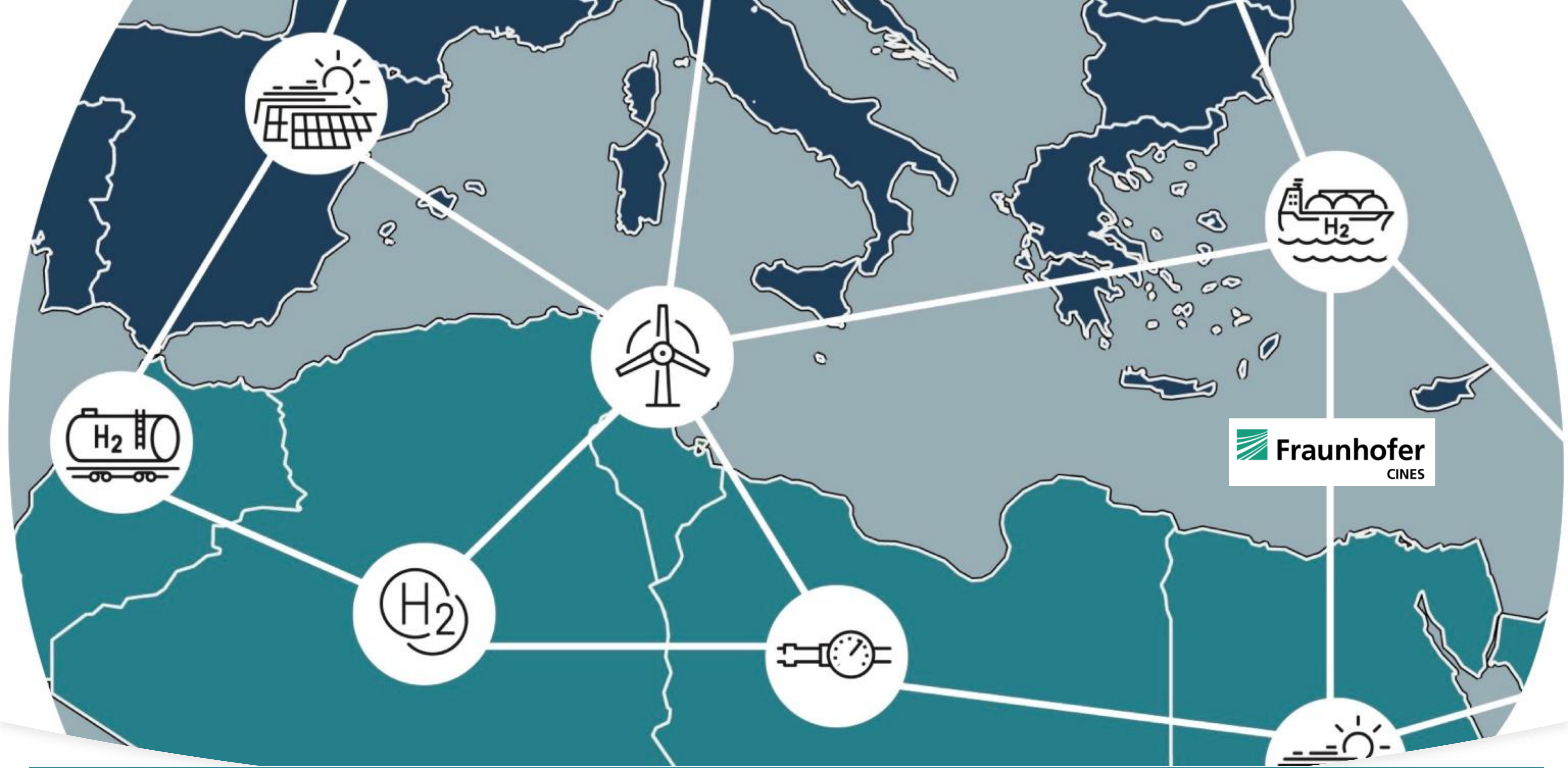

Potential and challenges of H_2 production and transport in the Europe-MENA region | BETD Partner Event, NUMOV (Berlin, March 22nd, 2024)

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About Fraunhofer CINES

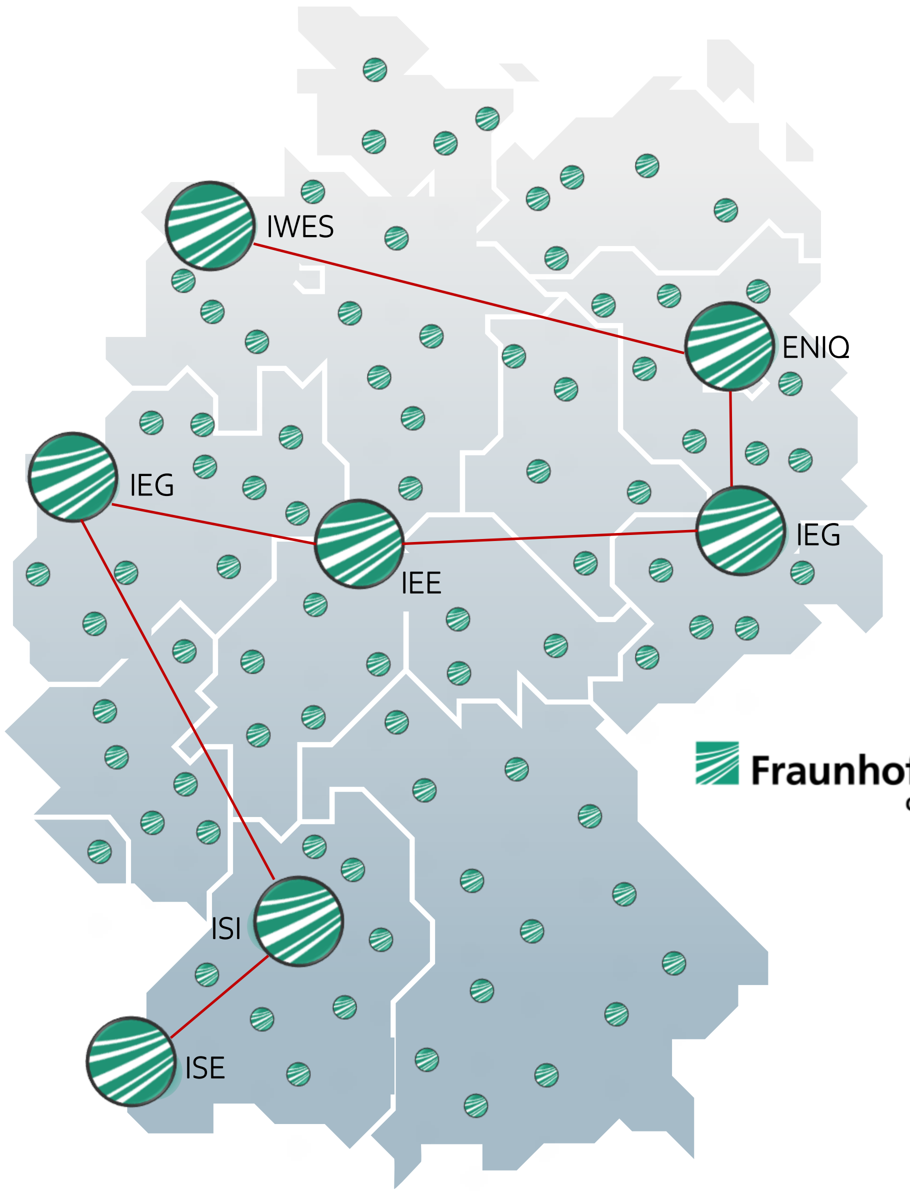
Cluster of Excellence Integrated Energy Systems - CINES

Core mission

System and market integration of high shares of variable renewable energy and low-carbon H_2 in the energy system.

Core institutes

- **Fraunhofer IWES** - Wind Energy Systems (Bremerhaven)
- **Fraunhofer ENIQ** – Representation Energy Research (Berlin)
- **Fraunhofer IEG** - Energy Infrastructures and Geothermal Systems (Cottbus, Bochum)
- **Fraunhofer IEE** - Energy Economics and Energy System Technology (Kassel)
- **Fraunhofer ISI** - Systems and Innovation Research (Karlsruhe)
- **Fraunhofer ISE** - Solar Energy Systems (Freiburg)



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Expertise along the H_2 value chain…..

- Materials
- Energy Sector & Power Economy
- Systems
- Technology Production
- Safety and Life Cycle

H_2 Production
- PEM
- AEL
- AEM
- SOEC
- Other modes

Storage

H_2 Conversion
- GH_2
- Ammonia
- DME*
- Methanol
- SAF
- LH_2

Transport / Infrastructure

H_2 End User
- Steel Industry
- Chemical Industry
- Mobility
- Heating
- Electricity

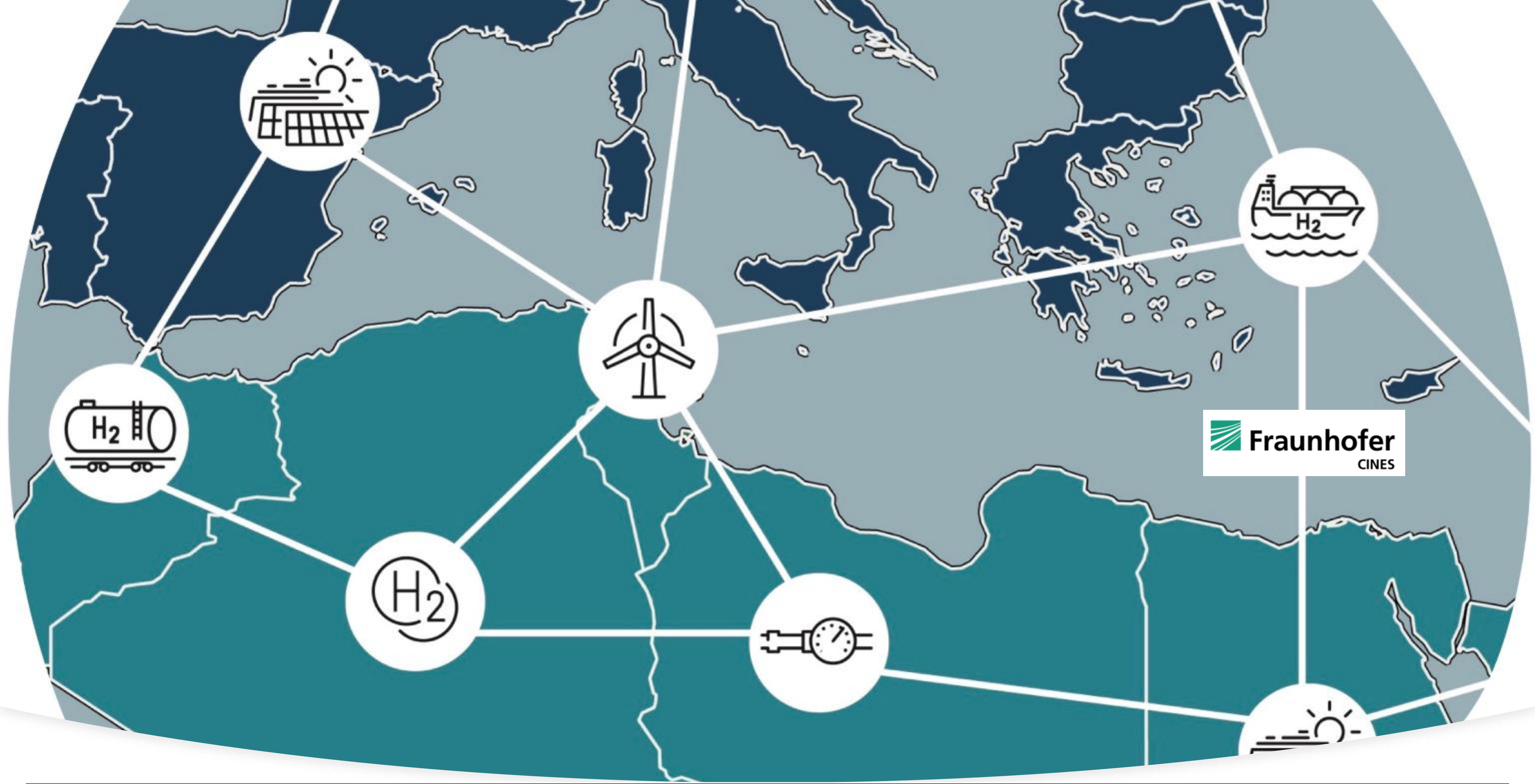
*) Dimethyl Ether; H_2 carrier with high tech. storage capacity (26.1 wt%) compared to ammonia (17.8 wt%); methanol (18.8 wt%)

ROUTLEDGE EXPLORATIONS IN
ENVIRONMENTAL ECONOMICS

ROUTLEDGE

The Hydrogen Economy and Saudi Arabia

Edited by Rami Shabaneh,
Jitendra Roychoudhury,
Jan Frederik Braun and
Saumitra Saxena



Methodology: Production, transport, and entire supply-chain

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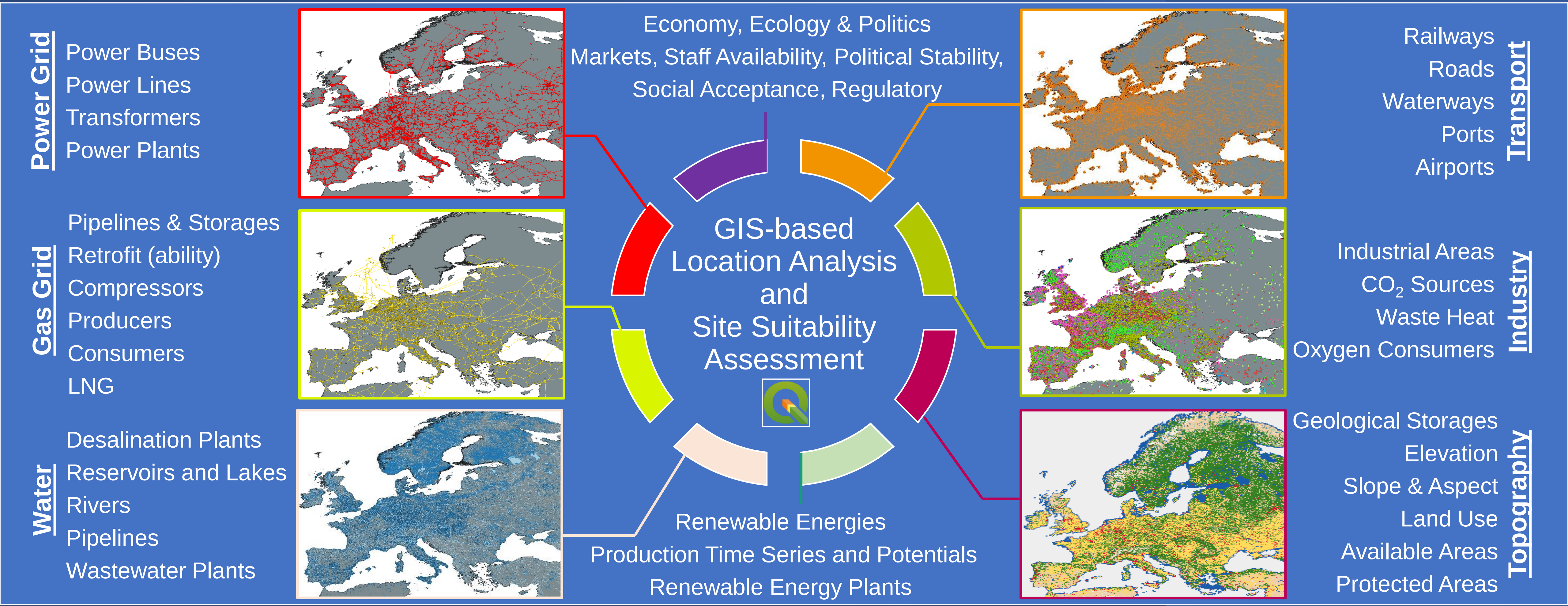
H_2 supply chain: System modelling



H_2 optimal production sites

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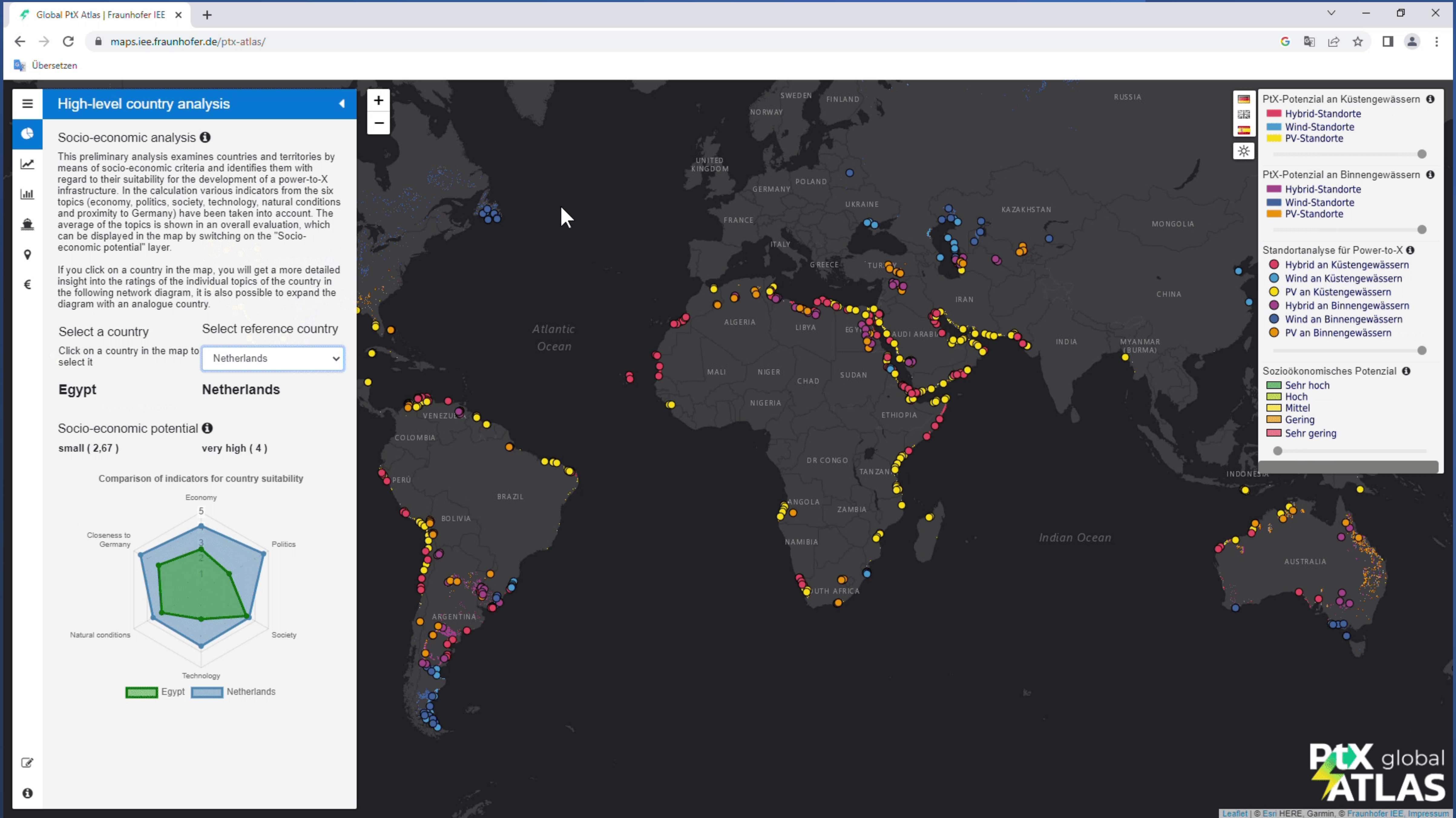

H_2 optimal production sites

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Nature conservation

Protected areas, critical habitats

Limited Water availability

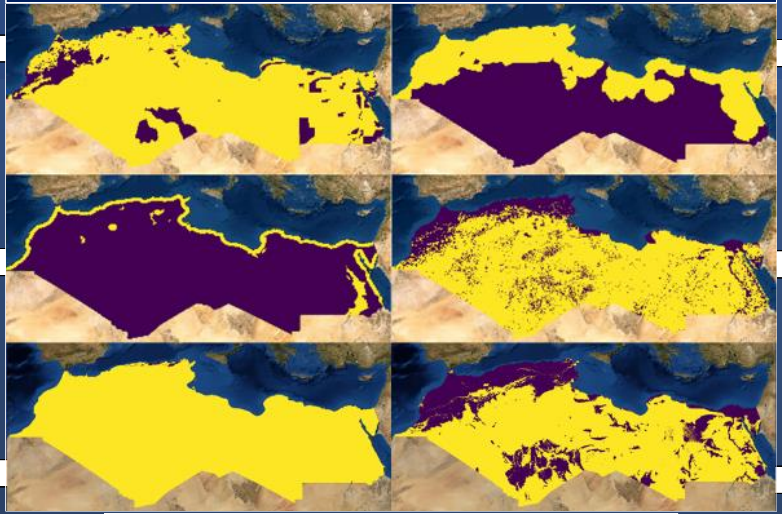
Distance to state-owned coasts or inland waters > 50 km

No use of surface waters with high water risk level, no ground water

RE sources (photovoltaic) using LCOE

PV > 30 €/MWh

Area assessment: Excluded areas*



Poor Infrastructure

Distance to ports > 500 km, pipelines > 50 km, Distance to cities > 200 km

Other unsuitable areas

Croplands, forests, residentials, water bodies, permanent ice…

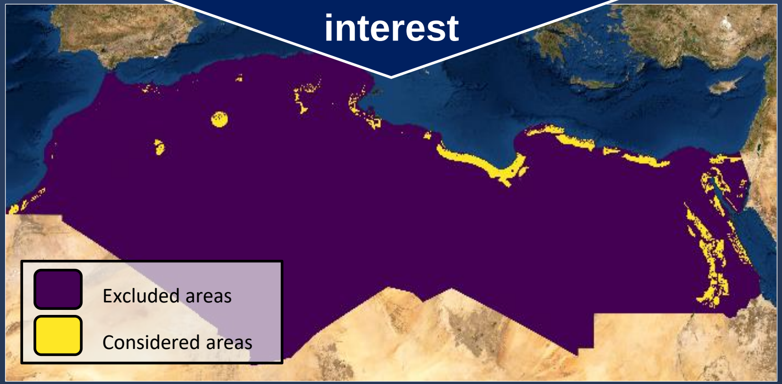
Population density > 50 habitants/km²

Slope > 5 percent

RE sources (wind onshore) using LCOE

Wind > 40 €/MWh

Areas of interest



PtX global ATLAS

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H_2 optimal production sites

General overview

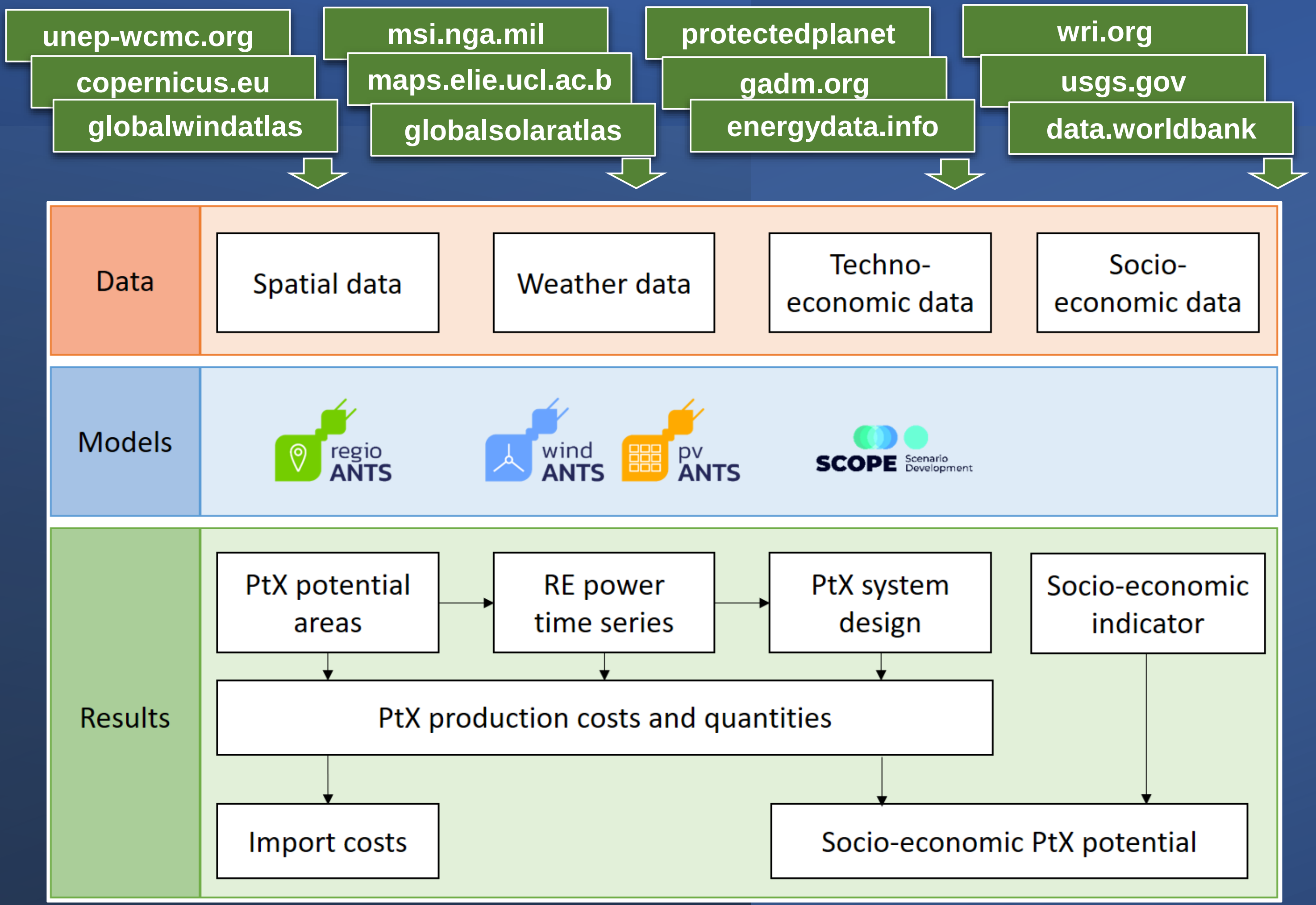
- Input: Spatial and meteorological as well as techno- and socioeconomic data
- Results: Costs and quantities for PtX products, PtX system design, socio-economic assessment
- Scenario year 2050

GIS based part

- PtX potential area identification
- Site selection for detailed PtX analyses

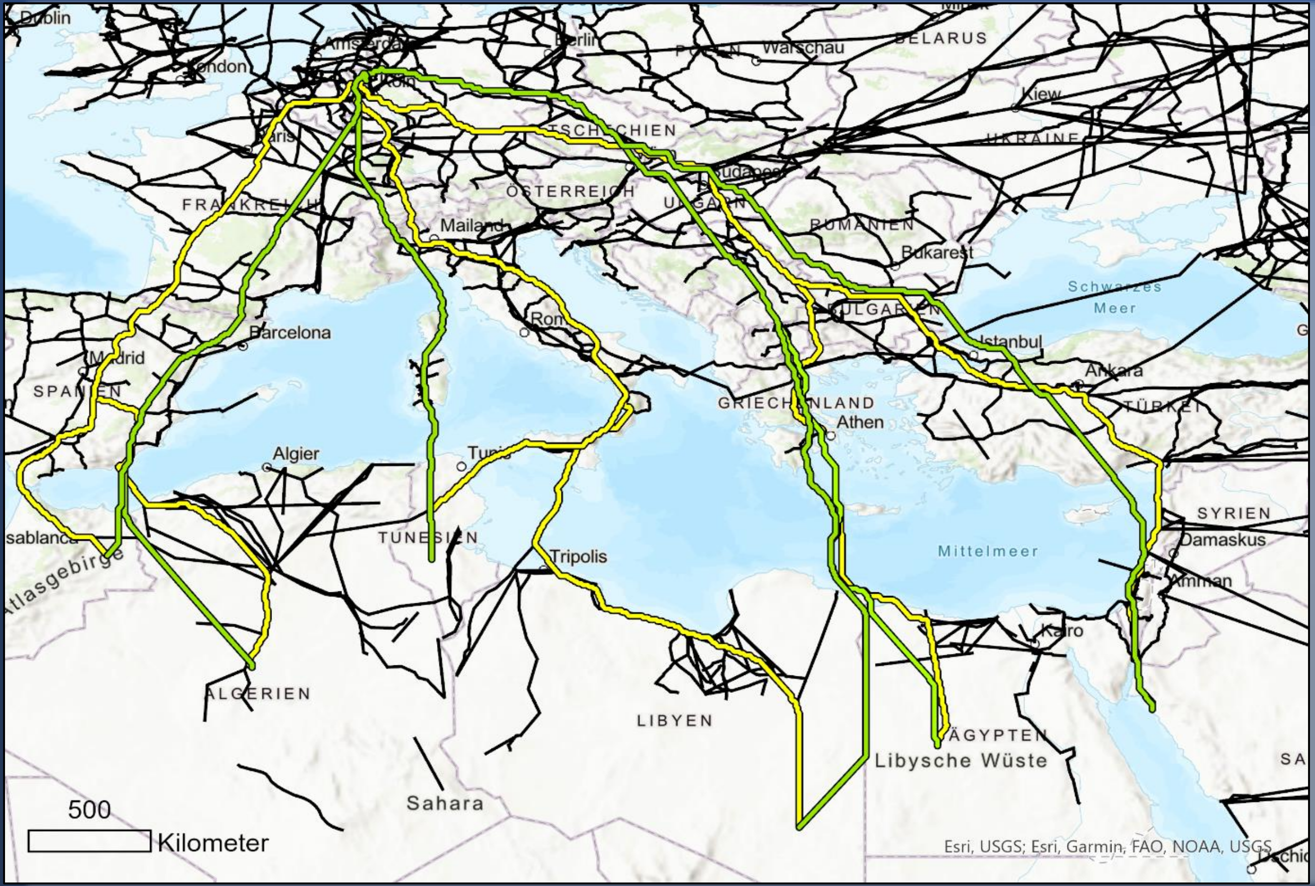
Time series based part

- Yield estimation for renewable energies
- Modeling of site specific PtX system configurations
- Estimation of total PtX generation quantities and costs



PtX global ATLAS

Calculation of pipeline transporting routes: Connecting Europe and the MENA region



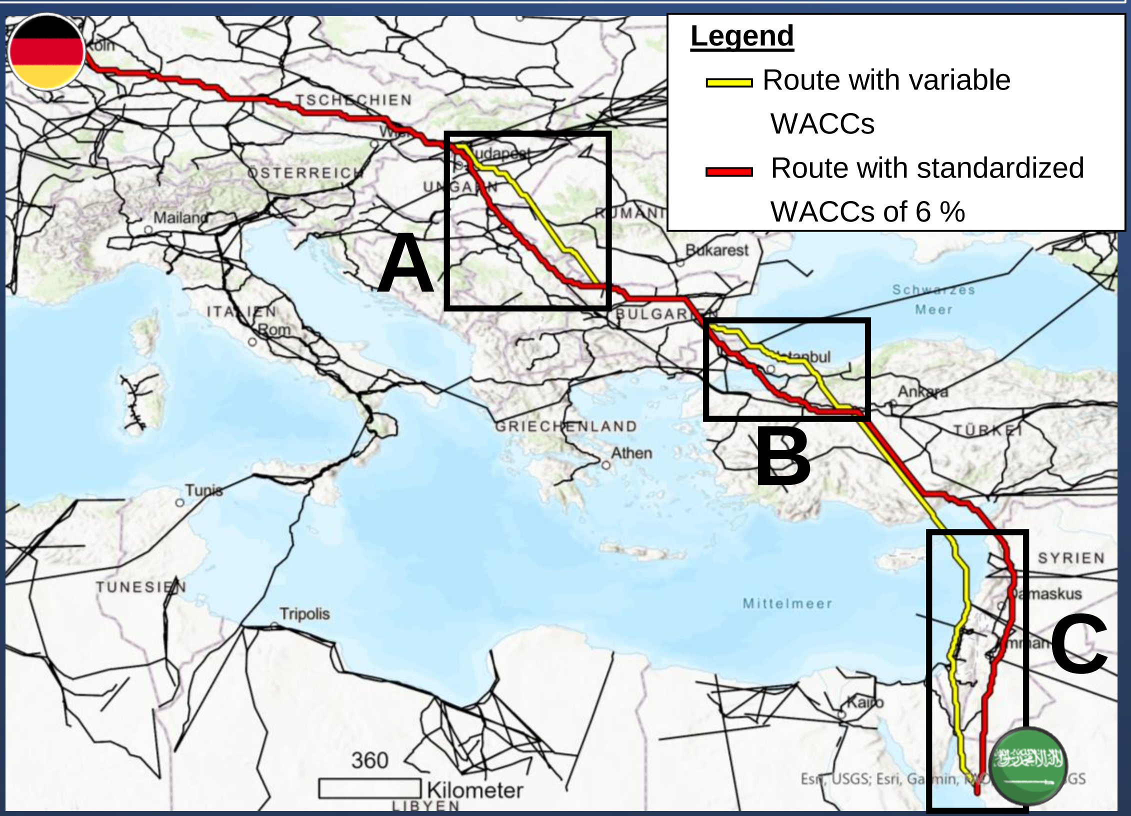
Yellow	**Route considering existing infrastructure**
Green	**Route without considering existing infrastructure**

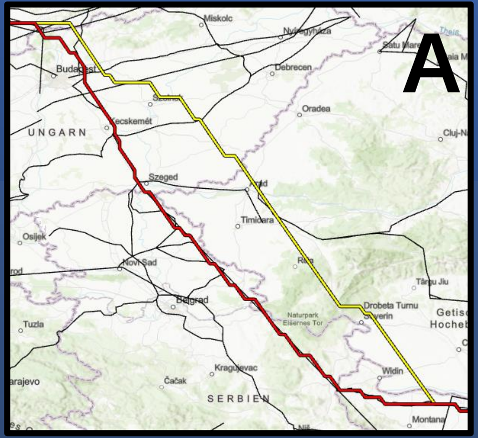
Analyzing factors influencing transport routes and cost:

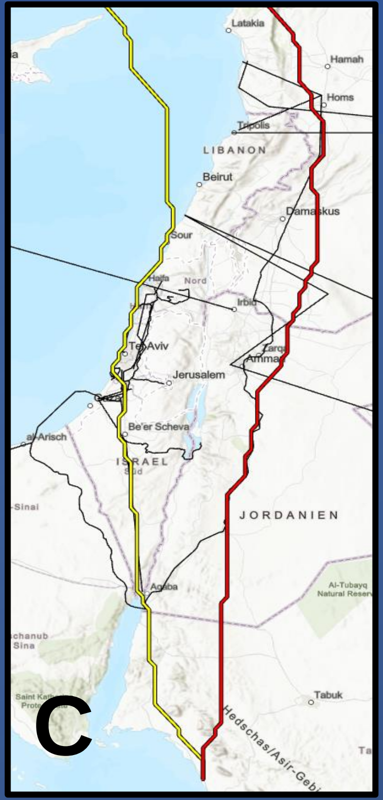
- WACCs
  - Country-specific WACCs with risk factors vs. standardized cross-country assumptions
- Effects due to topography
  - Offshore vs. onshore
  - Natural reserves, etc.
- Considering existing gas and oil infrastructure

Calculation of pipeline transporting routes (2)

Q: What effect do country specific WACCs have on a proposed pipeline route?







A: Country specific WACCs can change the routing and the costs compared to default WACCS

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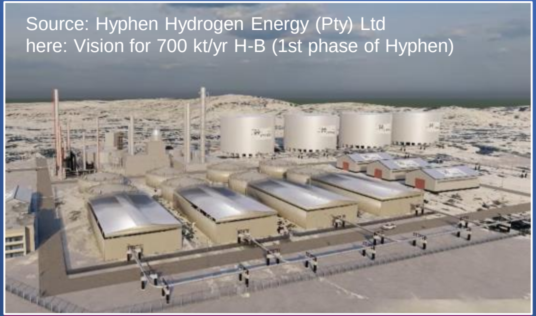
The example of Brazil: Green Ammonia production in Rio Grande do Norte


Source: ISPT NL 2020
here: Vision for 1GW Alkaline

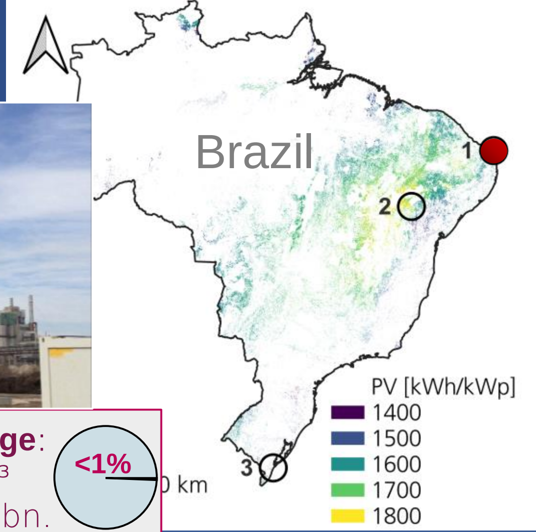
PEM Electrolysis: 15%
Installed cap.: 1 GW_{el}
CAPEX: EUR 0.75 bn.
Full load hours: 6716 h/yr
(77% CF)


Source: Hyphen Hydrogen Energy (Pty) Ltd
here: Vision for 700 kt/yr H-B (1st phase of Hyphen)

Haber-Bosch synthesis: 6%
Installed cap.: 7
kt/yr
Output: 723 kt/yr
CAPEX: EUR 0.34 bn.


Source: Engicon nv (Geldof)
here: 14 700 m³ refr. liquid NH_3

NH_3 intermediate storage: <1%
Size: 20 000 m³
CAPEX: EUR 0.01 bn.



NH_3

Renewable Energy

Onshore Wind and PV

Power-to-X Hub

PEM Electrolysis 1GW_{el}

Water supply via grid

H_2 intermediate storage (80 bar)

Haber-Bosch synthesis

N_2 via ASU

NH_3 intermediate storage

Transport

Long-distance transport via ships

Supply cost: 171 EUR/MWh
886 EUR/ton
Import: 723 kt/yr
3.75 TWh/yr
Total Invest.:
EUR 5.34 bn

Wind and PV: 57%
Installed cap. Wind / PV: 1
1.2 GW_{el}
CAPEX Wind+PV: EUR 2.9 bn.
LCOE Wind / PV: 41 / 29
EUR/MWh_{el}
Surplus RE pow

H_2 storage: 7%
Size: 272 000 m³
CAPEX: EUR 0.57 bn.

Air Separation Unit: 1%
Installed cap.:
kt/yr
CAPEX: EUR 0.08 bn

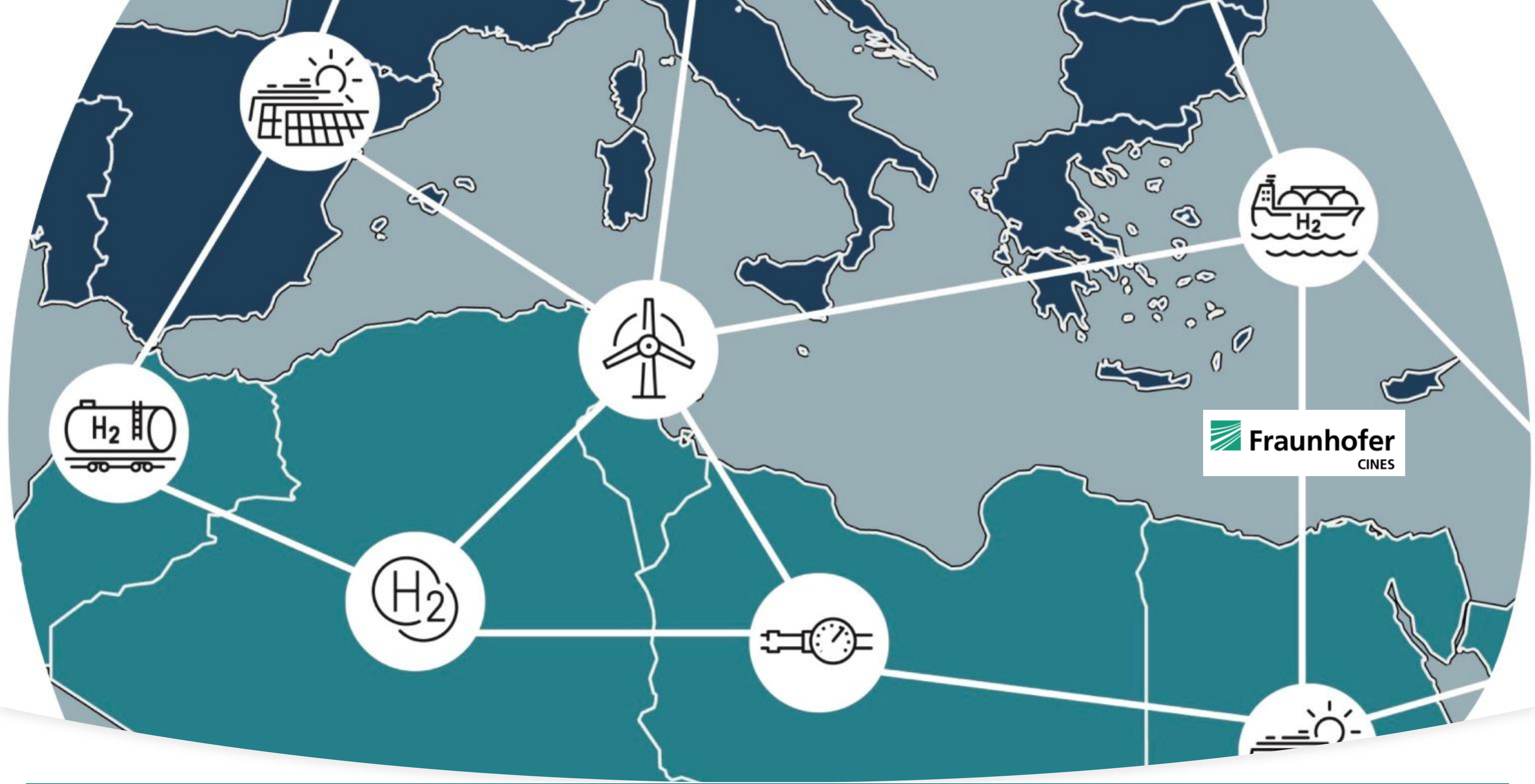
Ship transport: LPG Carrier 2%
Ship size: 84 000 m³
CAPEX: EUR 0.06 bn.
Distance: 7965 km

xx%
Contribution to total supply cost
Not shown here:
Desalination, Grid, Labor,
Insurance, EPC


Source: Bilfinger


Source: Air Products


Source: Kawasaki Heavy Industries



Potential of H_2 supply chains in the Europe-MENA region

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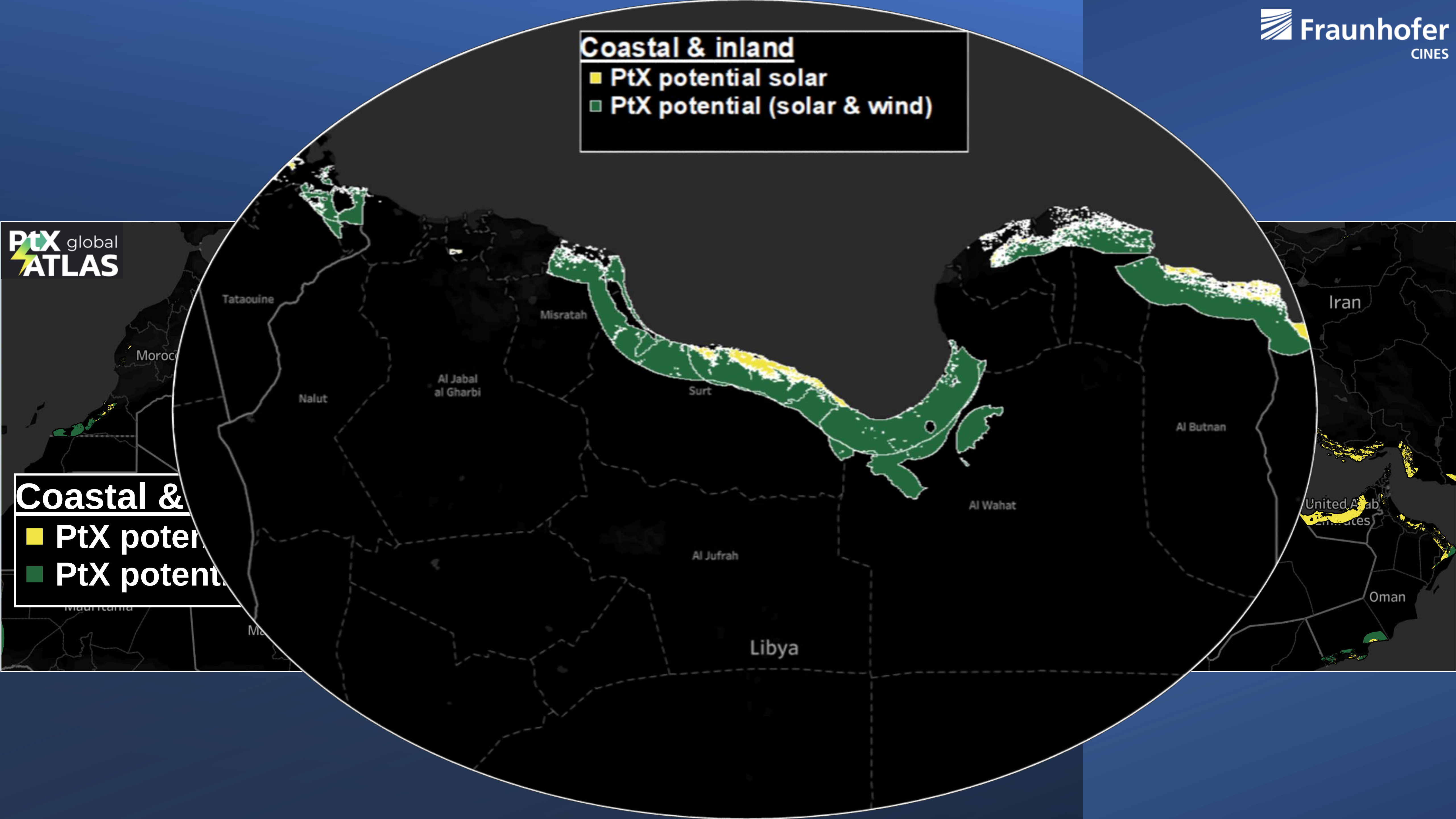

H_2 supply chains costs are low in selected MENA countries

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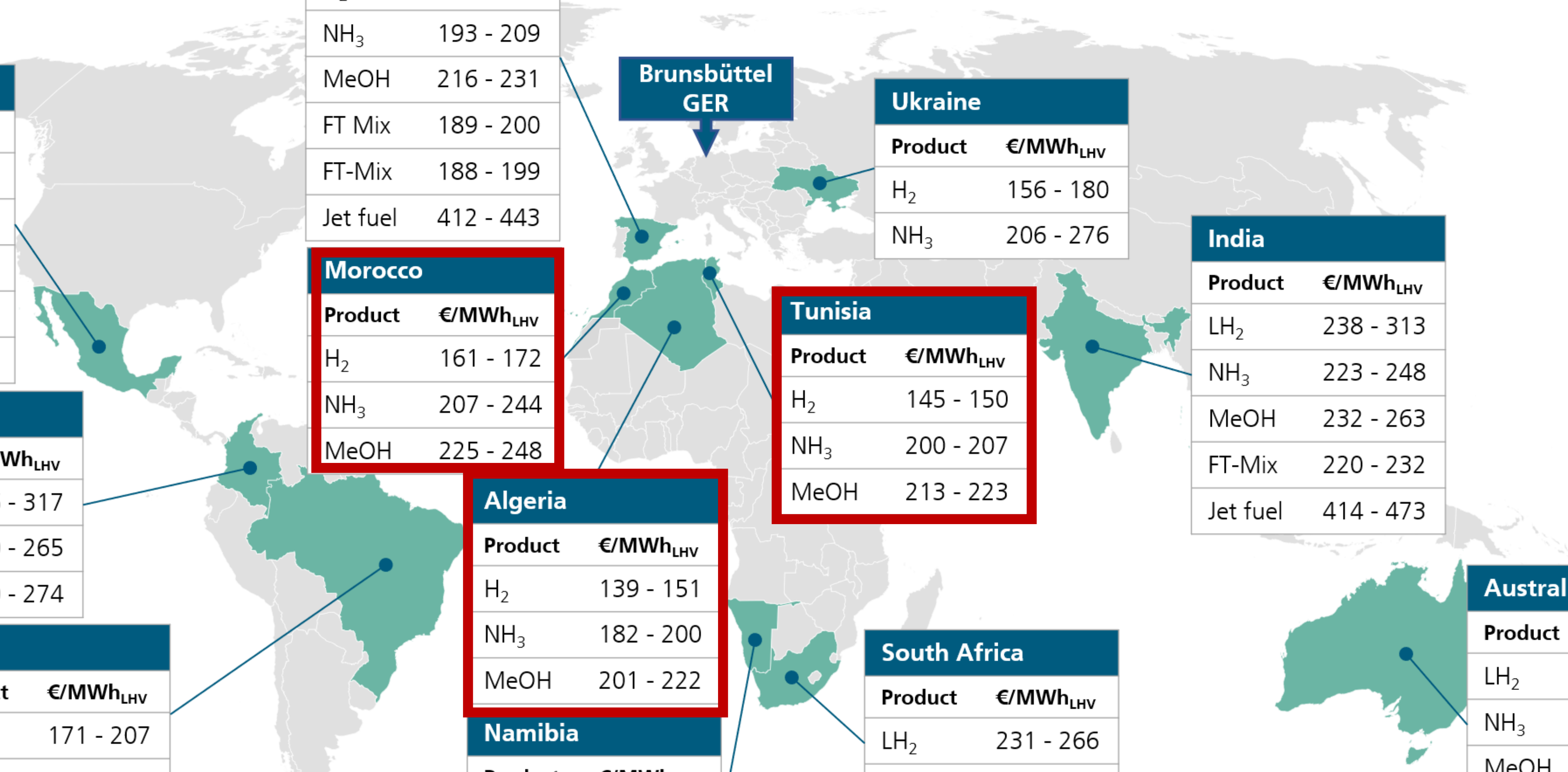


Spain

Product	€/MWh_{LHV}
H_2	134 - 146
NH_3	193 - 209
MeOH	216 - 231
FT Mix	189 - 200
FT-Mix	188 - 199
Jet fuel	412 - 443

Mexico

Product	€/MWh_{LHV}
LH_2	242 - 285
NH_3	215 - 233
MeOH	238 - 245
FT-Mix	210 -211
Jet fuel	406 - 430

Colombia

Product	€/MWh_{LHV}
LH_2	176 - 317
NH_3	190 - 265
MeOH	190 - 274

Brazil

Product	€/MWh_{LHV}
LH_2	171 - 207
NH_3	171 - 184

Morocco

Product	€/MWh_{LHV}
H_2	161 - 172
NH_3	207 - 244
MeOH	225 - 248

Algeria

Product	€/MWh_{LHV}
H_2	139 - 151
NH_3	182 - 200
MeOH	201 - 222

Namibia

Product	€/MWh_{LHV}
LH_2	244 - 270
NH_3	202 - 213
MeOH	222 - 240

Ukraine

Product	€/MWh_{LHV}
H_2	156 - 180
NH_3	206 - 276

Tunisia

Product	€/MWh_{LHV}
H_2	145 - 150
NH_3	200 - 207
MeOH	213 - 223

India

Product	€/MWh_{LHV}
LH_2	238 - 313
NH_3	223 - 248
MeOH	232 - 263
FT-Mix	220 - 232
Jet fuel	414 - 473

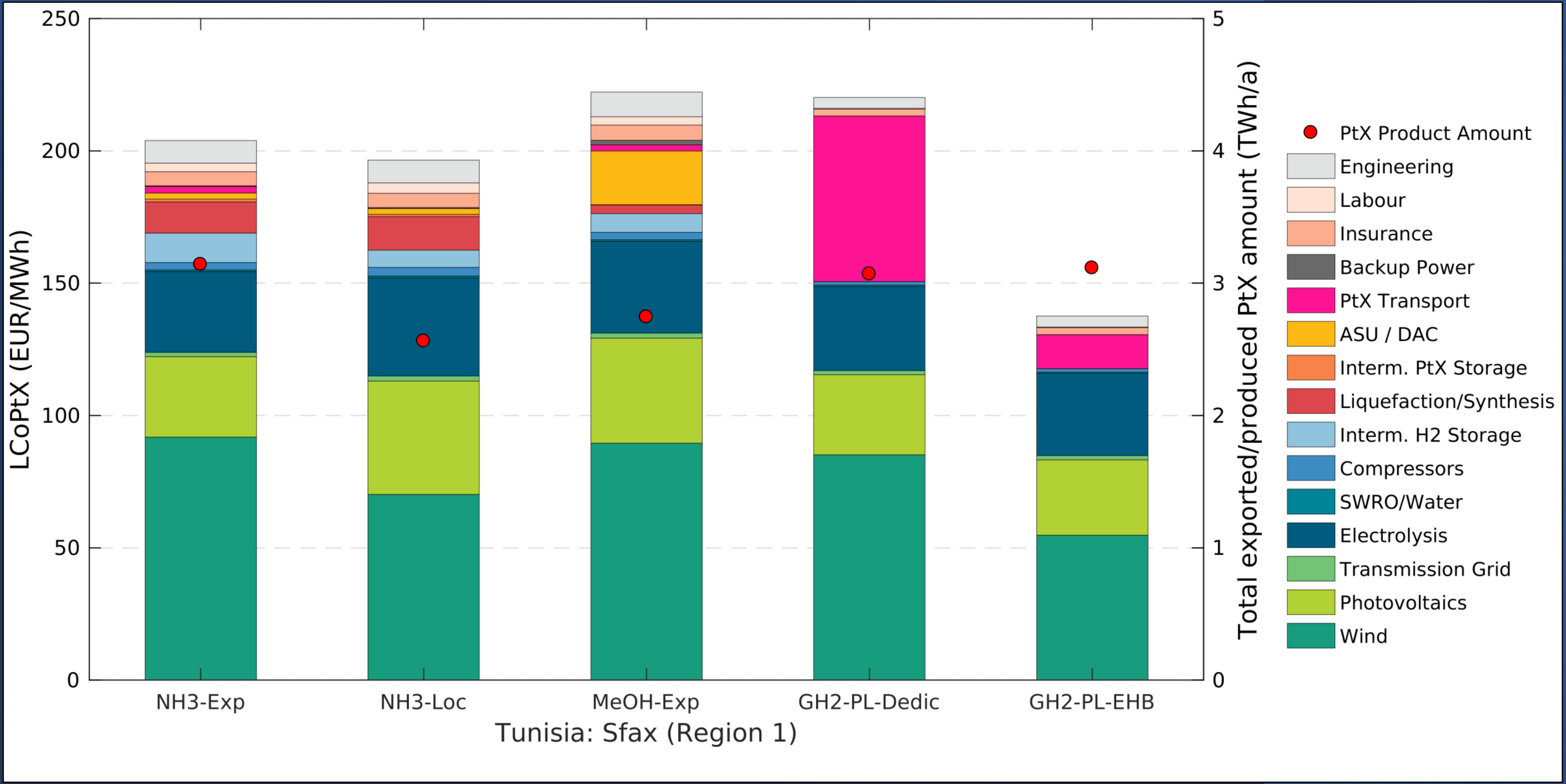
South Africa

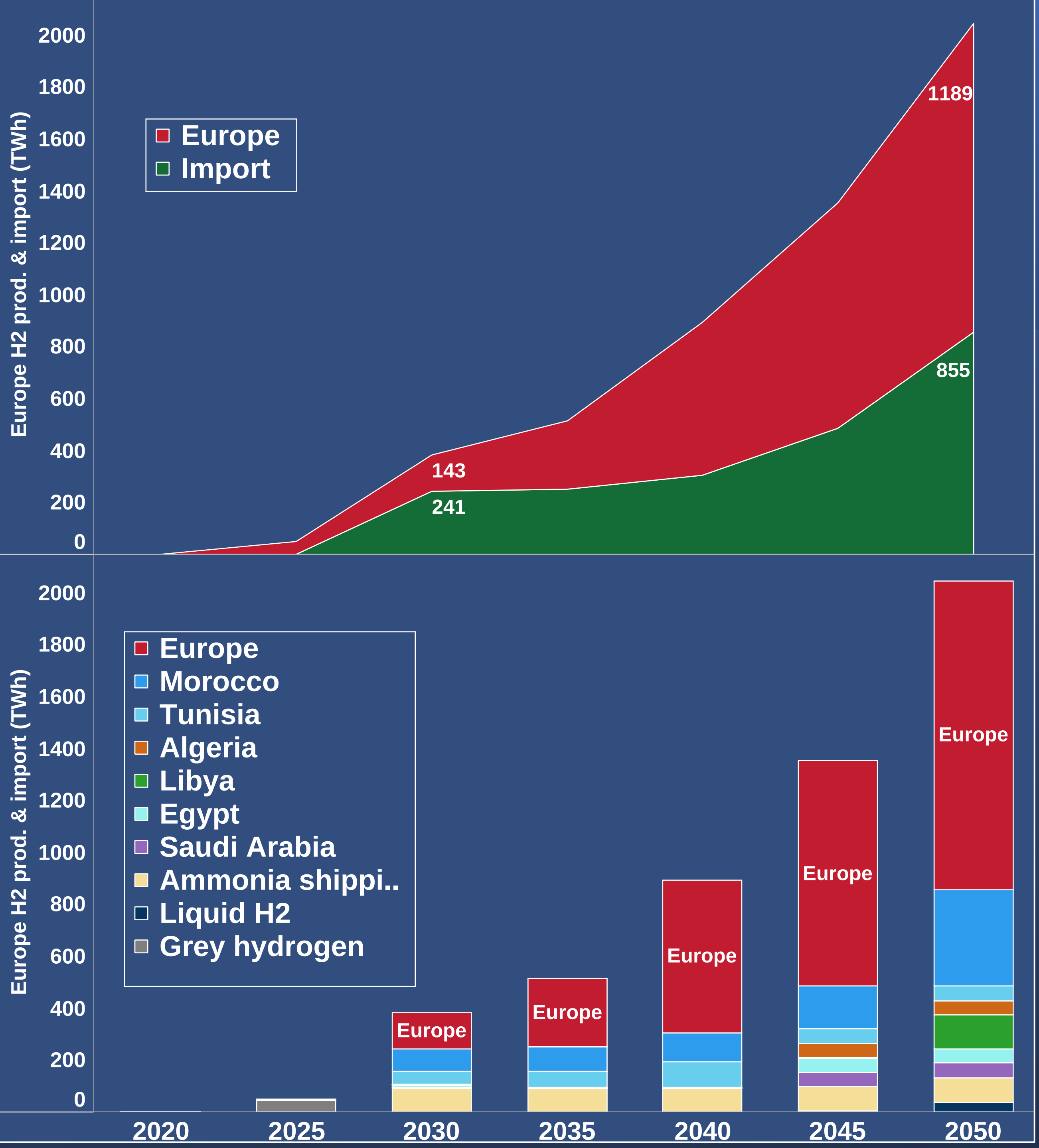
Product	€/MWh_{LHV}
LH_2	231 - 266
NH_3	203 - 223
MeOH	225 - 236

Australia

Product	€/MWh_{LHV}
LH_2	217 - 233
NH_3	172 - 184
MeOH	192 - 200
FT-Mix	166 - 181
Jet fuel	298 - 333

Calculation of H_2 supply chain: Tunisia





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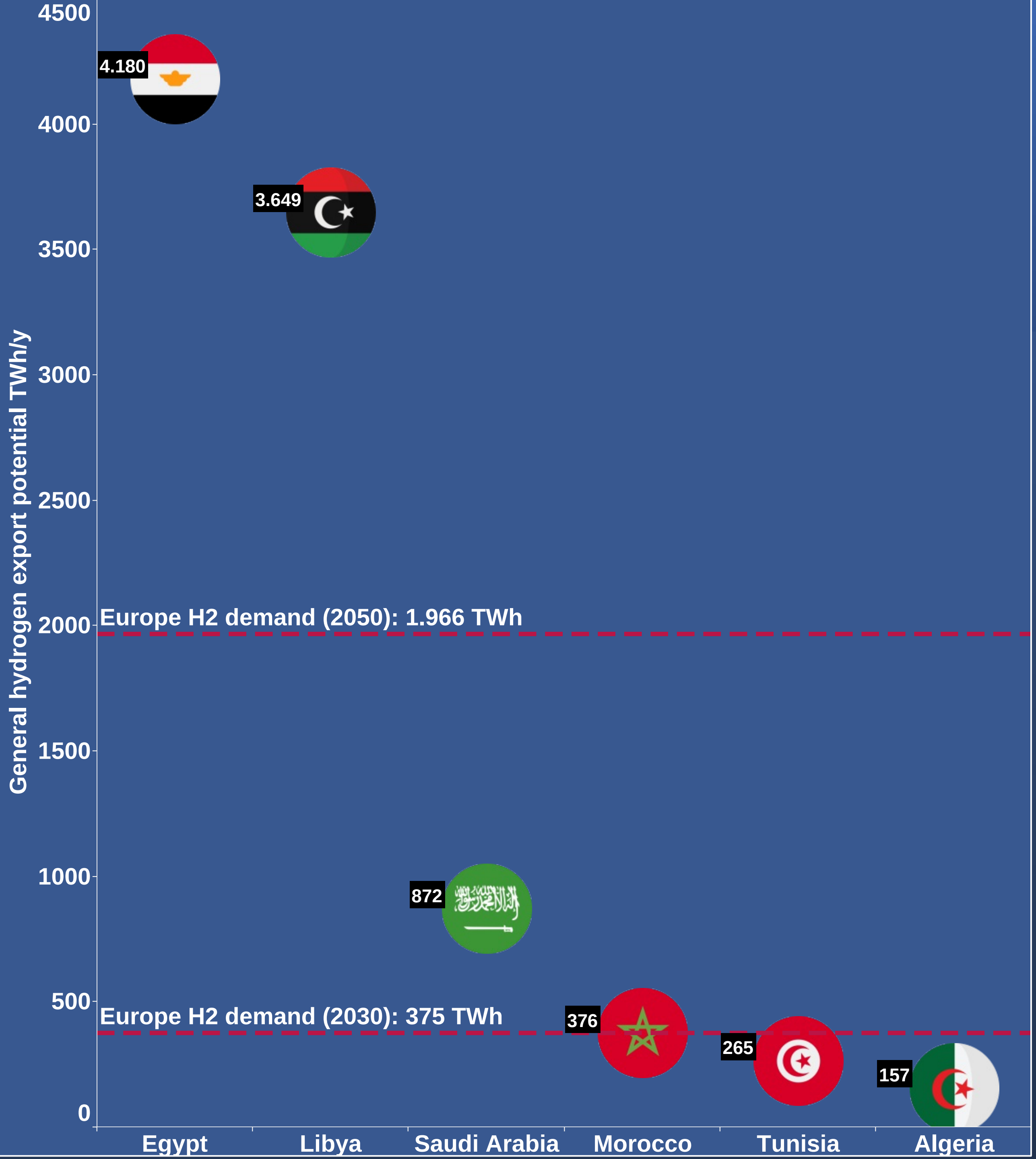
- For almost half of its H_2 demand (up to 2050), Europe **could** depend on imports from the MENA countries selected here based on low production costs, geographical proximity, and existing infrastructure. The bulk of imports from these countries to Europe must occur via pipeline.

- Simultaneously, from 2030 onwards, there is also a substantial role for ammonia imports via ship. Findings indicates a significant techno-economic potential for hydrogen exports from Morocco and Tunisia in 2030, followed by Libya, Algeria, Egypt, and Saudi Arabia from 2045 onwards.

Source: Fraunhofer CINES (2023).



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	Primary energy demand (TWh/a)	Hydrogen production potential (TWh/a)	Hydrogen export potential (TWh/a)
Egypt	728	4908	4180
Libya	127	3776	3649
Saudi Arabia	1813	2685	872
Morocco	198	574	376
Tunisia	96	361	265
Algeria	493	650	157

Source: Fraunhofer CINES (2023).

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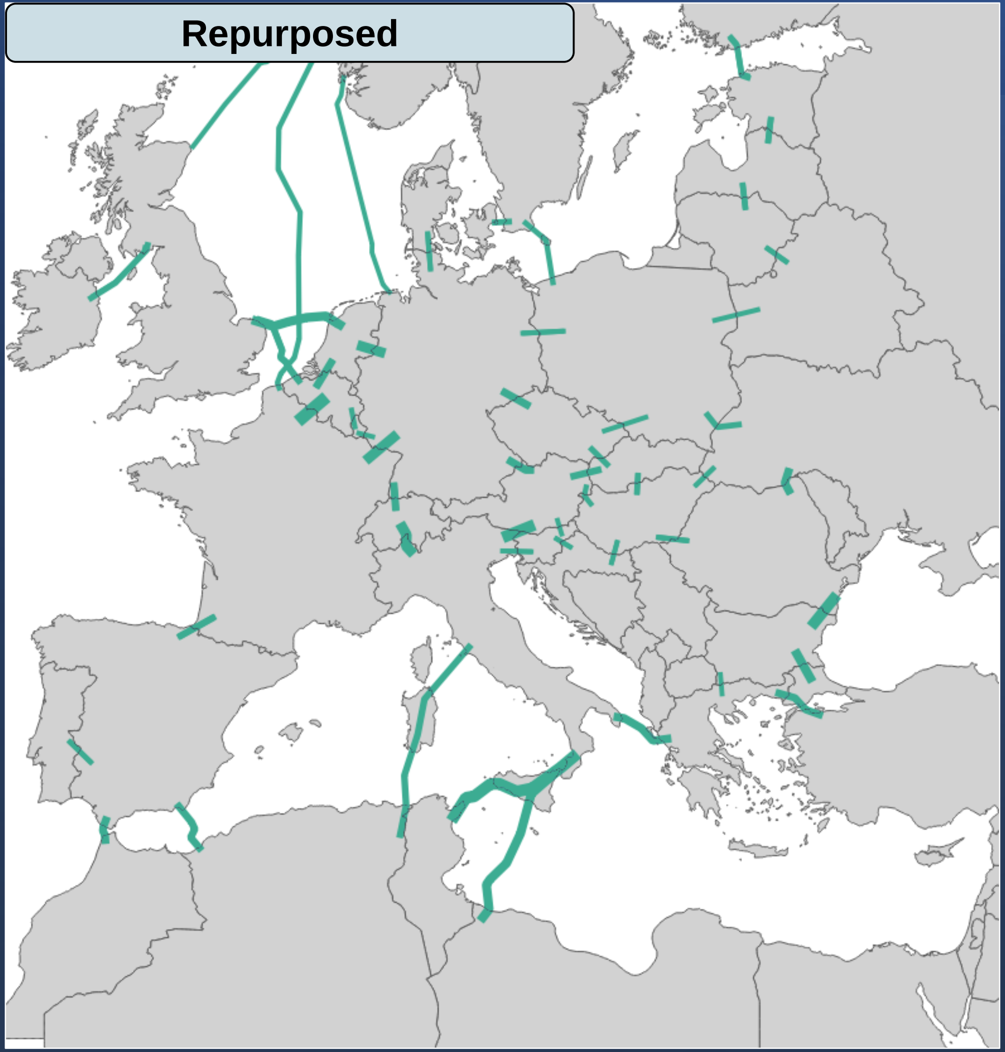
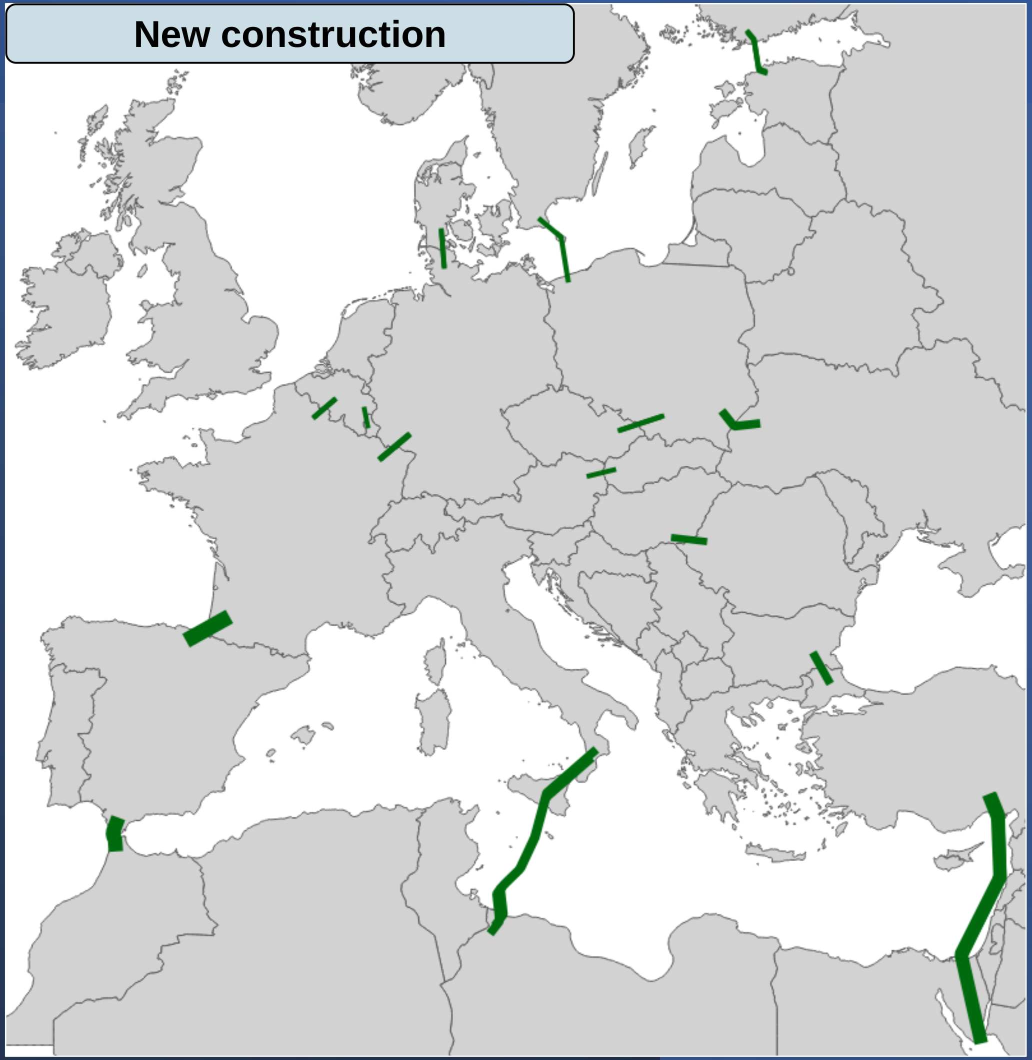
Hydrogen (repurposed)
Hydrogen (new capacity)

2030

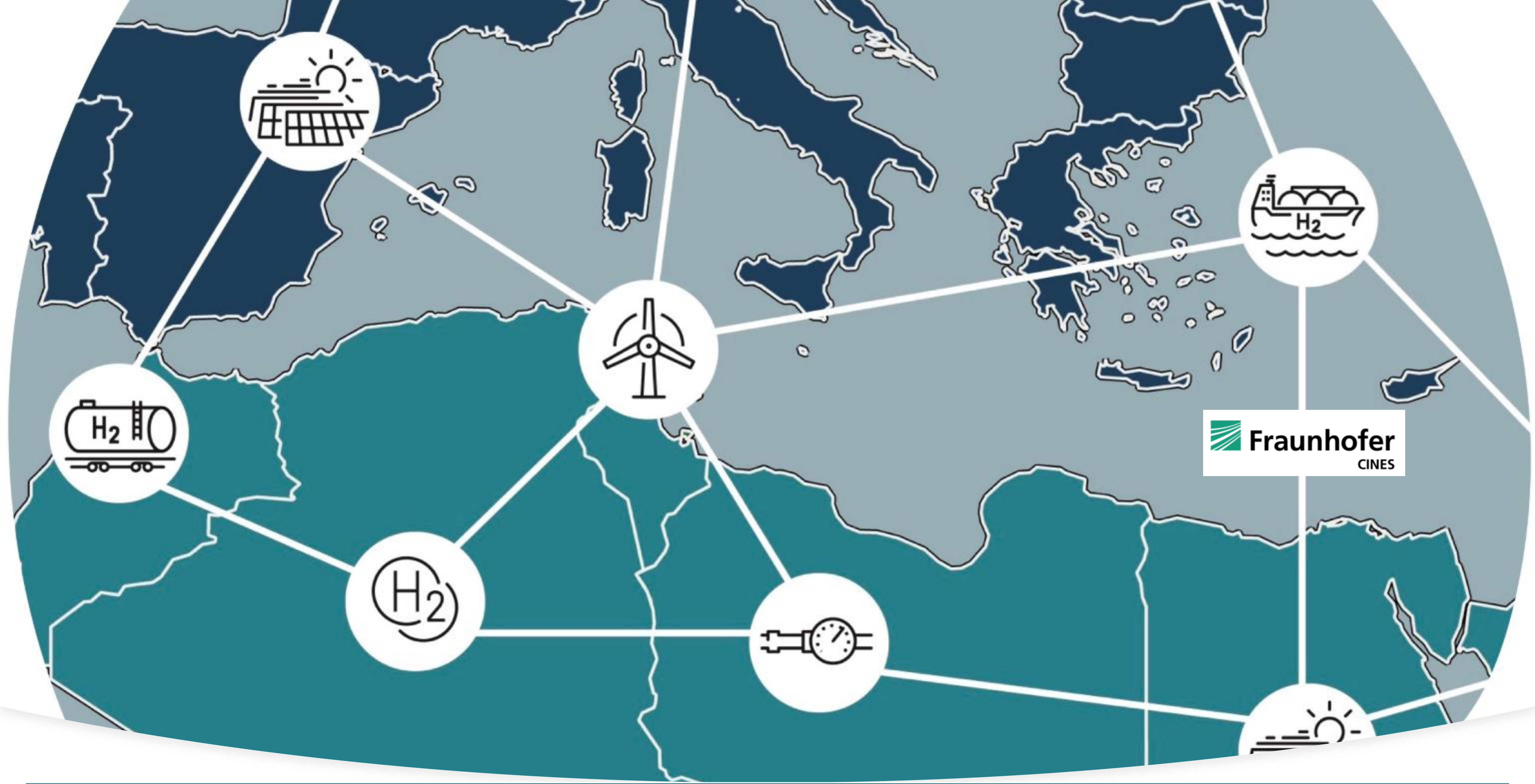


1500 GWh/d
1000 GWh/d
500 GWh/d

2050



Source: Fraunhofer CINES (2023).



H_2 economy challenges in the Europe-MENA region

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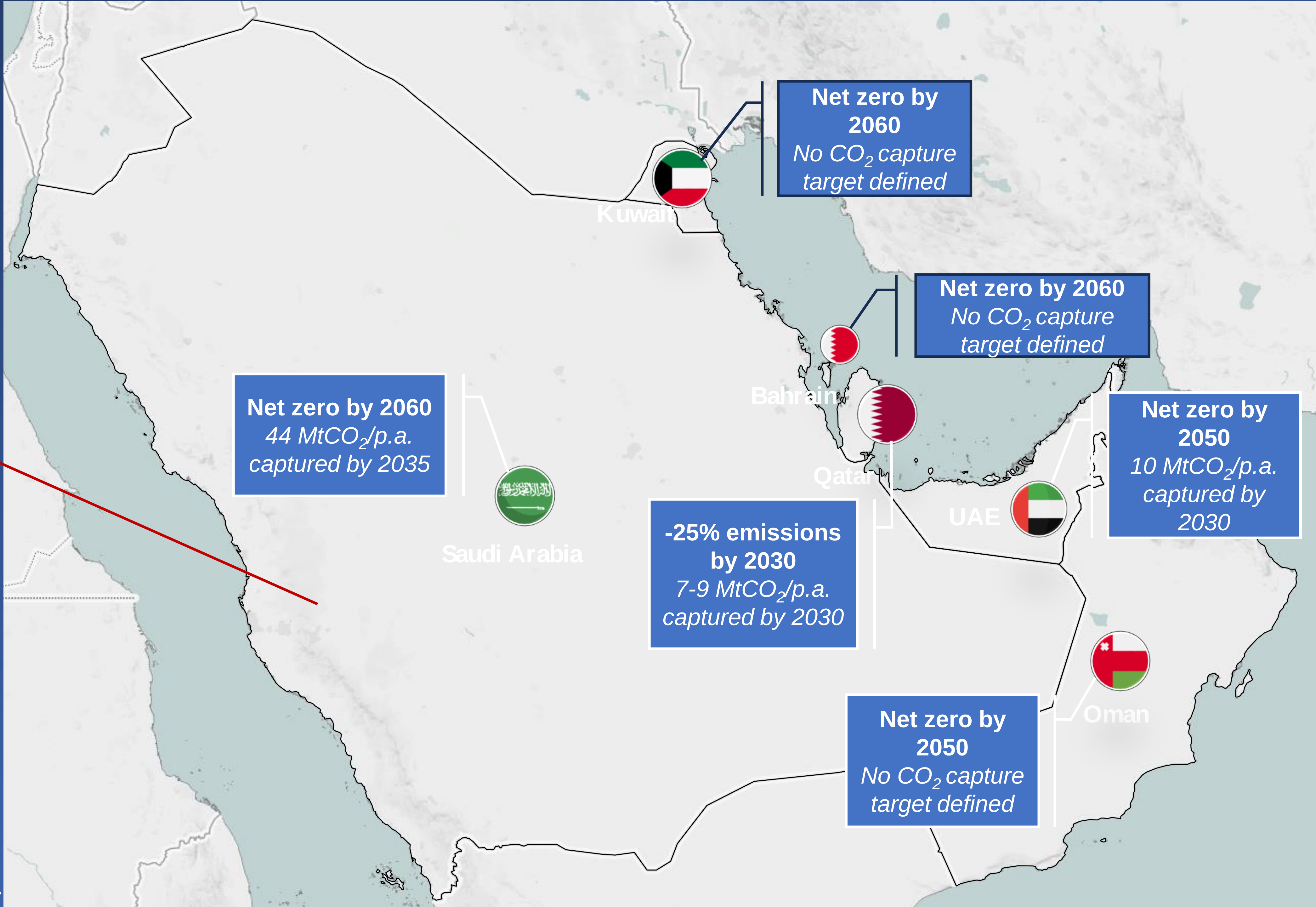
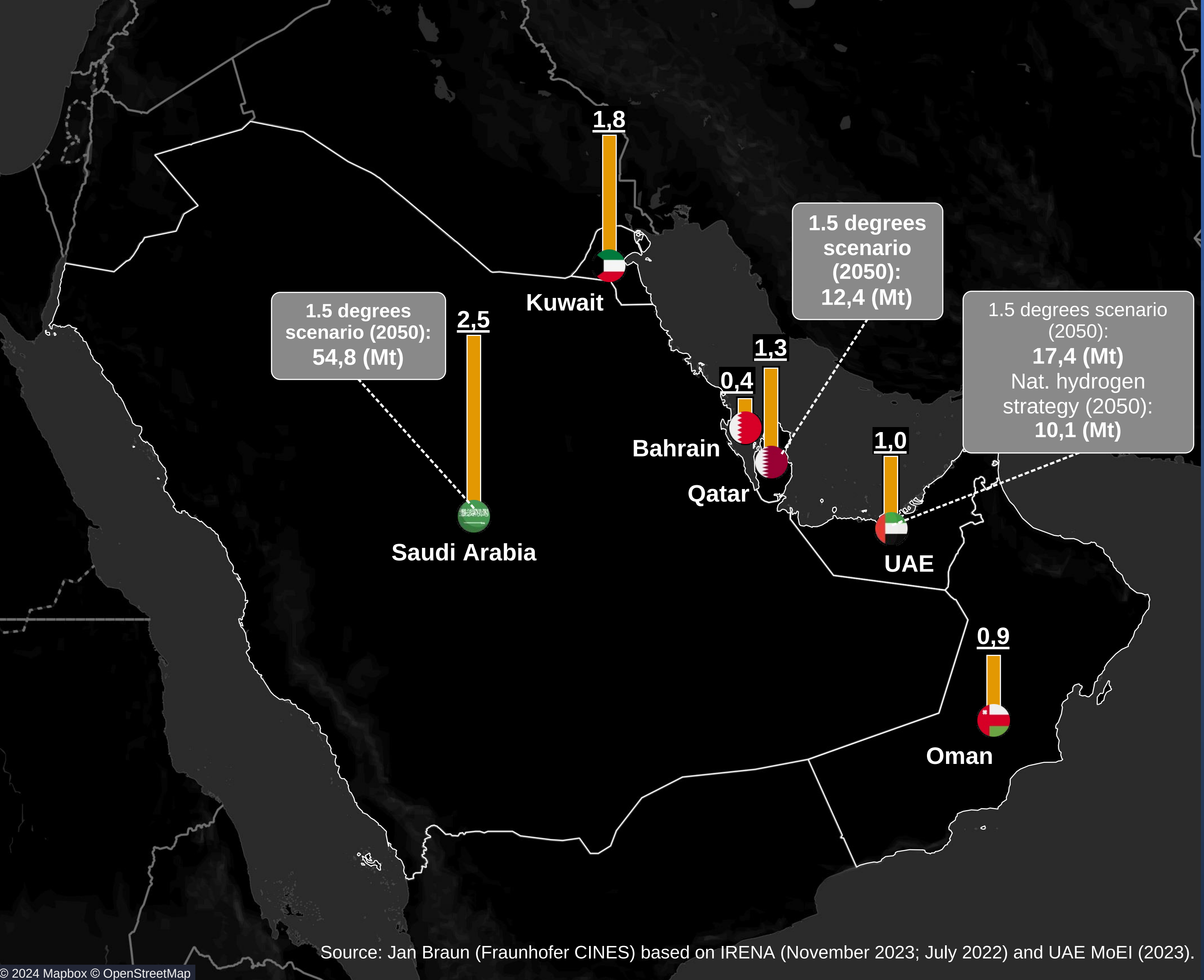
Announced (2023):
11 $MtCO_2$/p.a.
Target (2030):
65 $MtCO_2$/p.a.



Source:
Jan Braun (Fraunhofer CINES) based on Roland Berger (2024).

H_2 demand in the Gulf region in 2023 and 2050 (1.5 degrees scenario Mt*)

*) Where data available



Source: Jan Braun (Fraunhofer CINES) based on IRENA (November 2023; July 2022) and UAE MoEI (2023).

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H2 Potential

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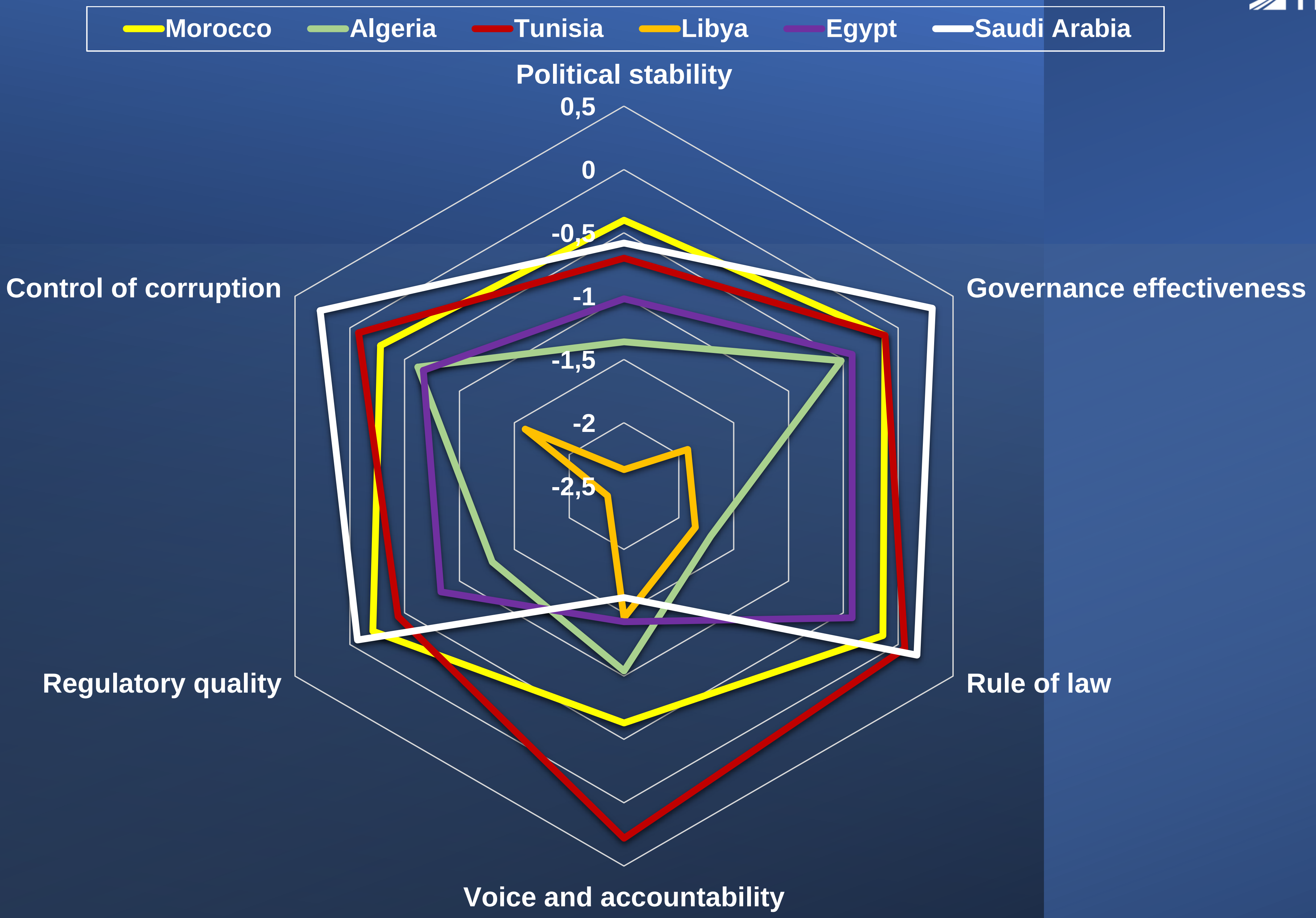
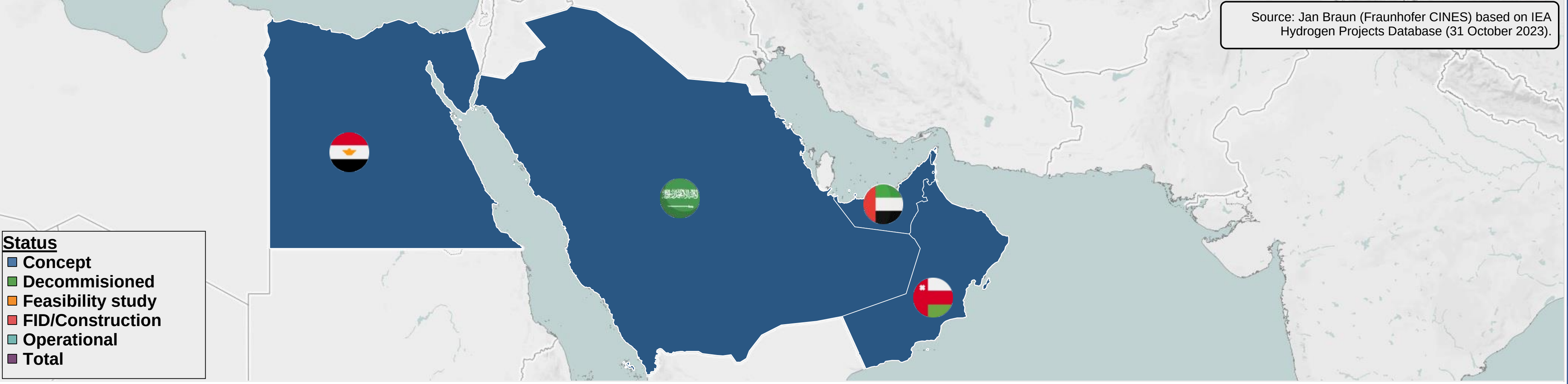


Source: Fraunhofer CINES (2023) based on World Bank (2022).



Country	Project name	Technology	Product	Status	Year..	Capacity MWel	Capacity kt H2/y
Egypt	Masdar Hassan Allam green hydrogen, phase 2	Electrolysis	Ammonia	Concept	2030	3,806	659
	ReNew Power - Egypt MoU, Ammonia phase 1	Electrolysis	Ammonia	Concept	2025	208	36
	ReNew Power - Egypt MoU, Ammonia phase 2	Electrolysis	Ammonia	Concept	2029	2,079	360
	ReNew Power - Egypt MoU, Hydrogen, phase 1	Electrolysis	H2	Concept	2025	231	40
	ReNew Power - Egypt MoU, Hydrogen, phase 2	Electrolysis	H2	Concept	2029	2,078	360
	Scatec Green Ammonia	Electrolysis	Ammonia	Concept	2025	1,823	316
	Total Eren, Enara green ammonia, phase 2	Electrolysis	Ammonia	Concept	2030	2,188	379
	KIMA - Aswan electrolyser	ALK	Ammonia	Decommissioned	2000		
	Ain Sokhna ammonia project	Electrolysis	Ammonia	Feasibility study	2027	1,459	253
	Ain Sokhna plant, Suez Canal Economic Zone (SCZone), ph..	Electrolysis	Ammonia	Feasibility study	2026	253	44
	EBIC - Ammonia plant	PEM	Ammonia	Feasibility study	2024	100	15
	Masdar Hassan Allam green hydrogen, phase 1	Electrolysis	MeOH	Feasibility study	2026	194	34
	Waste-to-hydrogen East Port Said	Other	H2	Feasibility study	2026		300
Oman	H2Oman (Dhofar)	Electrolysis	H2	Concept	2030	2,079	360
	Sohar Port, phase 1	Electrolysis	H2	Concept	2024	35	6
	Green Hydrogen Oman (GEO), phase 1 (green H2 project)	Electrolysis	Ammonia	Feasibility study	2028	1,732	300
	Green Hydrogen Oman (GEO), phase 2 (green H2 project)	Electrolysis	Ammonia	Feasibility study	2038	9,333	1,617
	Hyport@Duqm, phase 1	Electrolysis	Ammonia	Feasibility study	2026	500	87
	POSCO green ammonia plant	Electrolysis	Ammonia	Feasibility study	2030	2,540	440
	SalalaH2	Electrolysis	Ammonia	Feasibility study	2024	400	69
	Sur hydrogen cluster	Electrolysis	H2	Feasibility study	2030	1,300	225
	Green Hydrogen and Chemicals SPC, phase I	Electrolysis	Ammonia	FID/Construction	2025	320	55
Saudi Arabia	NEOM Green Hydrogen Project	ALK	Ammonia	FID/Construction	2026	2,000	339
UAE	Engie - Masdar - Fertiglobe Abu Dhabi	Electrolysis	Ammonia	Concept	2025	200	35
	MoU IHI-Enoc	Electrolysis	Ammonia	Concept	2028	693	120
	Khalifa Industrial Zone Abu Dhabi (KIZAD) - phase 1	Electrolysis	Ammonia	Feasibility study	2024	121	21
	Khalifa Industrial Zone Abu Dhabi (KIZAD) - phase 2	Electrolysis	Ammonia	Feasibility study	2026	572	99
	TA'ZIZ blue ammonia	NG w CCUS	Ammonia	FID/Construction	2025		180
	Emirates Steel Industries - Al Reyadah CCUS	NG w CCUS	H2	Operational	2016		
	Green hydrogen Project, Mohammad Bin Rashid Solar Park	PEM	H2	Operational	2021	1	0
Grand Total						**36,244**	**6,750**

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Source: Informaconnect (2020).

National H_2 pathways in Europe are generally marked by:

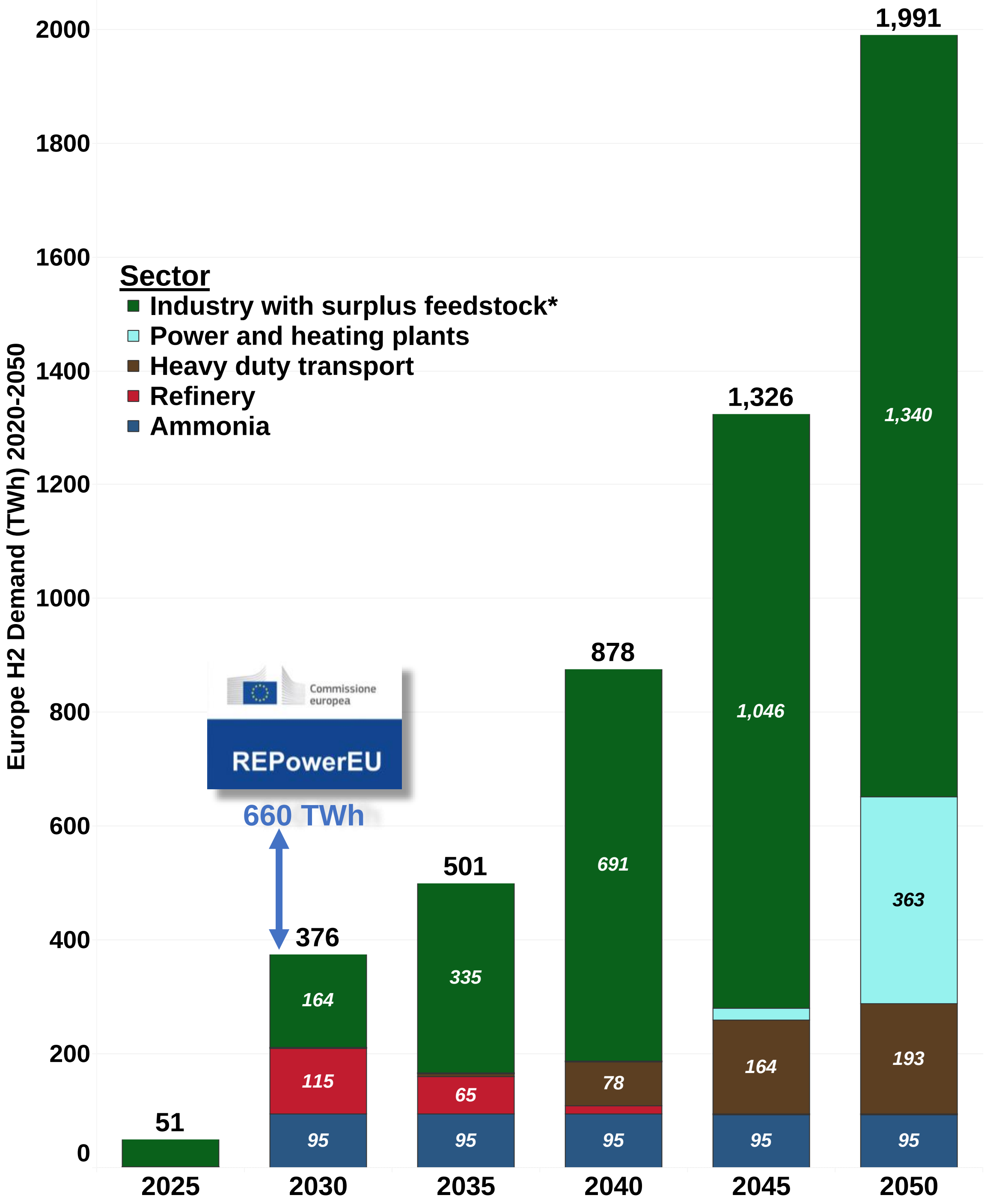
i. A gap between ambition and policy.

ii. Discord between import- and export-oriented countries.

iii. An incoherent assortment of hydrogen colors and carbon intensity.

iv. A lack of proper infrastructure planning.

Source: Braun, Van Wijk and Westphal (2024).



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Technical-economic assessment

vs.

Political targets

H_2

REPowerEU

(& Strategic Partnership with the Gulf)

EU Energy Platform (joint H_2 purchasing)

Global European H_2 Facility

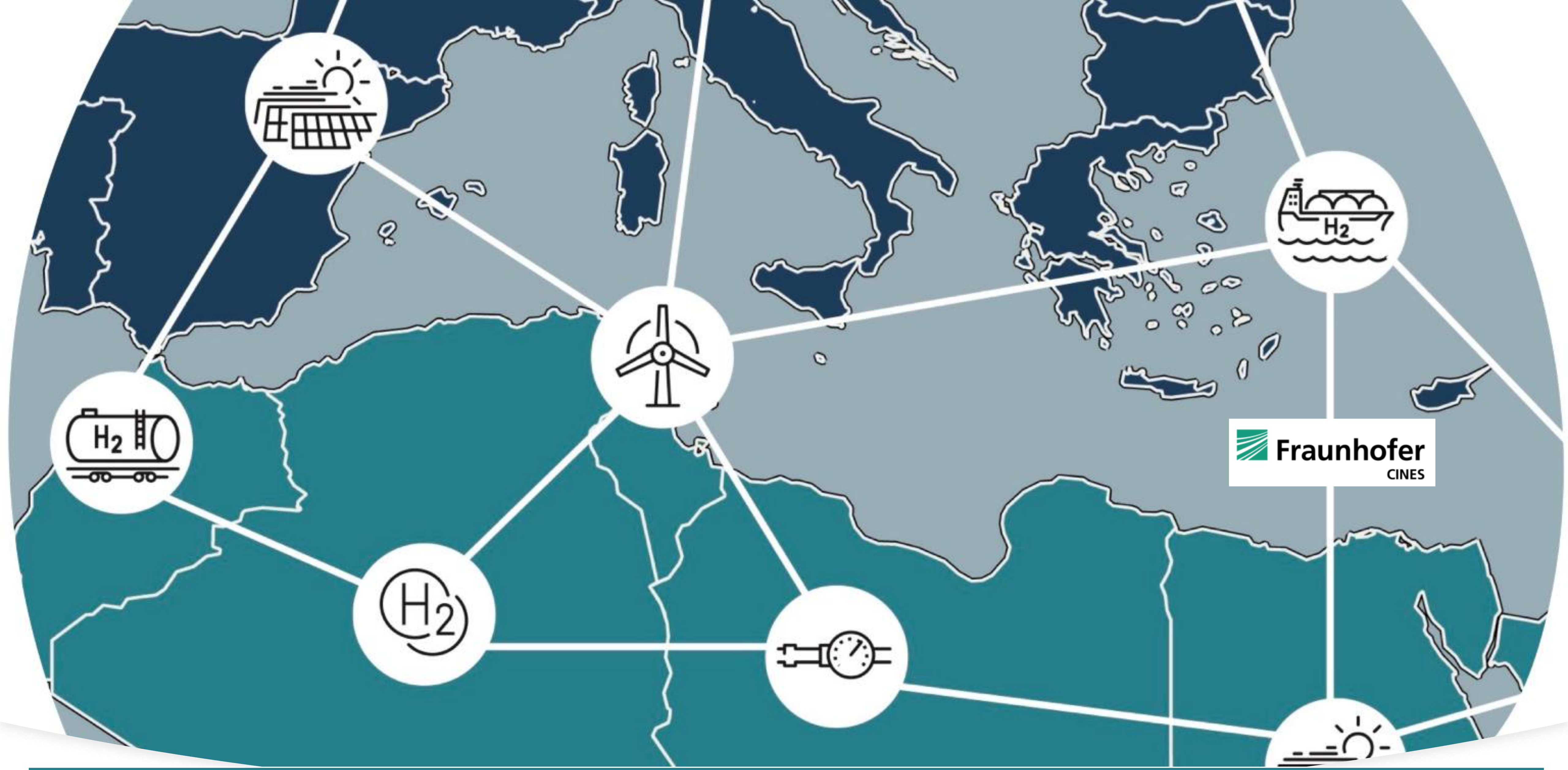
H_2 Partnerships*
(Member States and industries)

*) emission intensity of H_2 production under strict sustainability criteria & net-zero scenario:
e.g., 6-7 kg CO 2-eq/kg H_2 by 2030
e.g., < 1 kg CO 2-eq/kg H2 by 2050

Source: Braun, Van Wijk, and Westphal (2024).

Conclusions:

- **Fraunhofer supply chain modelling and analyses provide a wide range of scientifically substantiated assessments of the (potential) H_2 economy.**
- **Technical-economic assessments presented here has one overarching message: Europe’s H2 future lies in the MENA region and vice versa.**
- **Solving the most prominent H2 economy challenges in the Europe-MENA region involves most prominently (and pragmatically) bridging the gap between ambition and policy.**



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