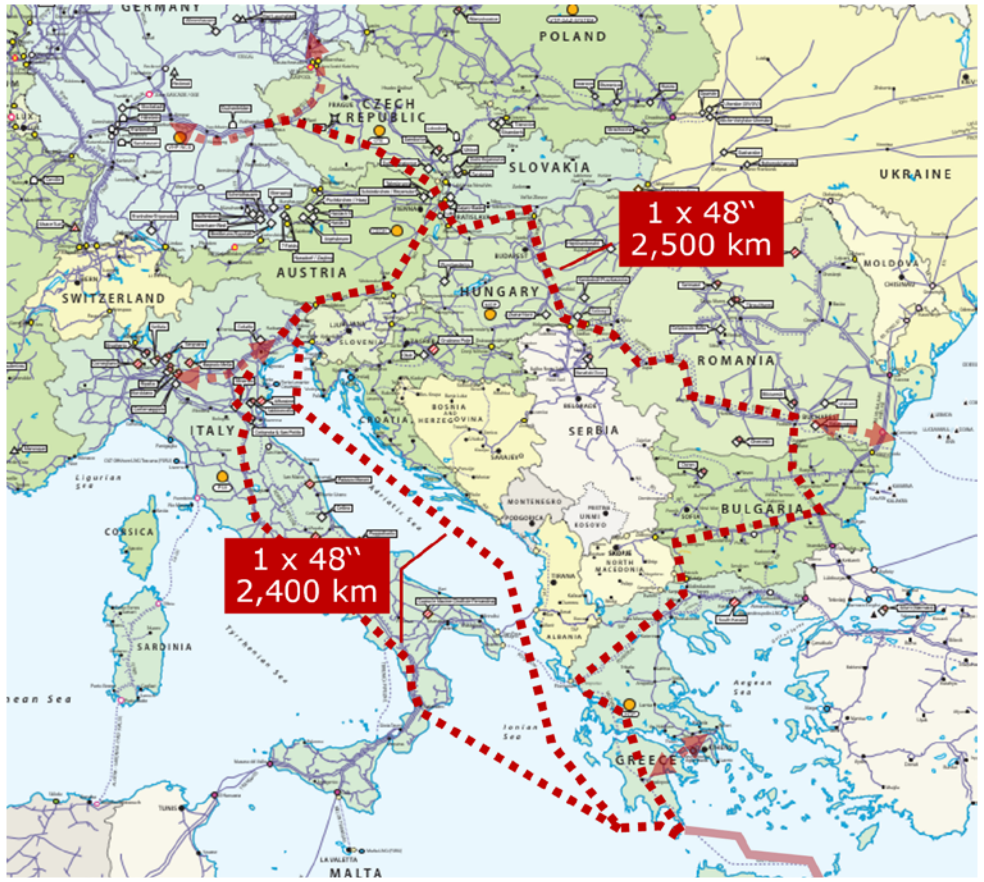
- Qatar as easternmost point: Blue H_2 from North Field as well as local Green H_2
- Onshore routing from Ras Laffan area to Riyadh
- Run by Haradh gas fields area as potential second source for Green as well as Blue H_2, subject to KSA policy choices regarding natural gas export
- Continuation to Red Sea along existing route via Medina and Jebel Jar
- Run north through Neom project region – potential for Green H_2 feed-in
- Red Sea sub-sea crossing in Gulf of Aqaba
- Potential for Green H_2 feed-in from Sinai peninsula
- Jump-off point into Mediterranean east of Port Said

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

HYDROGEN PIPELINE FROM THE GULF TO EUROPE: USE CASE AND FEASIBILITY CONSIDERATIONS

Routing (2/2): from landfall in Greece, several routes of around 2,500 km can connect to different prospective H_2 usage clusters in Europe

POTENTIAL ONWARD ROUTES AND CONNECTIONS



ROUTING CONSIDERATIONS

- Framework conditions:
  - Unlocking of pipeline's value potential suggests end point at German border, can be boosted by connection to further H_2 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 H_2
  - 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 SoutH2 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-G, SoutH2 Corridor, 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 H_2 ramp-up in H_2 source countries
- Construction and permitting challenges in the countries along the route
- Political risks
- Pipeline connection potential to further H_2 source and offtake regions[1]
- Technical integration concept for Green H_2 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., NH_3 shipping
- Etc.

PRE-FEASIBILITY STUDY

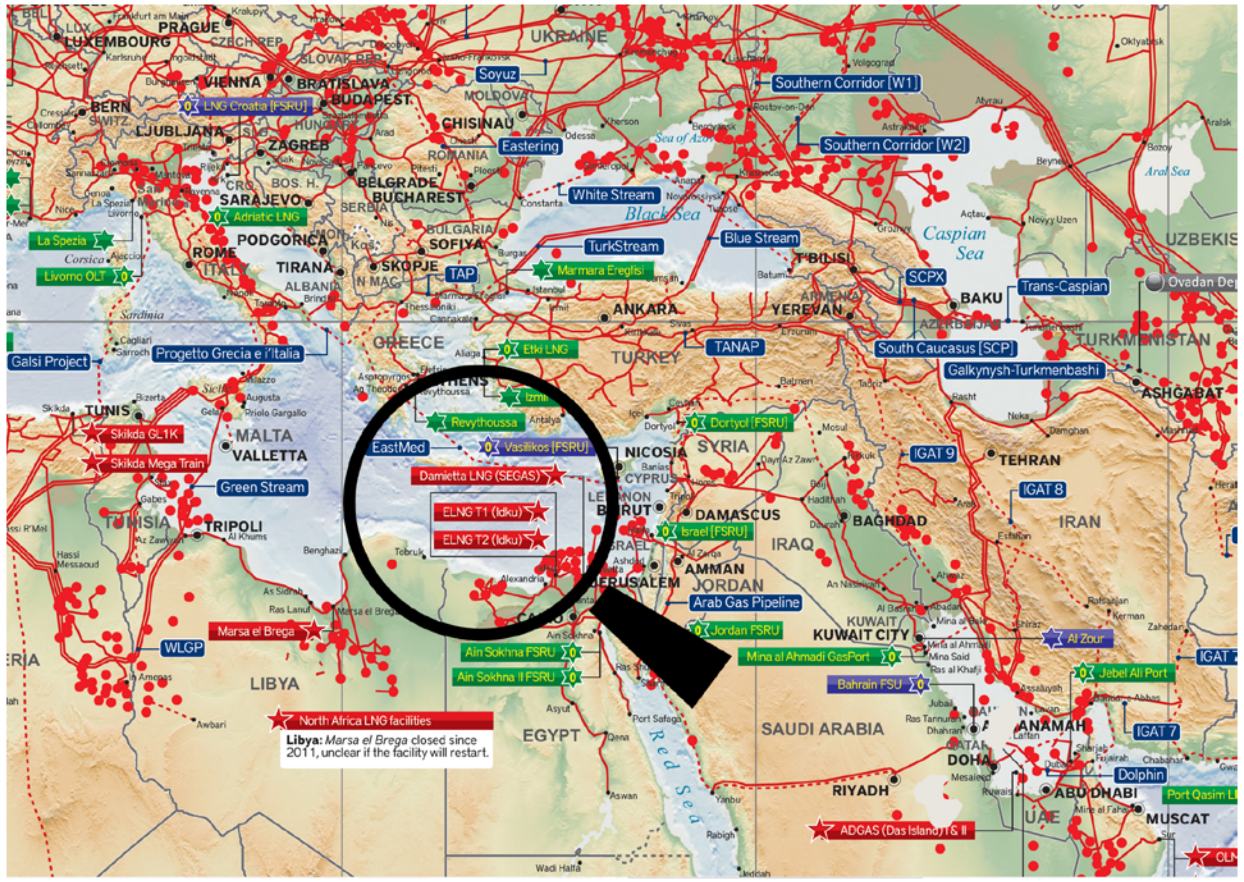
- FEL Phase 1 along entire route

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-feasibilty 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



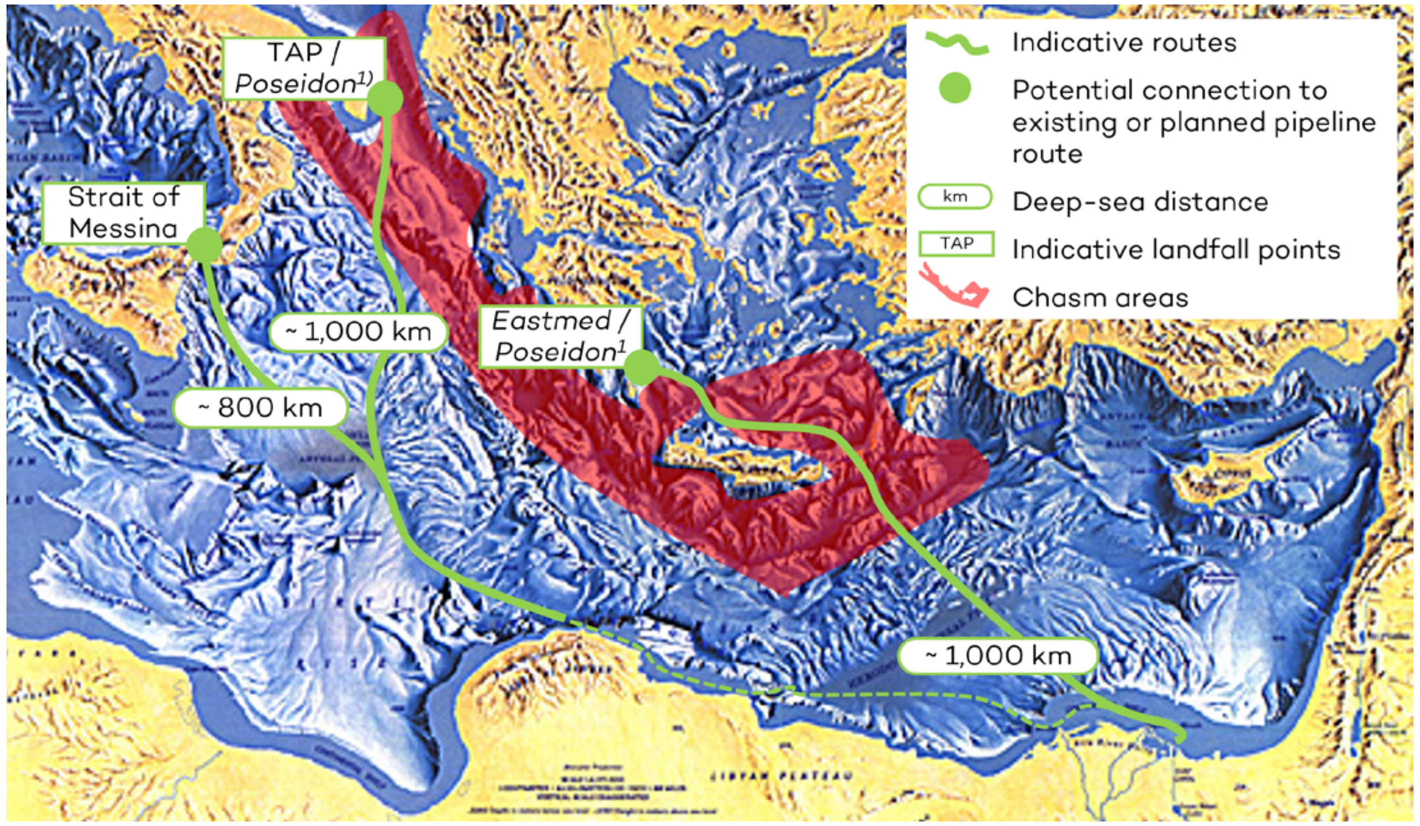
GEOSTRATEGIC CONSIDERATIONS

- 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 H_2 pipeline from Egypt to Europe were chosen for red-flag checks and dimensioning considerations

KEY ROUTE ALTERNATIVES FROM GULF TO EUROPE



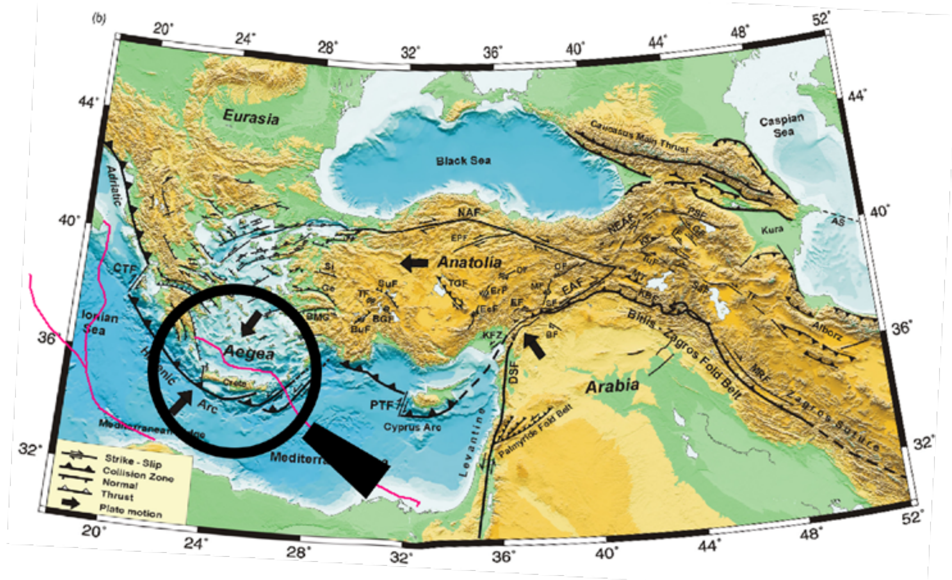
FRAMEWORK PARAMETERS

- Port Said area as common jump-off area
- Orientation value for transport capacity: 2.5mn tonnes / 100 TWh H_2 p.a.[2]
- Novel parameter bundle for feasibility appraisal[3]
  - Materials' H_2 embrittlement immunity
  - H_2 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 pressures[3]
  - Long uninterrupted deep-sea distance[3]
  - Maintenance and average management / recovery at depth

1) Projects in italics; 2) TWh/a HHV; figure chosen for relevance in European context: e.g., roughly equals Germany's 2030 H_2 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, Galsi project 2,800m depth) but not yet all combined
Source: National Geographic, AFRY and Rina analysis

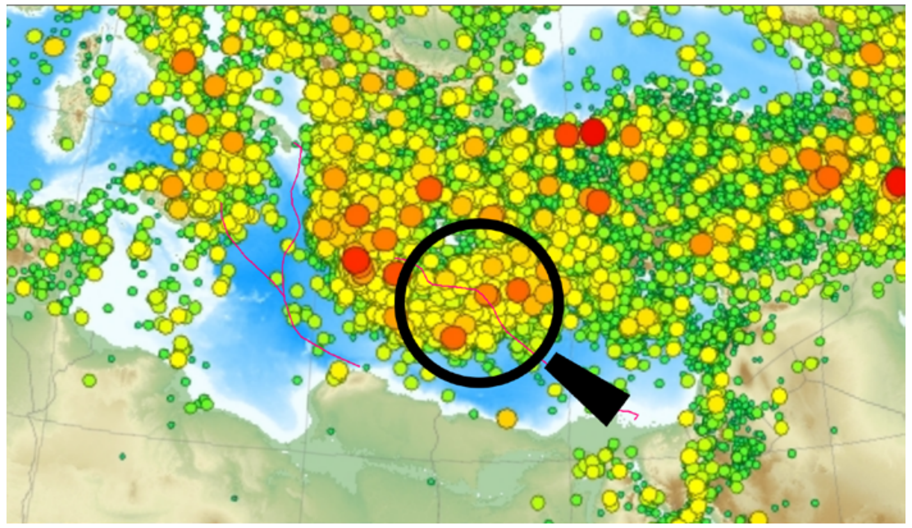
Appraisal of bathymorphology and seismic hazards shows relevant exposure of Northern part of Eastern route – preliminary view: challenging but feasible

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

Source: 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
  - H_2 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 recommended[2]
- Minimised ovality & thickness imperfections and buckle arrestors to foster stability

PRESSURE AND FLOW RATE CONSIDERATIONS

- Minimum H_2 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 thinkness
  - 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 H_2 on steel, i.e. less than 49m/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 H_2 embrittlement criticalities; 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

H_2 transport to Europe would cost approx. 1.2 EUR/kg, resulting in LCODH[1] 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 3.05 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

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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