Norsk Hydrogenforum

SINTEF

Steffen Møller-Holst

Chairman of the Board — Norsk Hydrogenforum

Vice President Marketing Hydrogen technologies — SINTEF

Chairman Transport — Hydrogen Europe Research

Decarbonizing the energy system by 2050

– reflections on success factors seen from a Norwegian perspective

Dutch visit to NTNU/SINTEF,
Trondheim, 24th June 2022

Norsk Hydrogenforum

Norwegian H_2 Forum's ***Mission***

- A driving force for implementation of 0-emission solutions in all sectors
- Facilitating education, research and innovation within hydrogen technologies
- Conveying information to & between Norwegian & international stakeholders
- Being a constructive dialogue partner for government and funding agencies

Norsk Hydrogenforum

Norwegian H_2 Forum's ***Members***

Industry

Statkraft, equinor, Aker Clean Hydrogen, Yara, nel, Hexagon Purus, UMOE Advanced Composites, Norwegian Hydrogen, Hydrogen pro, Gen2 Energy, Hy2gen Norge AS, Glomfjord Hydrogen, Meraker Hydrogen, Viken Hydrogen, Akershus energi, TrønderEnergi, Nordkraft, HYDS Hydrogen Solutions, hystar, ZEG Power, agri-e, DNV, PXG, proactima, Greenstat, Clara Venture Labs, HYSTORSYS, Air Liquide, Hydrogen Storage, CerPoTech, Ballard, Everfuel, westgass, Fuella Future of Fuel, GreenH, Hynion, Hyundai, Toyota, HYON, HYREX, Litra, Thema, Havrand Hydro, Lhyfe

Component Suppliers

Emerson, Worley Worley Origo Process, J.S.Cock, flowtec Instrumentation · Pumps · Solutions, Eltek, habu oilfield supply, OTECHOS, Håland Instrumentering AS, Swagelok, Slåttland, Parker, Haakon Ellingsen, HydraServ, Hoerbiger because performance counts

Research & Development

FFI Forsvarets forskningsinstitutt, IFE, NORCE, SINTEF, USN Universitetet i Sørøst-Norge, UiO Universitetet i Oslo, Høgskulen på Vestlandet, NTNU Energy Team Hydrogen, Nordic Energy Research

Organizations

Industri Energi, Småkraft Foreningen, EGN Energigass Norge, ZERO, Kunnskapsbyen Lillestrøm, BIL, Energi Norge, Nasjonalt Vindenergisenter

Governmental Entities

Sjøfartsdirektoratet Norwegian Maritime Authority, Justervesenet

Norwegian H_2 Forum's ***Board***

Norsk Hydrogenforum

Chairman of the Board, SINTEF

Norwegian Hydrogen

Are Opstad Sæbø
Co-chair of the Board, Greenstat

Julie Wedege
Statkraft

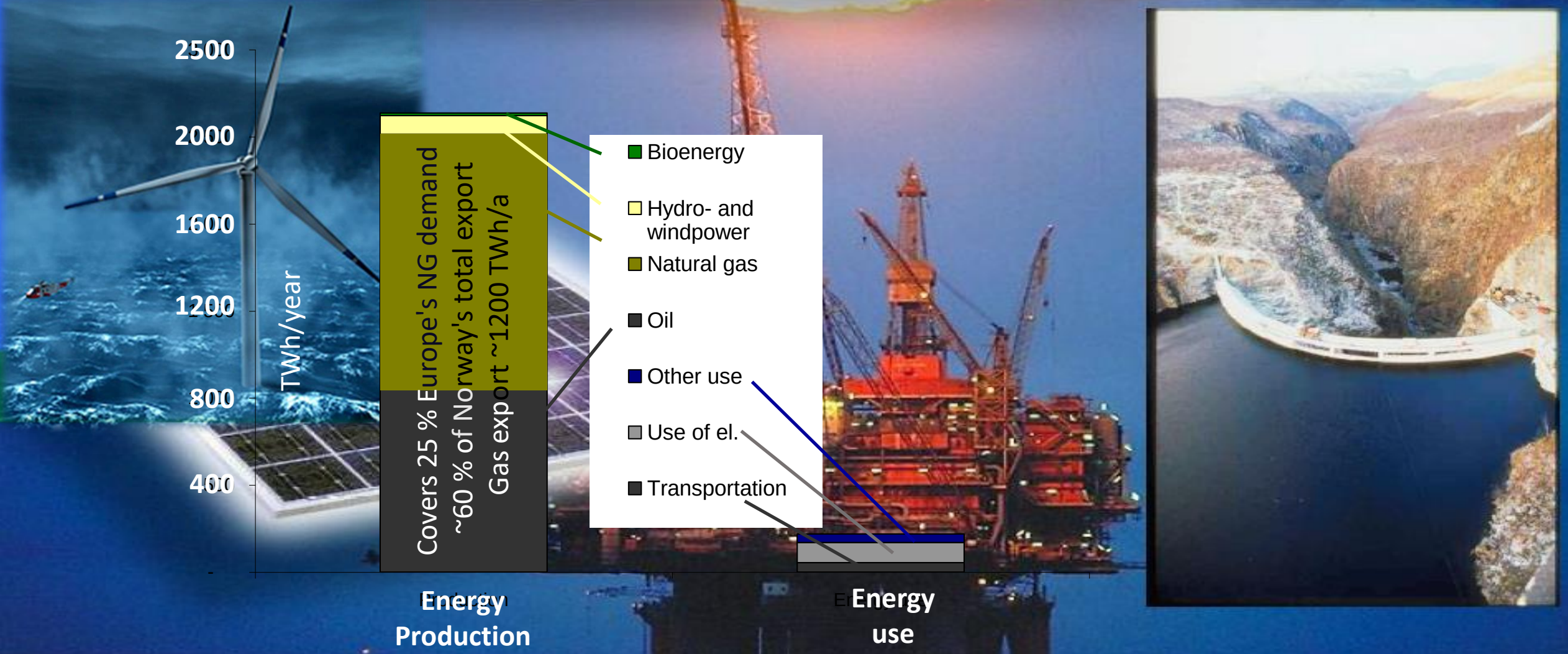
Frida Eklöf Monstad
Equinor

Morten Solberg Watle
GreenH

Liv-Elisif Kalland
Zero

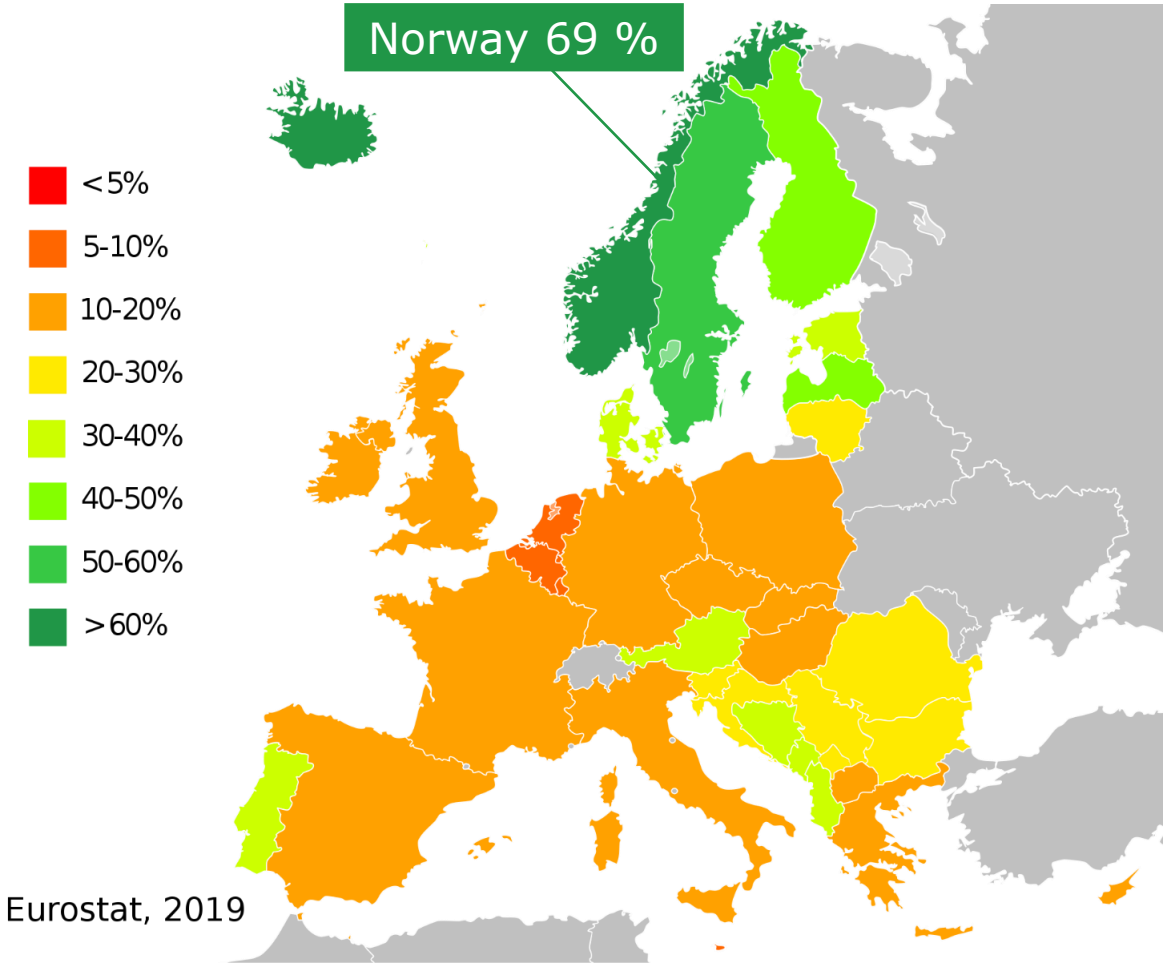
Johan E. Hustad
NTNU

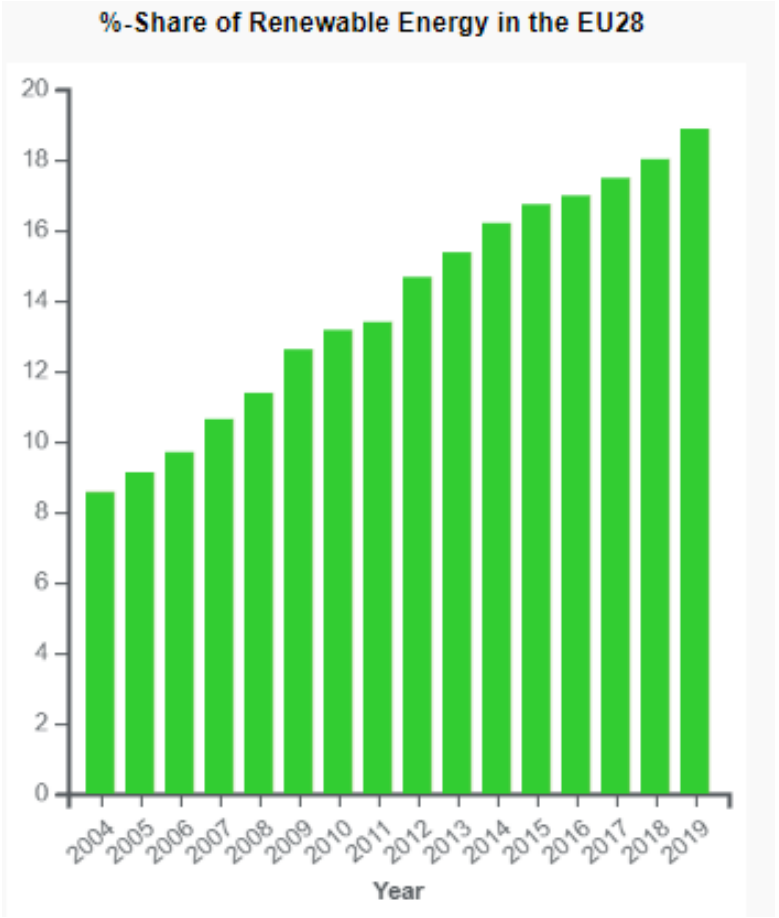
Norway - an energy nation.....



Courtesy: RCN

Renewables in energy consumption





Source: https://en.wikipedia.org/wiki/Renewable_energy_in_the_European_Union

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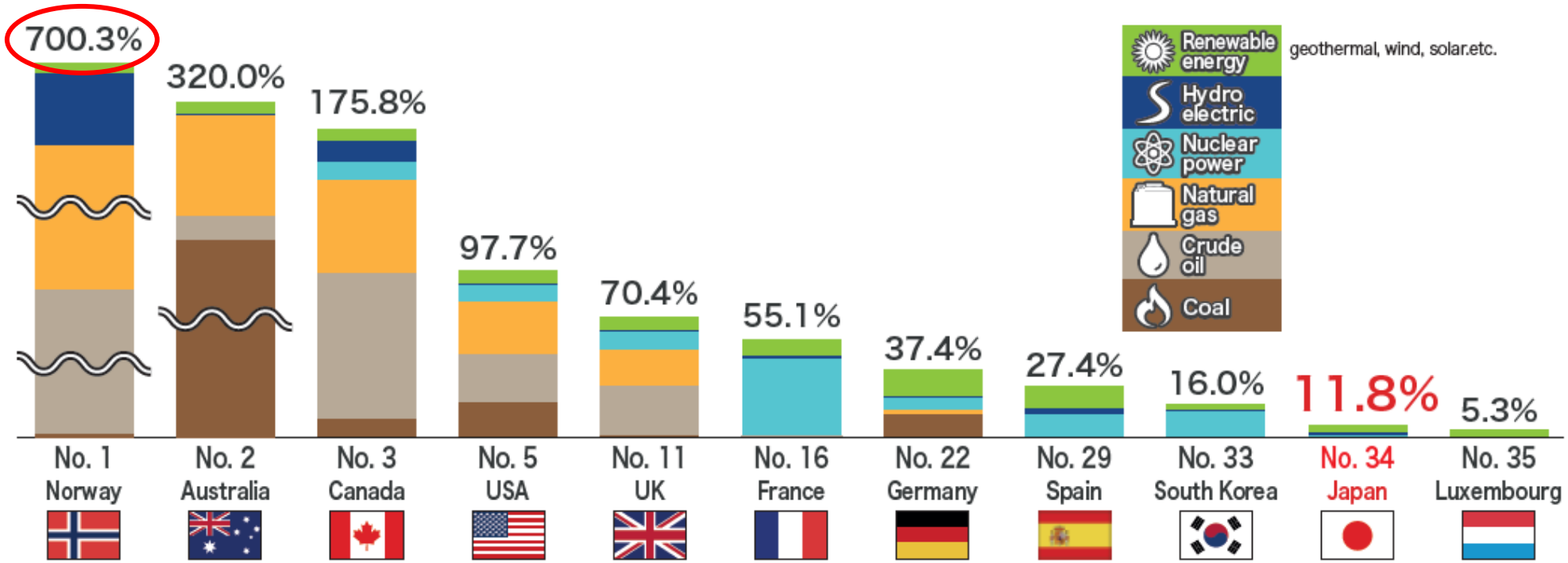
Primary Energy Self-Sufficiency Rate (2018)



Source: Estimates for 2018 from IEA "World Energy Balances 2019", except for data for Japan, which are confirmed values of FY 2018, derived from "Comprehensive energy statistics of Japan", Agency for Natural Resources and Energy. ∗ The ranks in the table are those of the 35 OECD member countries.

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Norwegian Prime Minister, Jonas Gahr Støre

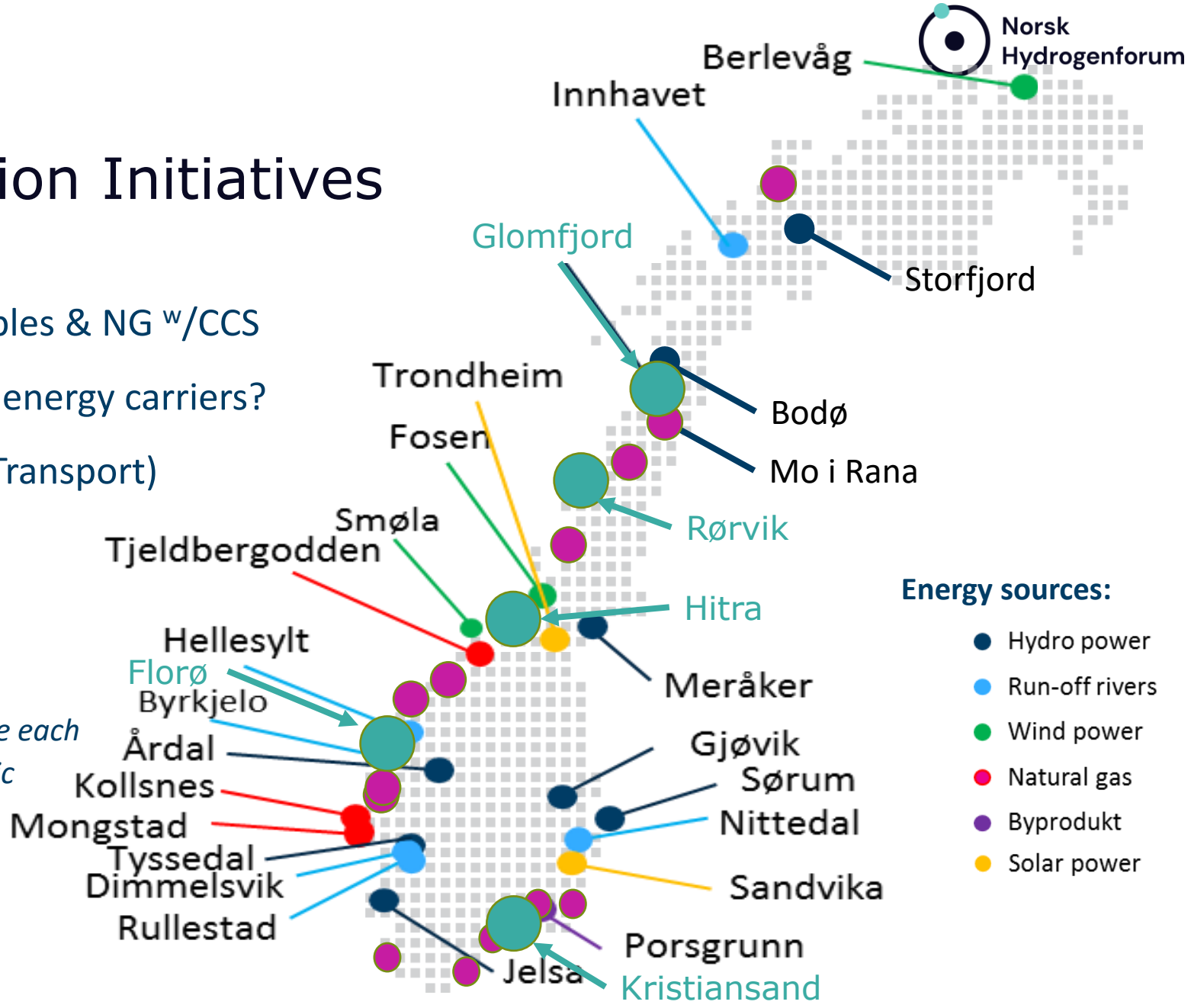
Norway will install 30 GW of offshore wind by 2040. With this ambition we go from the two offshore wind turbines that are in operation today to ~1500 offshore wind turbines.

Hydrogen Production Initiatives

- H_2 & NH_3 prod. from renewables & NG ^{w}/CCS
- Energy export of H_2 & NH_3 as energy carriers?
- H_2 & NH_3 as fuels (Maritime Transport)

- Hydrogen Hubs
  - *15 pre-studies financed Q3 2021*
  - *Five (5) full scale projects were each granted up to 15 M € each in public support yesterday (June 23rd)*

ENOVA



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H_2 and NH_3 as fuel for maritime transport, 7 ships funded

Key factors

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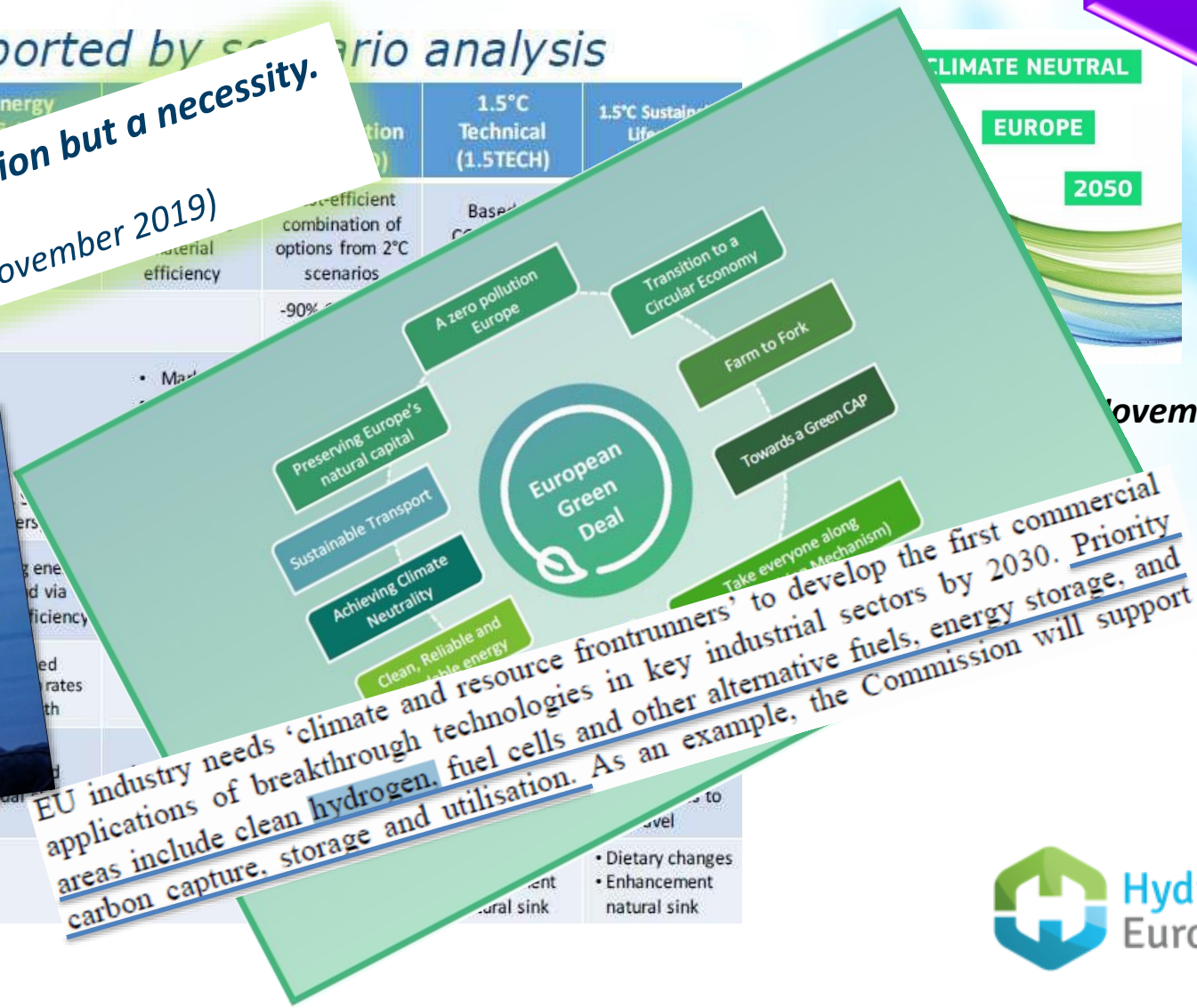
Climate Neutral Europe 2050, "*a key role for hydrogen*"

Strategies and Drivers

Detailed assessment supported by scenario analysis

	Electrification (ELEC)	Hydrogen (H2)	Power-to-X (P2X)	Energy	1.5°C Technical (1.5TECH)	1.5°C Sustain... Life...
Main Drivers	Electrification in all sectors	Hydrogen in indust...		...efficiency	...t-efficient combination of options from 2°C scenarios	Based...
GHG target in 20...					-90%...	
					• Mar...	
Tran...						
Othe...		H2 in gas distribution grid	E-gas in gas distribution grid			• Dietary changes • Enhancement natural sink

"The green energy transition is not an option but a necessity. I see a pivotal role for clean hydrogen.."
(Frans Timmermans, First Vice-President EC, November 2019)



...November 2018

EU industry needs 'climate and resource frontrunners' to develop the first commercial applications of breakthrough technologies in key industrial sectors by 2030. Priority areas include clean hydrogen, fuel cells and other alternative fuels, energy storage, and carbon capture, storage and utilisation. As an example, the Commission will support

Hydrogen Europe

Strategies and Drivers

Drivers, seen from Europe's perspective

- Europe imports fossil fuels valued at ~ 1 billion €/day
- Europe aims at increasing their primary energy self-sufficiency rate while strengthening competitiveness
- Hence EU's Energy and Climate Policies focus on:
  - Production of hydrogen from domestic available sources (=RES)
  - Stimulating Europe's industrial capacity and capabilities
- EU's Hydrogen strategy, targets (examples):
  - Focus on green hydrogen production (from renewable energy)
  - 6 GW electrolysis by 2024, 40 GW++ electrolysis by 2030

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Key factors

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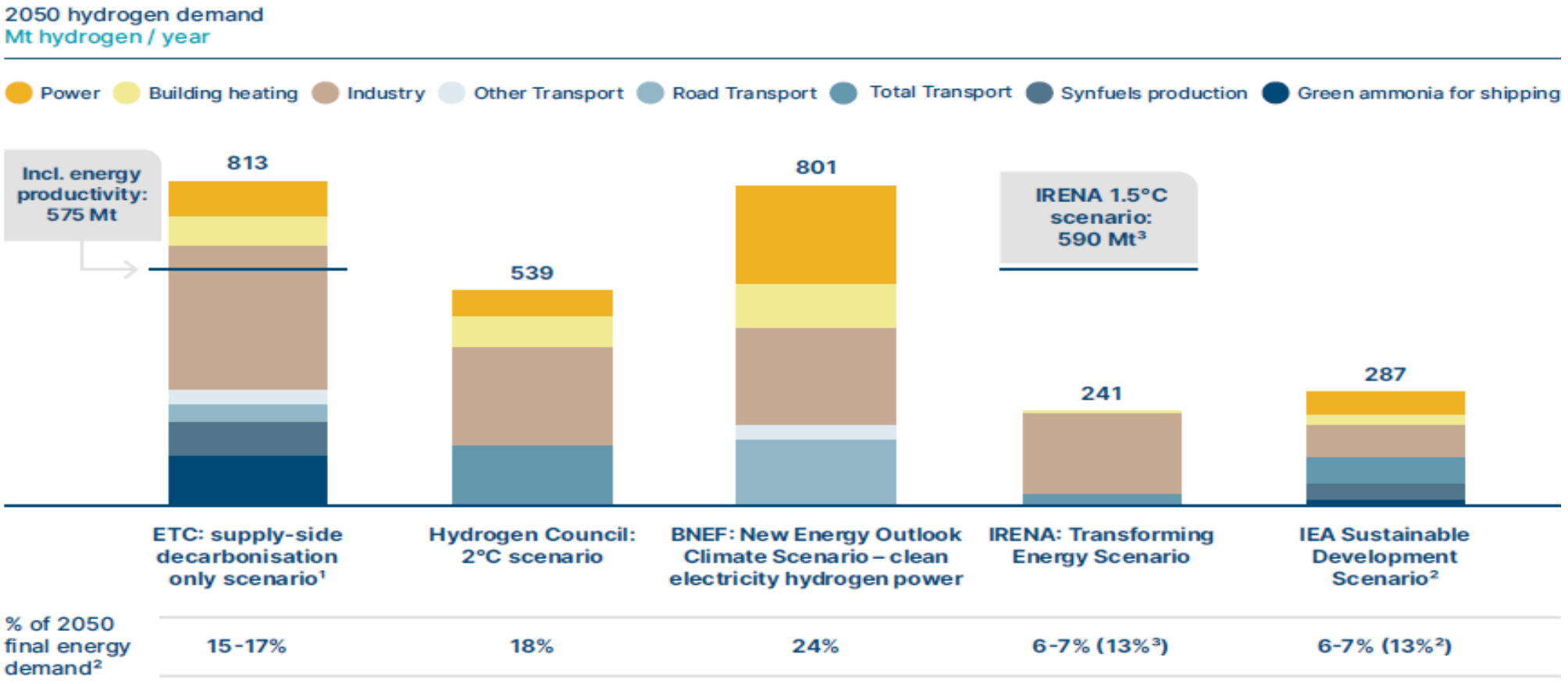
Future demand for H_2 globally

Demand for hydrogen



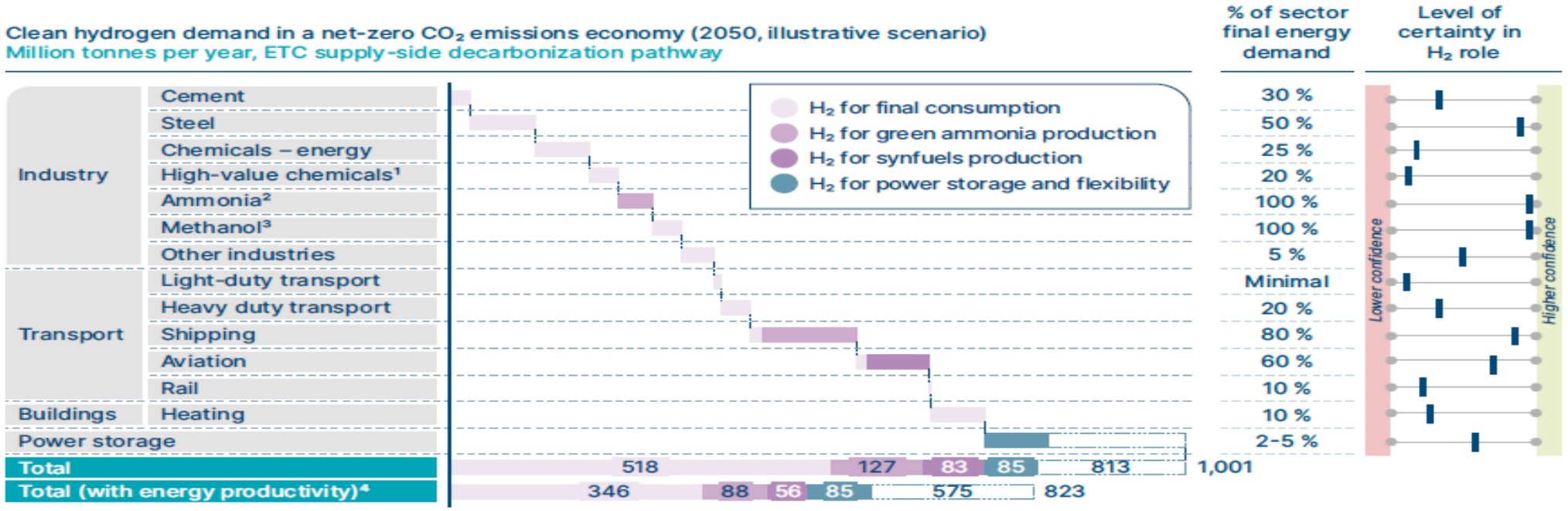
NOTES: ¹ Illustrative scenario considering 2050 final energy demand without application of energy productivity levers which would reduce energy needs in a net-zero scenario,
² Hydrogen reaches 13% of final energy demand by 2070 in IEA SDS, with hydrogen volumes of 520 Mt/year,
³ IRENA 1.5C scenario does not include split in uses, but represents 13% final energy demand.

Future demand for H_2 globally

Demand for hydrogen

Clean hydrogen will play a growing role across the economy as the world transitions towards net-zero

Clean hydrogen demand in a net-zero CO_2 emissions economy (2050, illustrative scenario)
Million tonnes per year, ETC supply-side decarbonization pathway



Level of confidence in role of H_2 in a net-zero CO_2 emissions economy

Lower — Multiple decarbonisation routes available, eventual role of hydrogen likely to vary by region depending on local costs and availabilities

Higher — Hydrogen based routes likely to play a significant decarbonisation role due to, e.g. limits to alternative routes, likely cost evolution, industry actions

Exhibit 1.4

NOTES: ¹ High value chemicals predominantly used to produce plastics, which could potentially be produced via Hydrogen and CO_2 in the future (via methanol and MTO process); ² Around 80 % of ammonia (excl. shipping) is used to produce fertilisers; ³ Methanol is used as intermediate in numerous chemical processes, including plastics production. ⁴ ETC scenario including maximum energy productivity improvements.

SOURCE: SYSTEMIQ analysis for the Energy Transitions Commission (2021)

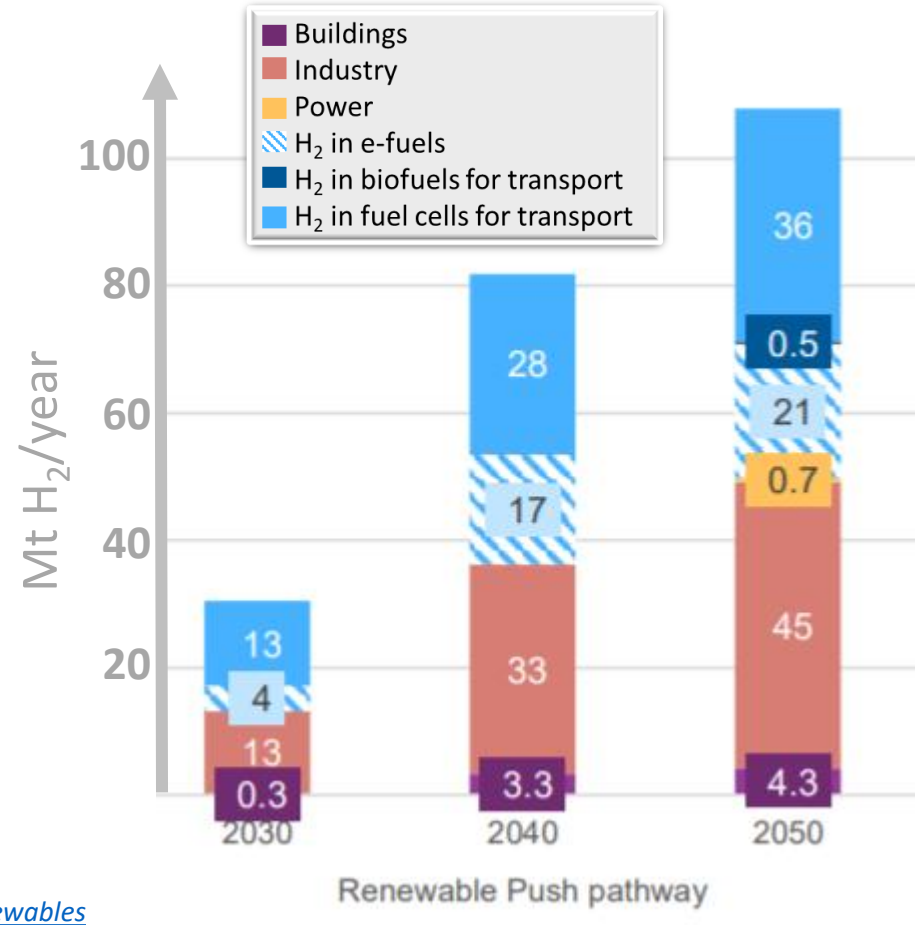
Future demand for H_2 in Europe

Demand for hydrogen

- H_2 production today in Europe ~ 10 Mt/a [1]
- Majority of H_2 produced from fossil resources
- Significant increase in all scenarios towards 2050
- High variations in volume & major application areas

<u>One likely scenario [2]:</u>

- European demand increase to 30 Mt/a in 2030 [2]
- 'Hard-to-abate' sectors - ***transport and industry*** - make up the vast majority of hydrogen demand
- Synthetic fuels are foreseen to play a major role
- Hydrogen also contributes to a smaller degree to decarbonization in buildings and power generation



Sources:

1) **Green hydrogen in Europe** – *A regional assessment: Substituting existing production with electrolysis powered by renewables*

2) Hydrogen4EU – Charting Pathways to Net Zero, *Hydrogen4EU study*, *2021*

Key factors

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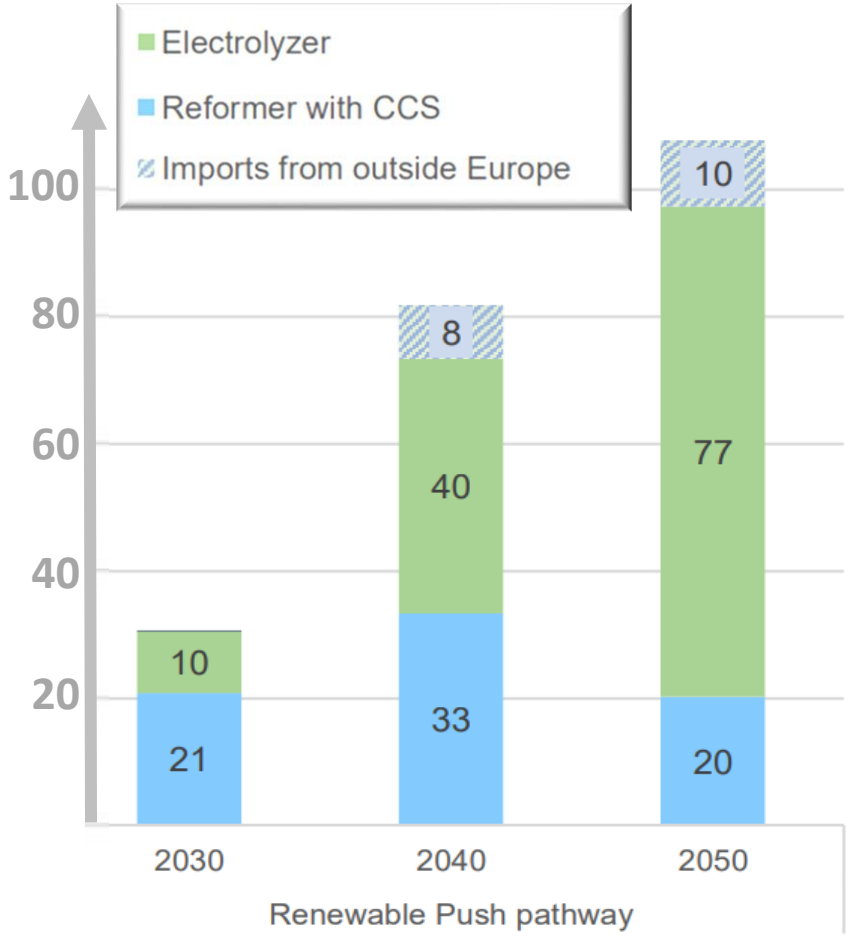
Future supply of H_2 in Europe

Supply & Distribution Options

- Europe is aiming at complying to IPPC's 1,5°C scenario → by increasing the ambitions for GHG emissions 2030
- The targeted 40 GW electrolysis to be supplemented by import of another 40 GW green hydrogen from southern & eastern neighbours (e.g., Ukraine or Morocco)) in 2030
- Dramatic increase in green H_2 → 2050
- *"Blue hydrogen will be needed"*, says EU-comm. Kadri Simson
- **Window of opportunity for blue H_2 from Norway to Europe?**



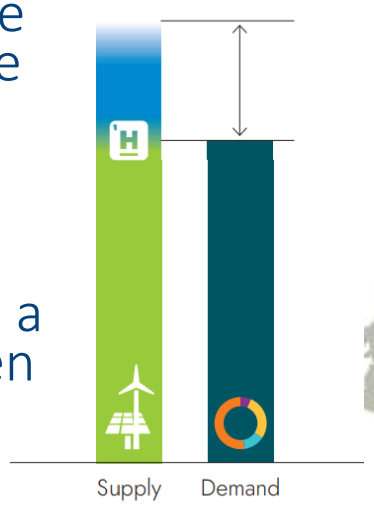
Sources:

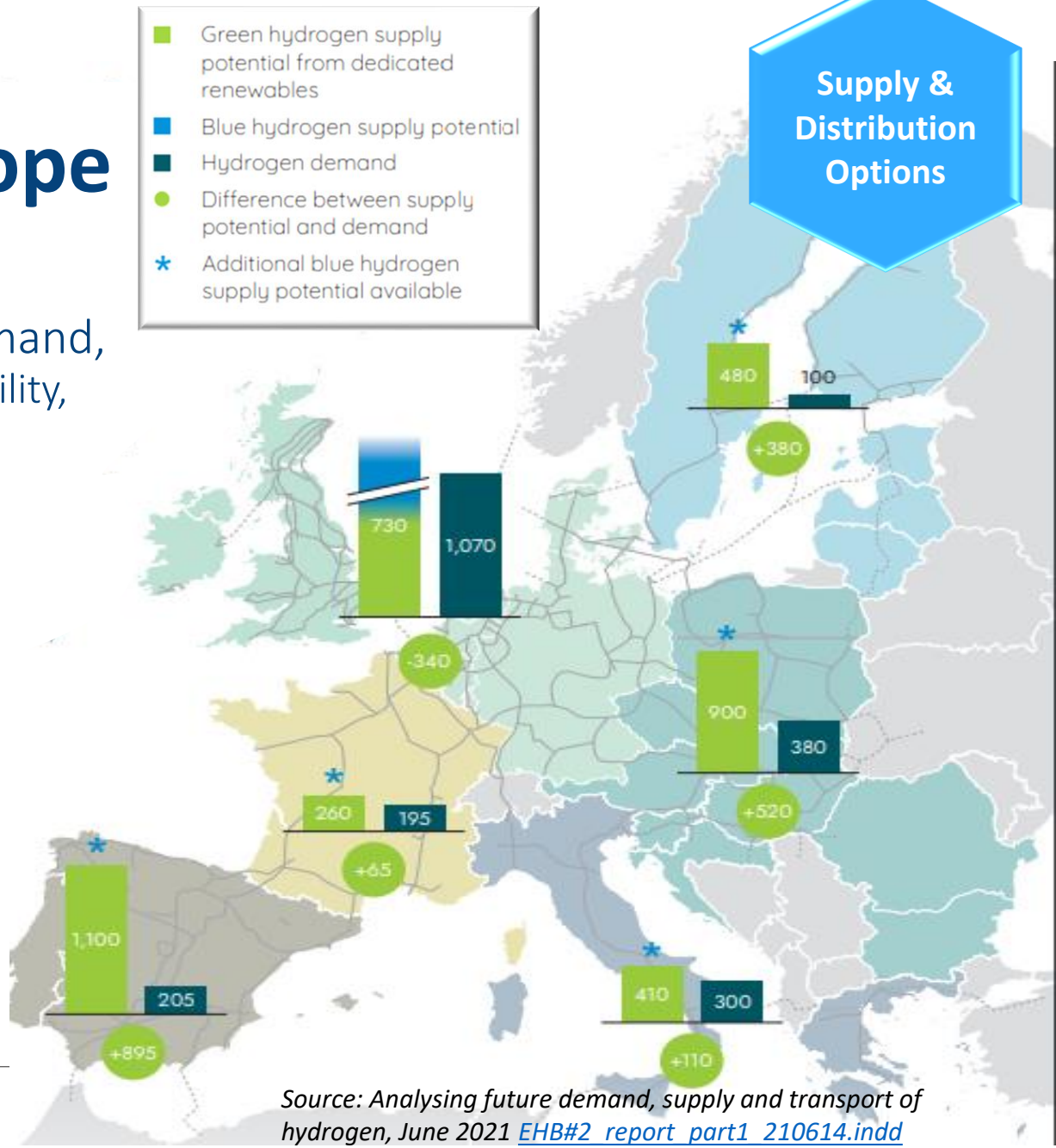
1) Hydrogen4EU – Charting Pathways to Net Zero, *Hydrogen4EU study*, *2021*

Potential for H_2 production in Europe

- Domestic EU + UK supply potential exceeds demand,
  - considering needs of electricity market, land availability, environmental regulations, installation rates

  Dedicated renewables for H_2-production:
  - 2030: 9 Mt (460 TWh)
  - 2040: 40 Mt (2100 TWh)
  - 2050: 80 Mt (4000 TWh)
- Favourable economics of pipeline transport allows cost competitive imports from North Africa, **Norway** and Ukraine
- Blue H_2 as *"quick start"*
- European wide use of H_2 require a distribution network for hydrogen



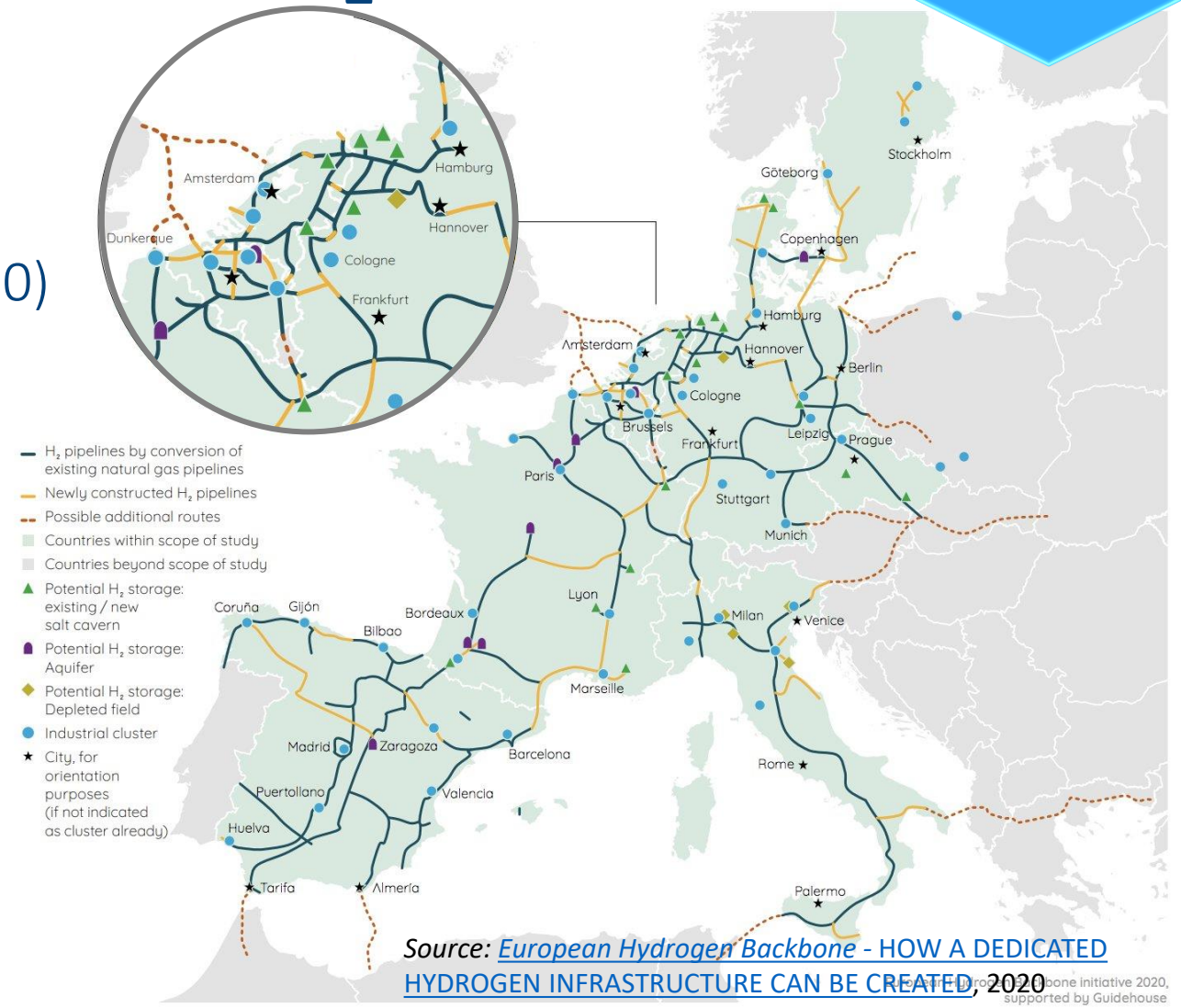


Source: Analysing future demand, supply and transport of hydrogen, June 2021 EHB#2_report_part1_210614.indd

Preparing for a European H_2-network

Supply & Distribution Options

- Low cost distribution of large volumes
- Initial pipeline network of 6,800km (2030) maturing into a European Hydrogen Backbone in 2040 totalling 23,000km
- Additional H_2 import routes indicated
- Is Ammonia a viable alternative for long distance transport?

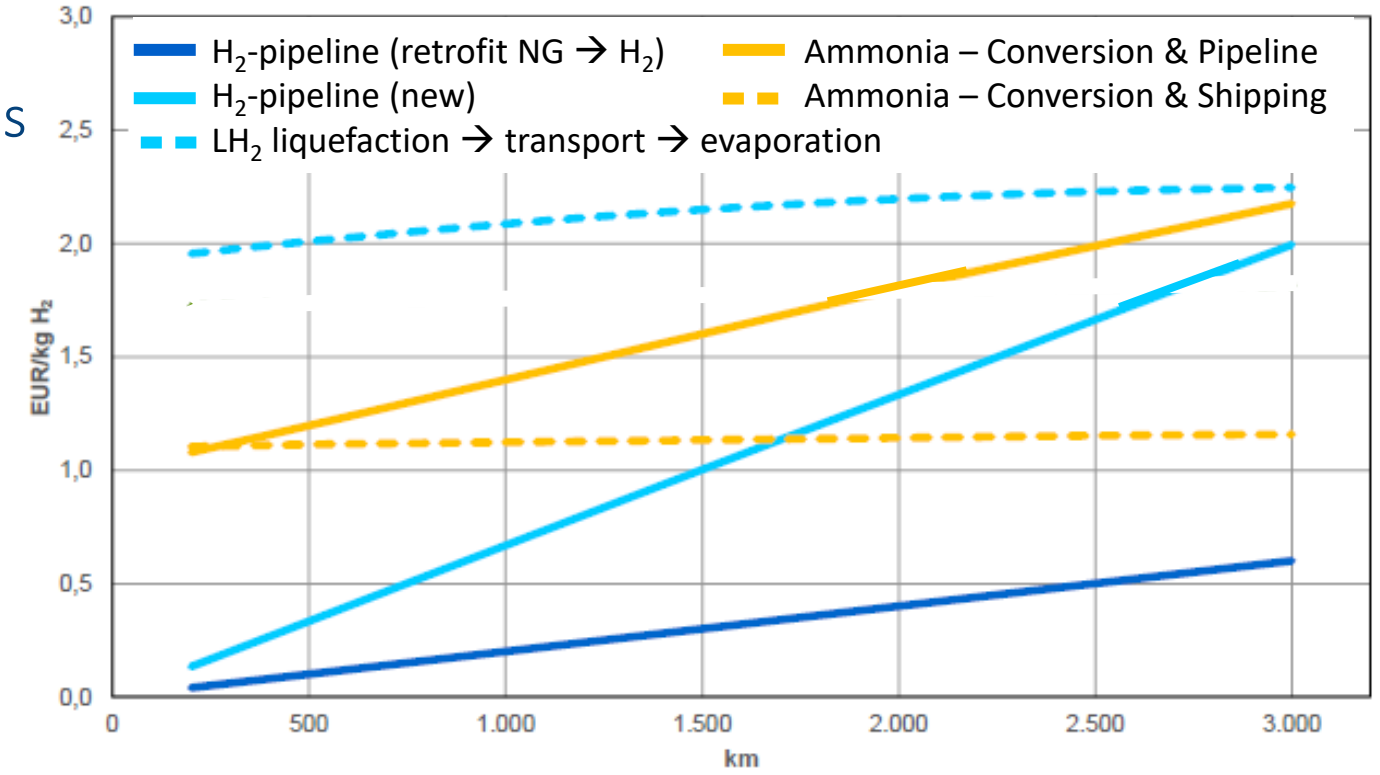


Source: European Hydrogen Backbone - HOW A DEDICATED HYDROGEN INFRASTRUCTURE CAN BE CREATED, 2020

Transport cost for H_2 carriers vs. distance

Supply & Distribution Options

- Retrofitting existing NG-pipelines far cheaper than building new ones
- Conversion to LH_2 very costly
- NH_3-ships cheaper than pipeline

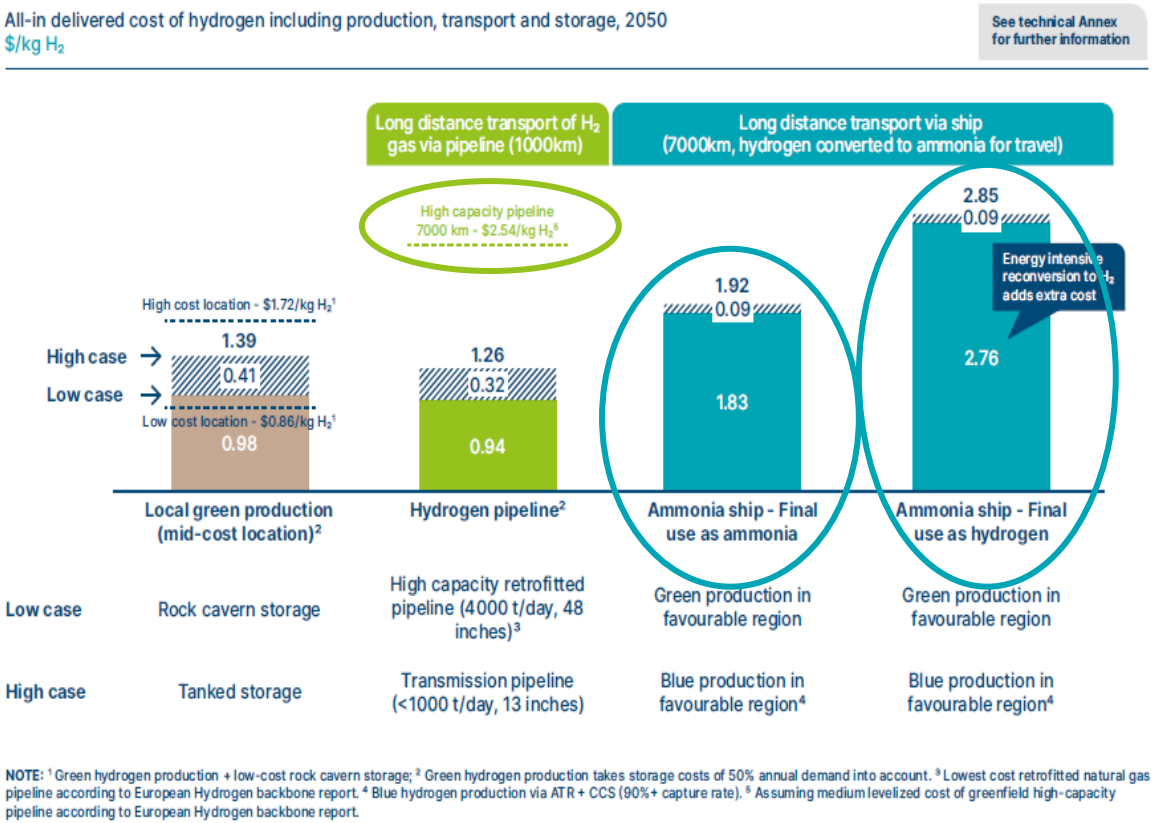


Sources:
1) https://www.oeko.de/fileadmin/oekodoc/Wasserstoff-und-wasserstoffbasierte-Brennstoffe.pdf

Transport cost for H_2 carriers vs. distance

Supply & Distribution Options

- Retrofitting existing NG-pipelines far cheaper than building new ones
- Conversion to LH_2 very costly
- NH_3-ships cheaper than pipeline
- Pipeline H_2 transport (even 7000km) is cheaper than shipping of NH_3, when end use is H_2 (i.e., incl. NH_3 cracking),
- Locally produced green hydrogen (left) competitive in 2050 time frame.



Sources:
1) https://www.oeko.de/fileadmin/oekodoc/Wasserstoff-und-wasserstoffbasierte-Brennstoffe.pdf
2) BloombergNEF (2019), the Economics of Transport & Delivery, Guidehouse (2020), European Hydrogen Backbone, Industry interviews

Key factors

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Green hydrogen, cost developments

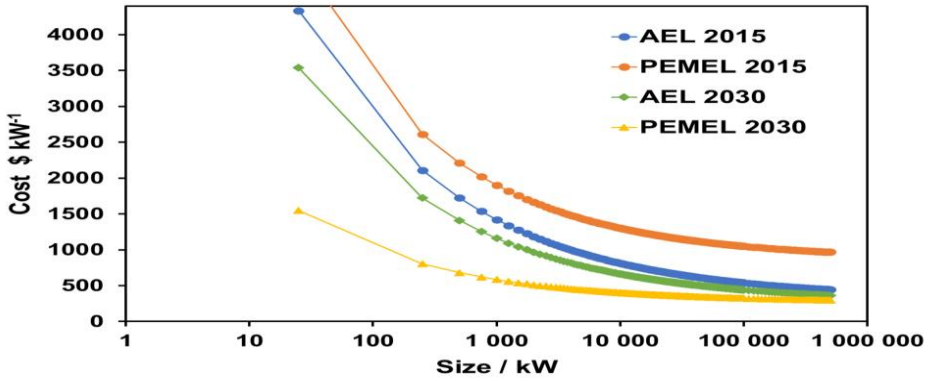
Cost and Volume

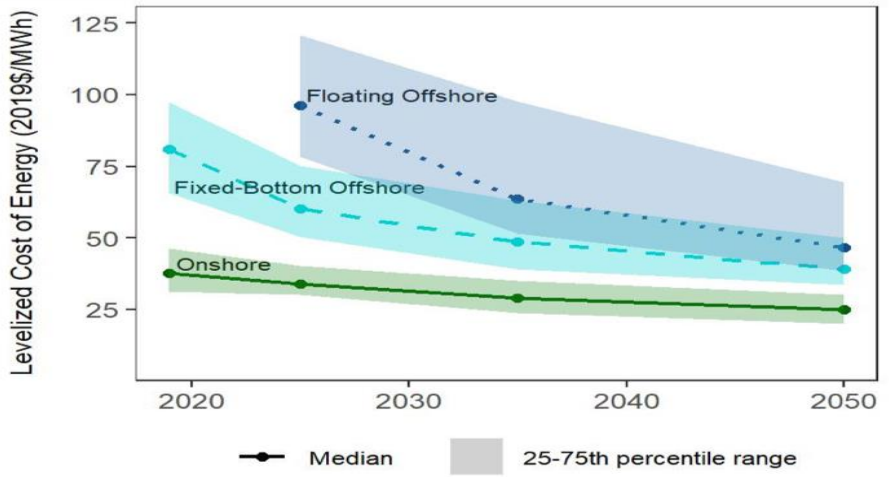
Investment cost for PEMEL (dynamic) electrolysers

- Expected to fall dramatically towards 2030 [1)]
  - Due to increased volume and automated production
- Modular technology → smaller WE plants cost effective
- Green hydrogen cost significantly influenced by power cost

Renewable energy cost

- Cost projected to fall significantly towards 2050 [2)]
- Possibly competitive with fossil energy from 2030 →





Sources:

1) SINTEF-study, publication submitted to Journal of Hydrogen Energy

2) Berkley Lab

Green vs. Blue hydrogen

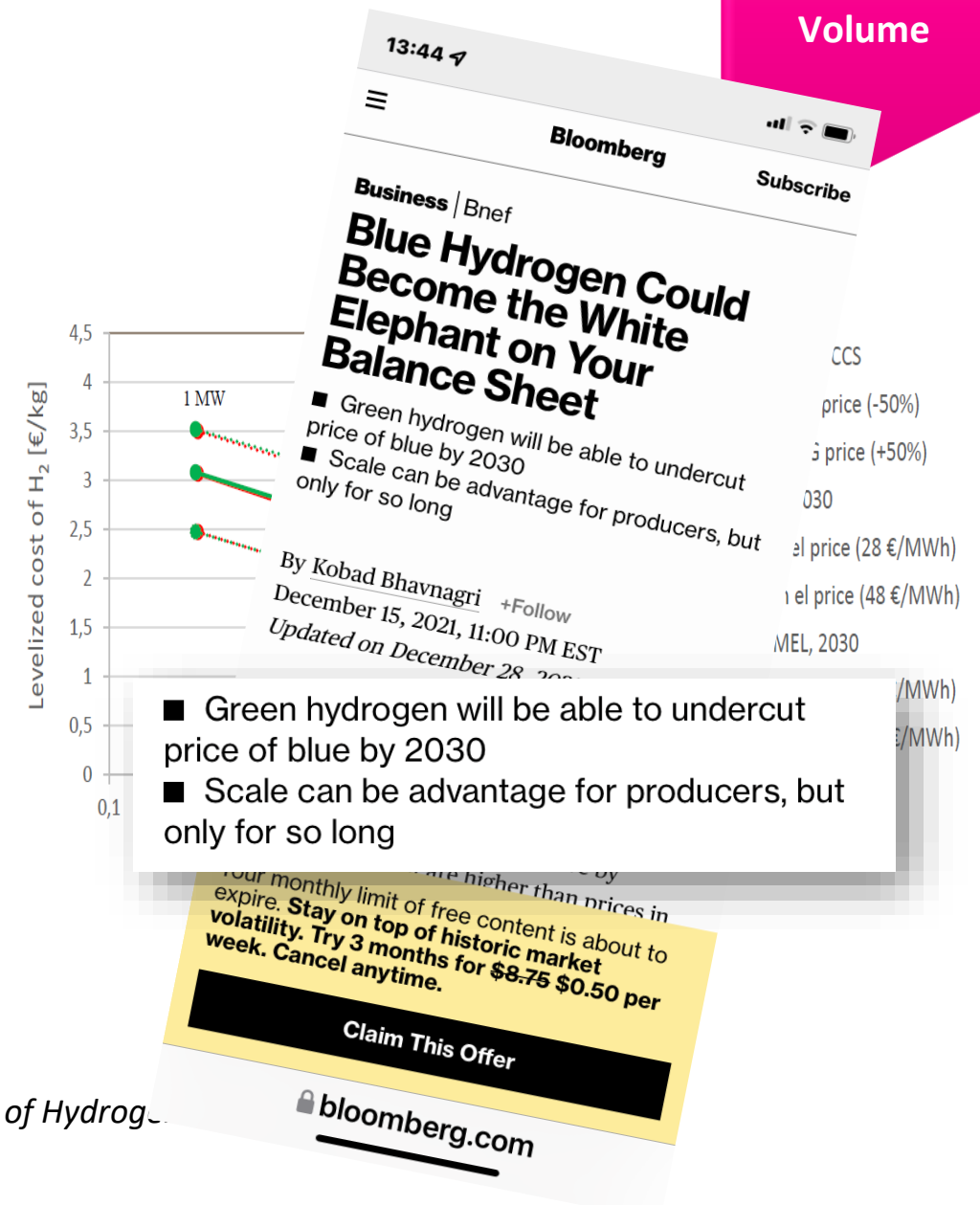
Cost and Volume

Blue hydrogen

- Low(er) cost at high volumes
- High dependence on natural gas price
- High initial investments, require long term depreciation

Green hydrogen

- Local/regional production stepwise following demand
- High(er) focus on green hydrogen in most European MS
- Uncertainties related to requirement on Additionality



Sources:

1) SINTEF-study, publication submitted to Journal of Hydrog

Initiatives for green hydrogen production

Cost and Volume

- Northern Horizons:
  Floating wind to hydrogen,
  ➔ net zero refinery (Shetland),
  conversion to LH_2, NH_3, e-fuels

Similar initiatives/projects

- AquaVentus (Germany)
- NortH2 (Netherlands)

Aker world-record 10GW floating wind-to-hydrogen plan 'to turn Scotland into green energy exporter'

Illustration: Aker

Initiatives for green hydrogen production

Cost and Volume

- Northern Horizons:
  Floating wind to hydrogen,
  ➔ net zero refinery (Shetland),
  conversion to LH_2, NH_3, e-fuels

Similar initiatives/projects

- AquaVentus (Germany)
- NortH2 (Netherlands)

Europe's largest today: 10 MW ➔

- Funding given to Refhyne II: 100 MW

REFHYNE
CLEAN REFINERY HYDROGEN FOR EUROPE

REFHYNE 2
CLEAN REFINERY HYDROGEN FOR EUROPE

SINTEF

elementenergy sphera ITM POWER Energy Storage | Clean Fuel

Key factors

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Safety and Regulations

Regulatory Framework

Clean Hydrogen Partnership

Financial and funding framework

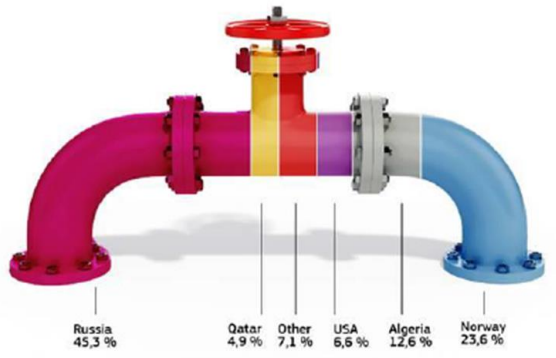
- Clean Hydrogen Partnership (2021-2027), EC funding 1 B€, launched Q4 2021
- IPCEI, ETS Innovation Fund, Tax exemptions and incentives

Standards and Technical approvals

- EN 17339, TPED and CEN standards, Pre-Normative Research → new regulatory requirements

Operational/Market regulatory framework

- Hydrogen and Decarbonized Gas Market Package
- Taxonomy, RED II Delegated Act, Additionality, RePowerEU
- CO_2 boarder tax under discussion to prevent Carbon leakages



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REPower EU - Boosting the use of hydrogen

Safety and Regulations

Hydrogen Accelerator

- An additional 15 million tonnes (mt) of renewable hydrogen on top of the 5,6 mt foreseen under the Fit for 55 can replace 25-50 bcm per year of imported Russian gas by 2030.
  - Of this additional 10 mt can be imported hydrogen
  - While 5 mt of additional hydrogen produced in Europe*
  - New cross border gas infrastructure should be hydrogen compatible
  - Commission will support pilot projects on renewable hydrogen production and transport in the EU neighbourhood, starting with a Mediterranean Green Hydrogen Partnership.

** Ambition is going beyond the targets 5,6 mt of the EU's hydrogen strategy in FIT for 55*

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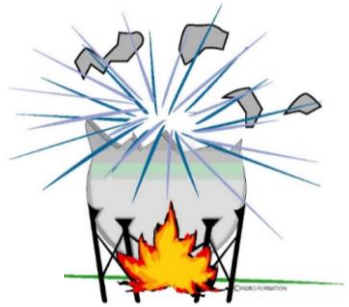
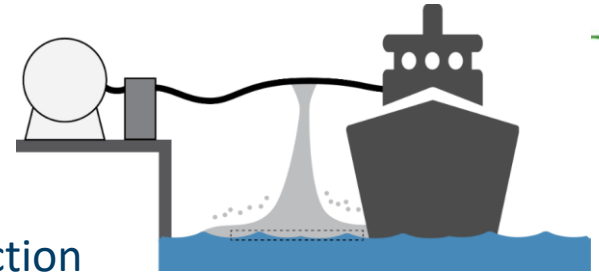
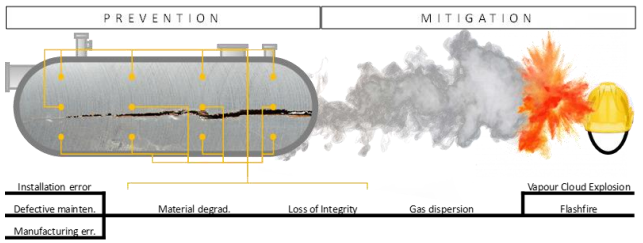
Hydrogen safety SH2IFT

Safety and Regulations

- SH_2IFT 1 (2018-2021)
  - Hydrogen jet fires
  - LH_2 BLEVE (Boiling liquid expanding vapor explosion) & RPT (Rapid Phase Transition) (tests in Sept 2021)
  - Modelling activities on both gaseous and liquid hydrogen
- SH_2IFT 2 (2021-2024)
  - Gaseous & Cryogenic jet fires with and without Passive Fire Protection
  - Ventilation experiments (also with ammonia)
  - Further on modelling and risk analysis
  - Material degradation – integrity







With funding from The Research Council of Norway

Key factors

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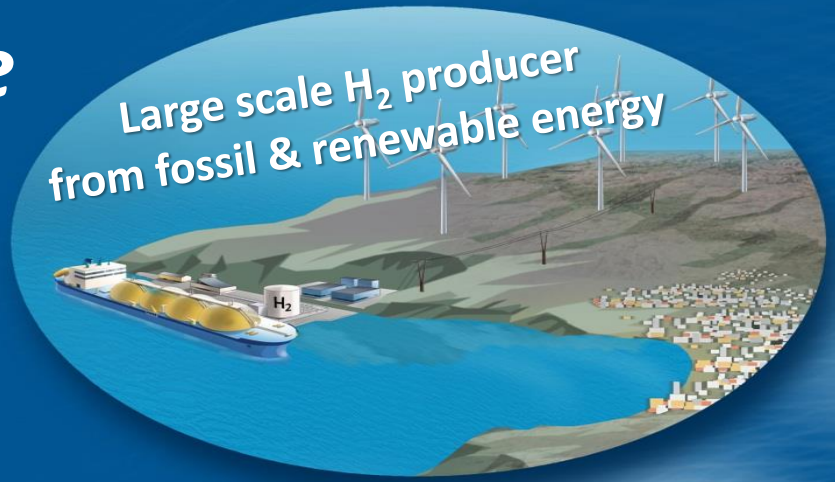
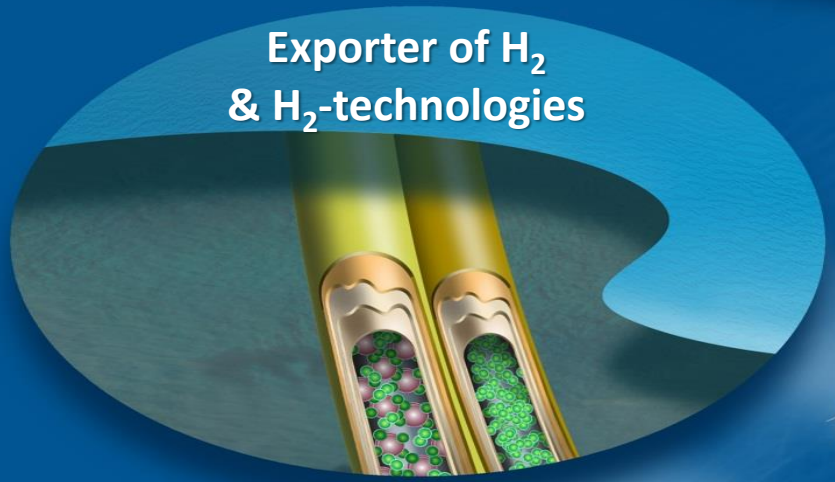
Areas where Norway can play a key role internationally within hydrogen





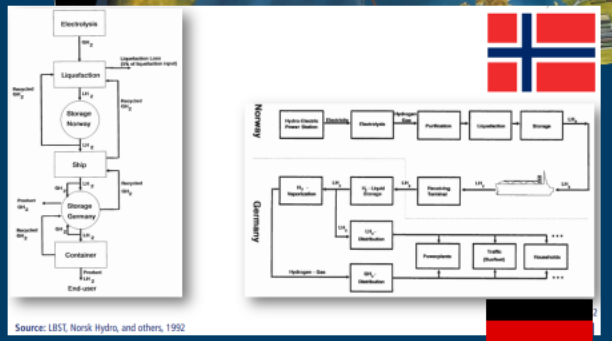
Global Market → 2050

SINTEF *Technology for a better society*

Global H_2 market evaluations

Global Market → 2050

- **Import of energy/H_2 from Africa 1988**
- **The EQHHPP 1989 → 1992**
  Euro-Quebec hydro-hydrogen pilot project
- Norwegian Hydro Energy in Germany (NHEG) Norsk Hydro, and others, 1992
- World Energy Net, Japan 1995 →



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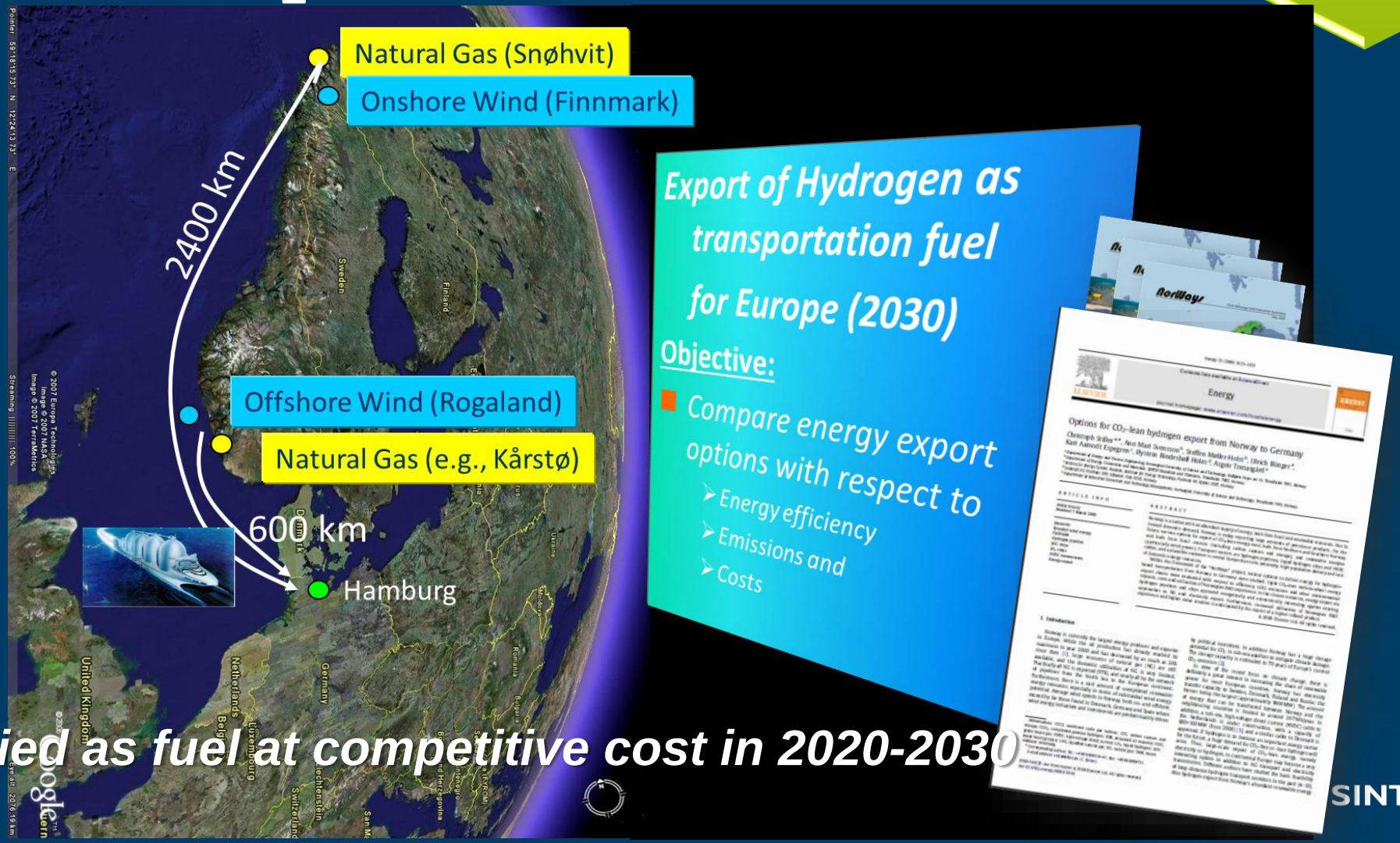
Energy export, H_2 as fuel for transport

Global Market → 2050

Relevant study on hydrogen export to Europe (2008):

norWays



Conclusion:

H_2 may be supplied as fuel at competitive cost in 2020-2030

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Global market under development

Global Market → 2050

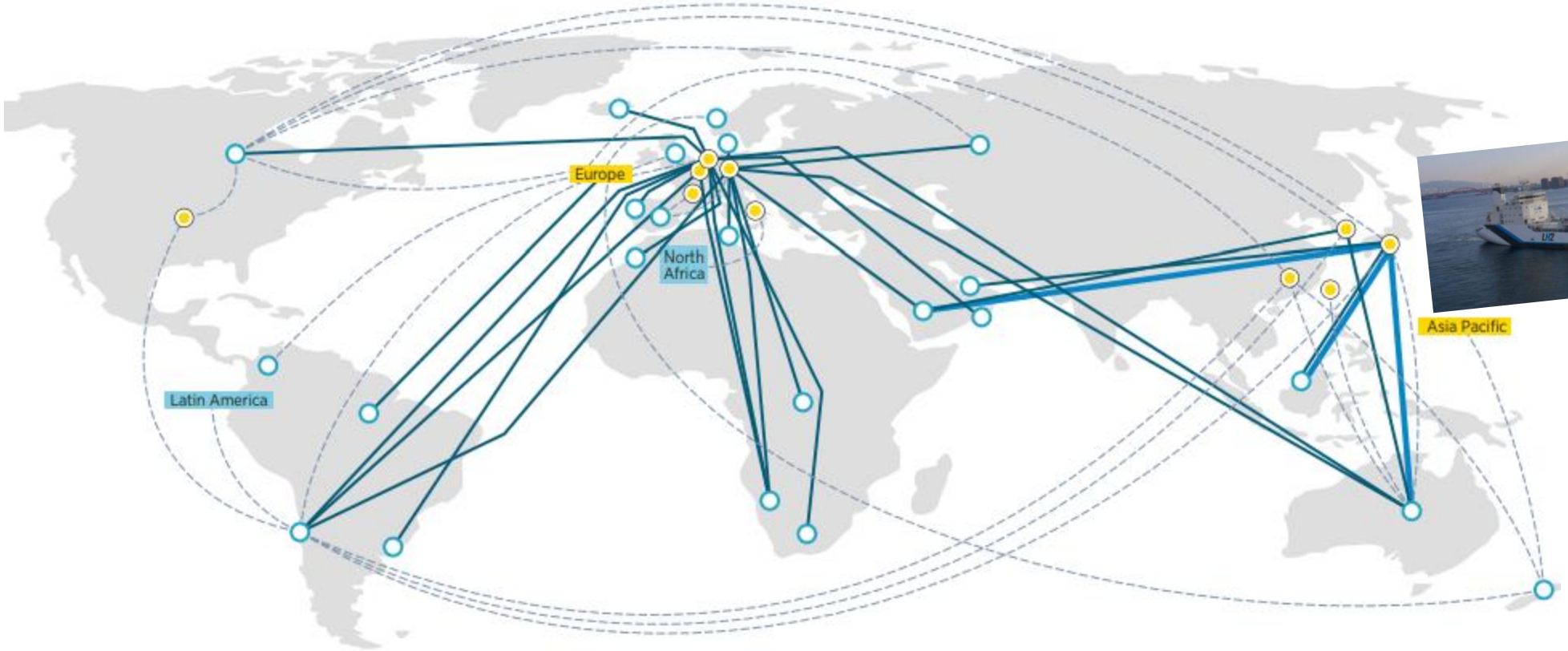
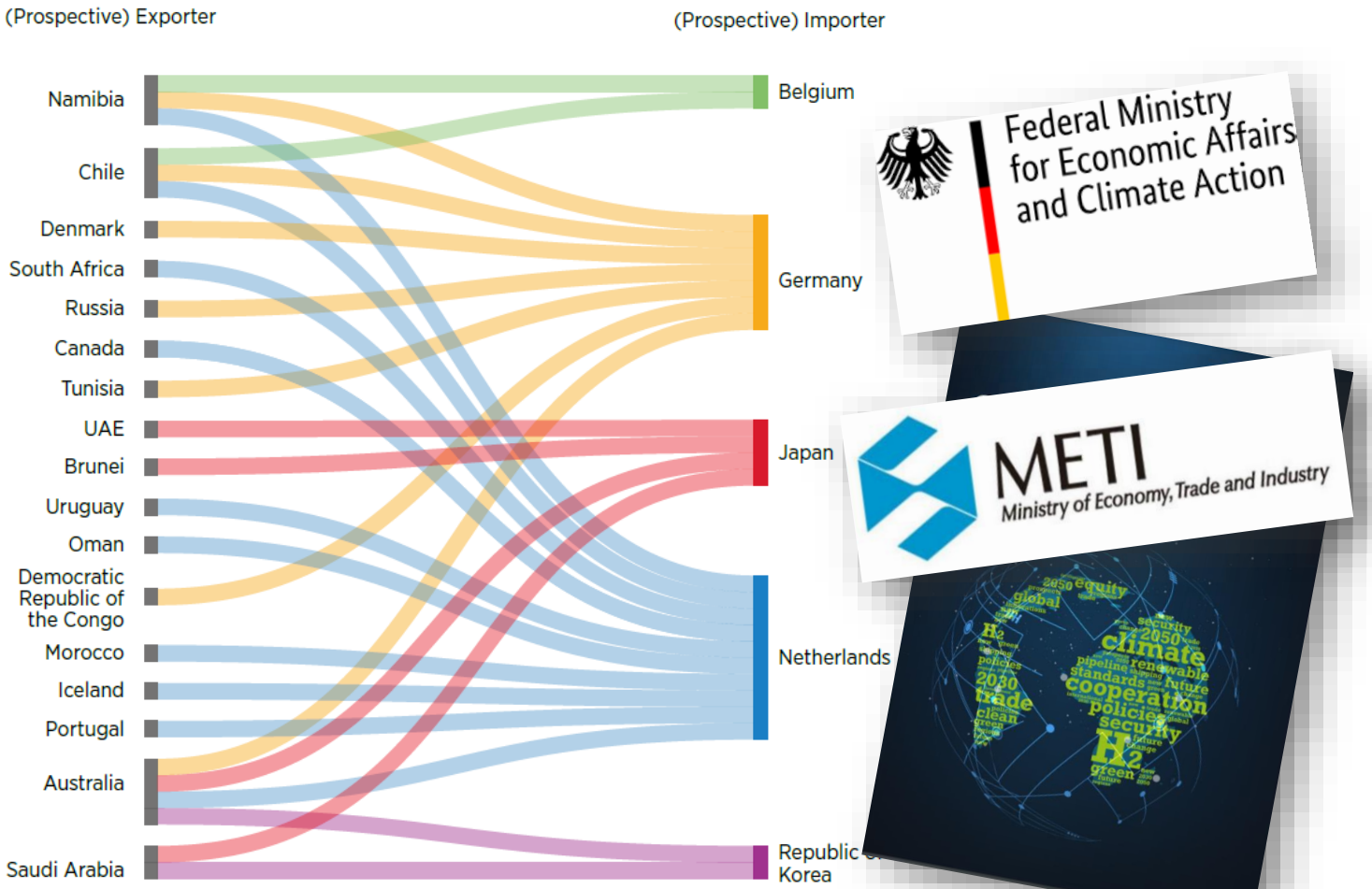


Photo: HySTRA

Global market guided by alliances

Global Market → 2050

- Many nations are establishing trade agreements & MoUs
- This is showing contours of future trading routes of H_2 as a global commodity
- Is the Norwegian governmental structure well suited for the green energy transition?
- Norwegian industry has European customers to CO_2-storage
- Additional proposition Q2 2022 to white paper *"Energi til Arbeid"*



Global Market → 2050

Norwegian Minister of Trade, Jan Christian Vestre

"The Government is now mapping the Norwegian coastal shelf and is discussing establishing hydrogen pipelines to Germany»

Summary and Conclusions

- High and increasing focus on hydrogen as key for decarbonizing the energy system
- European drivers: Increased Primary energy self- sufficiency rate & Competitiveness
- Clearly expressed preference for domestically produced green hydrogen in Europe
- Ambitious Climate targets and high H_2-damand in EU leaves door open for H_2 import
- High interest and strong global competition from several potential H_2-suppliers
- Norway's export potential closely linked to conversion of NG-resources → Blue H_2
- Low cost pipeline transport of H_2 in retrofitted NG-pipelines is Norway's *"gold card"*
- Inherent investment risk in high cost CO_2-storage facilities weigh heavily on Norway

Technology for a better society