Green Hydrogen in the Global Energy System Transformation

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1. Nationales Wirtschaftsforum Wasserstoff

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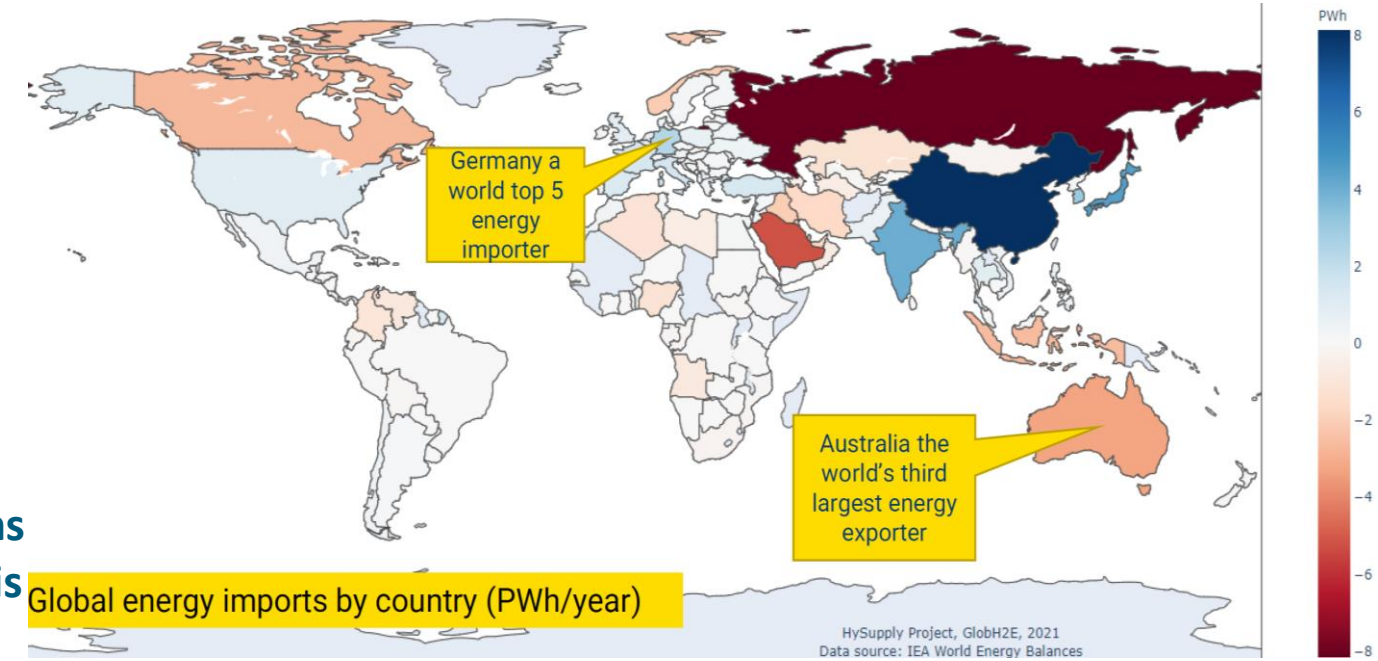
www.ise.fraunhofer.de

The Paradigm Shifts

The Needs for Climate Change and Energy Security

- **Global commitment to the defossilization of the global energy system**
- **»Net-Zero Emissions Race« with Nationally Determined Contributions** (NDCs)
  as a cornerstone of the Paris Agreement:
- Over 100 states in **»Net-Zero Emissions Race«**
  - in law
  - proposed legislation
  - in policy document
  - target under discussion
- **IPCC 4 April 2022:**
  “Without immediate and deep emissions reductions across all sectors, limiting global warming to 1.5°C is beyond reach.”

- **Energy Security and Technology Sovereignity**



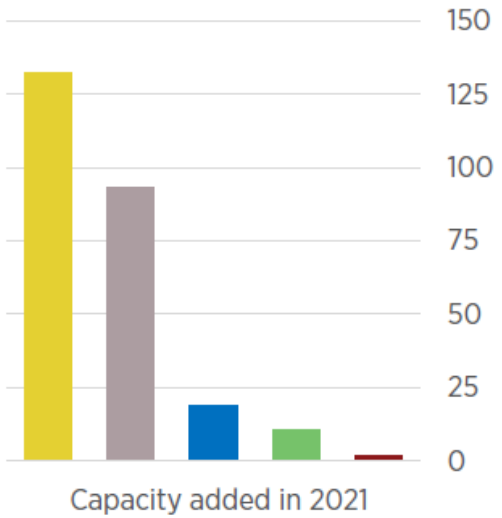
The Backbone of the Future Energy System: Renewable Energy

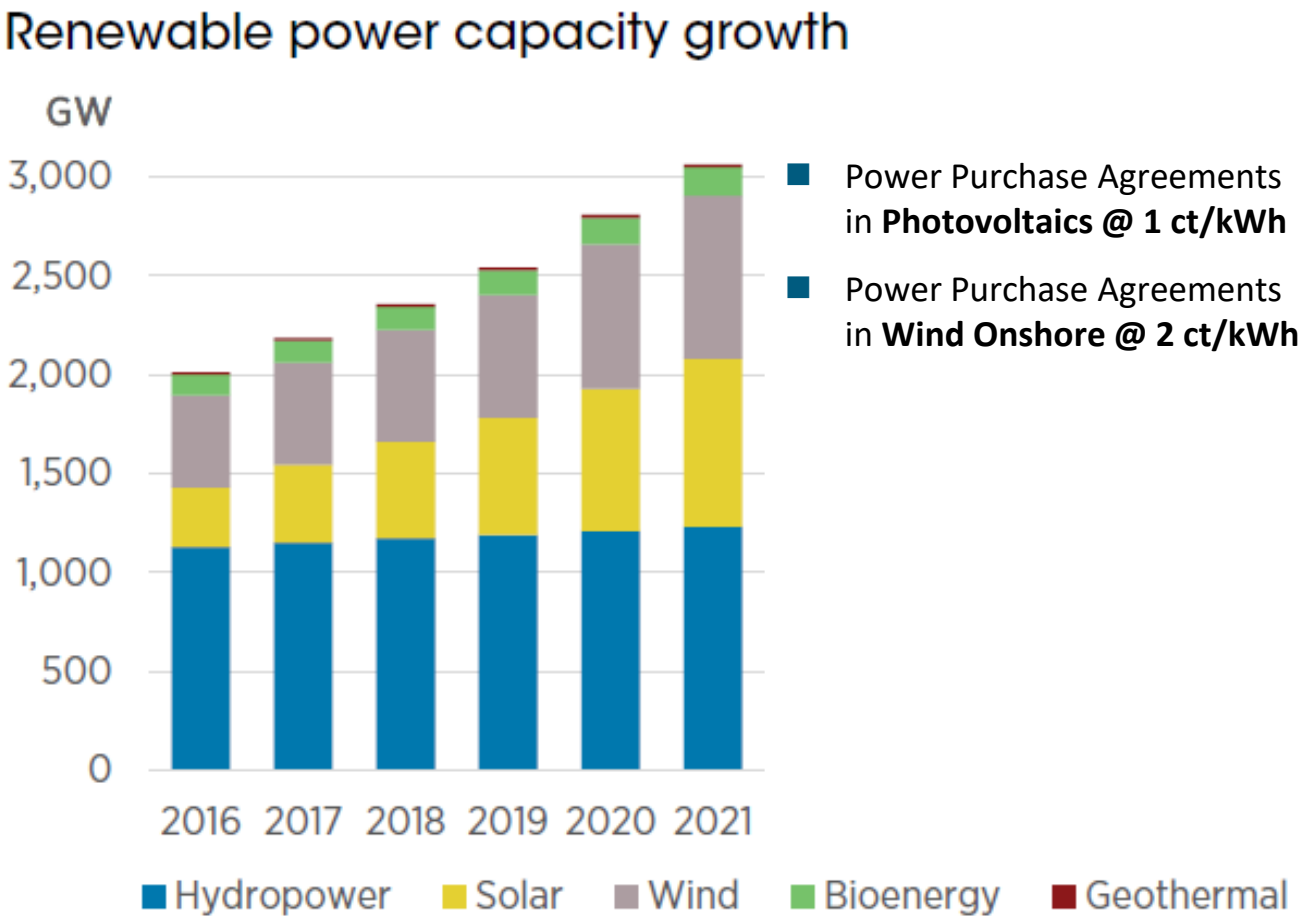
Global Wind and Photovoltaic Installations at 1.5 TW Total Capacity

3064 GW Global Renewable Capacity

- 849 GW Wind
- 825 GW Photovoltaics
- 524 GW Hydro
- 143 GW Bioenergy

- **257 GW new renewable capacity (2021)**





Source: IRENA, 2020, http://resourceirena.irena.org/gateway/dashboard/

IRENA International Renewable Energy Agency

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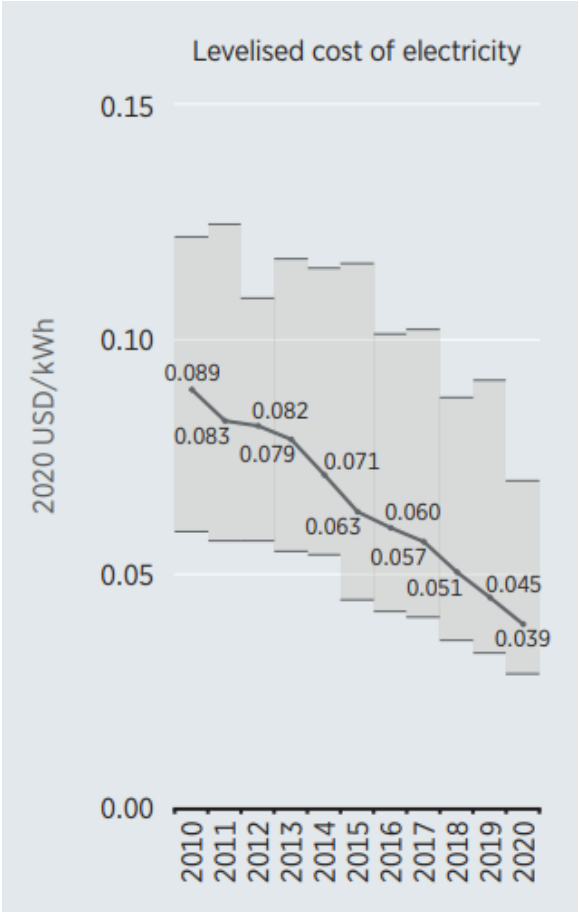
Levelized Cost of Electricity by Wind and Photovoltaics from 2010 to 2020

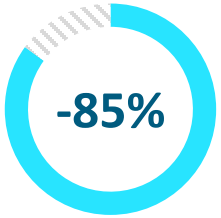
Onshore Wind

Between 2010 and 2020,the global weighted-average LCOE for offshore wind fell 56%, **from USD 0.089/kWh to USD 0.039/kWh.**



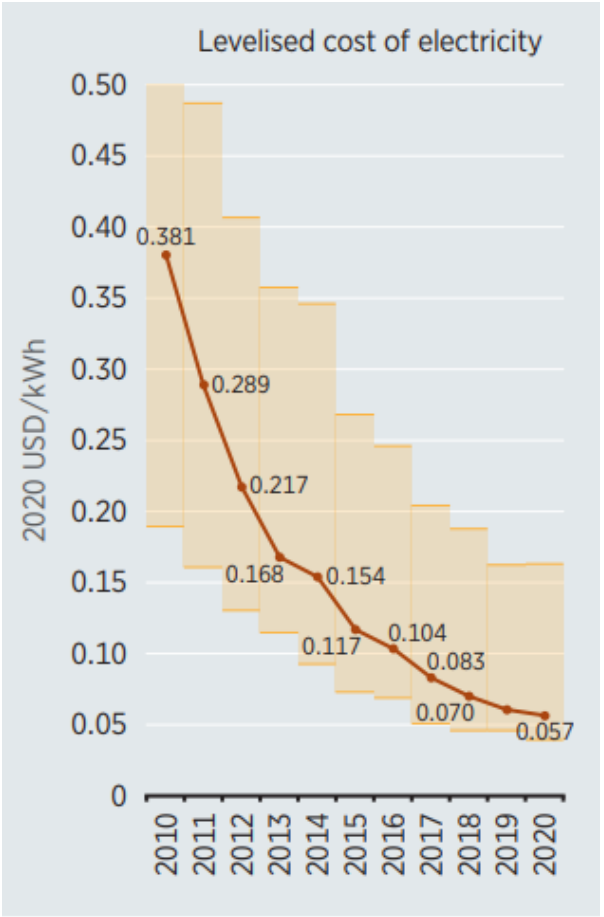
Global weighted-average LCOE for onshore wind, 2010-2020

Source: IRENA Renewable Cost Database



PV

Between 2010 and 2020,the global weighted-average LCOE for PV fell 85%, **from USD 0.381/kWh to USD 0.057/kWh.**

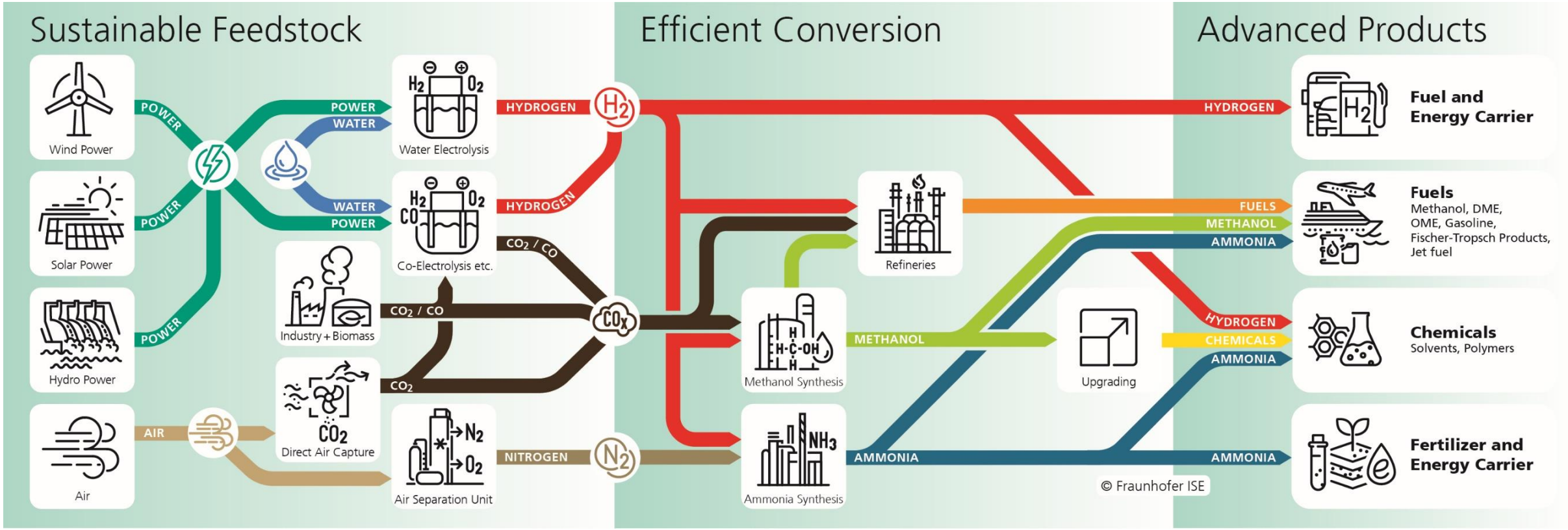


Global weighted-average LCOE for PV, 2010-2020

Source: IRENA Renewable Cost Database

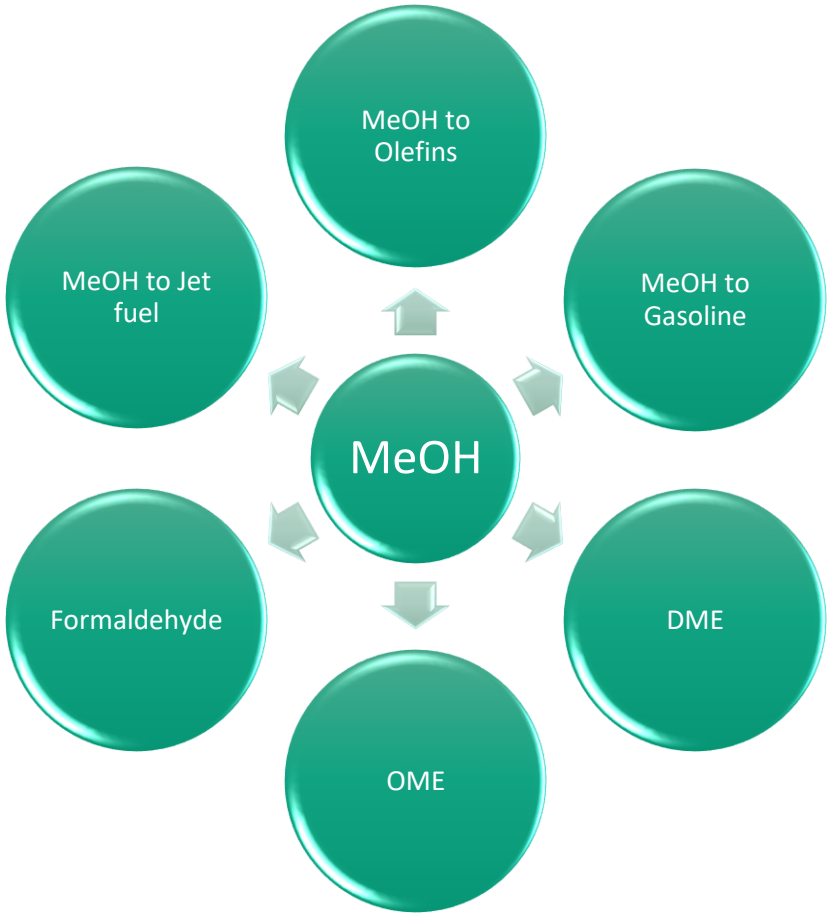
Sustainable Energy Carriers, Fuels and Base Molecules

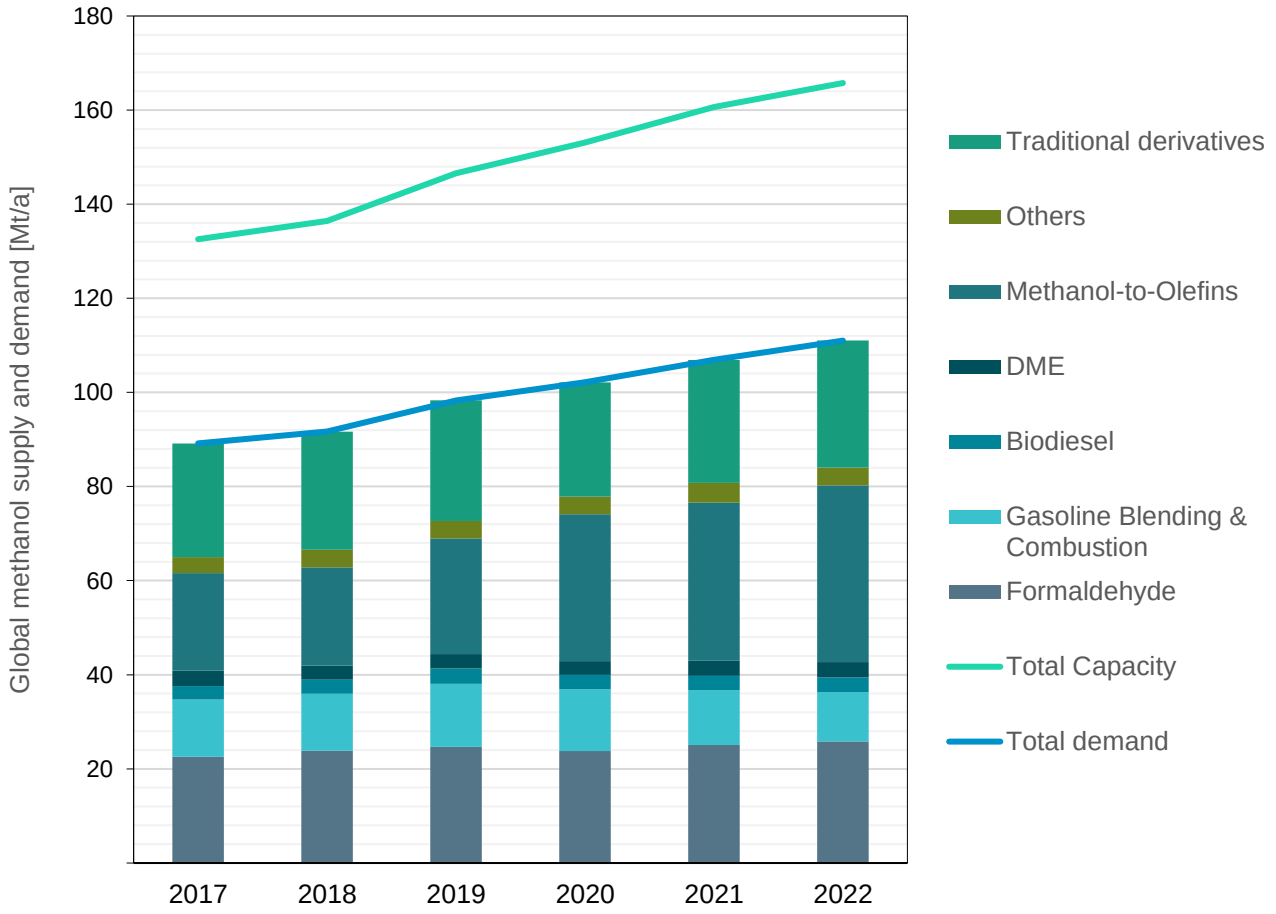
The Promise: Power-to-X - H_2-based Molecules for Mobility, Industry & Chemistry



Promising Perspective for Methanol

Methanol as Feedstock for Chemical Industry and for all Modes of Transport (Otto & Diesel Engines)





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Methanol and Ammonia as Preferred Shipping Fuels

Maersk – Worlds Largest Integrated Logistics Company

Methanol and NH_3 will play an important role:

- Maersk Sustainability Report 2020:
  »Continued research on priority future fuels (biodiesel, methanol, ligning fuels and ammonia) confirming that net-zero technologies are available.
  Maersk will not use transition fuels (such as LNG) but leapfrog to fully net-zero fuels.«

- LNG as short-term solution; danger of stranded assets

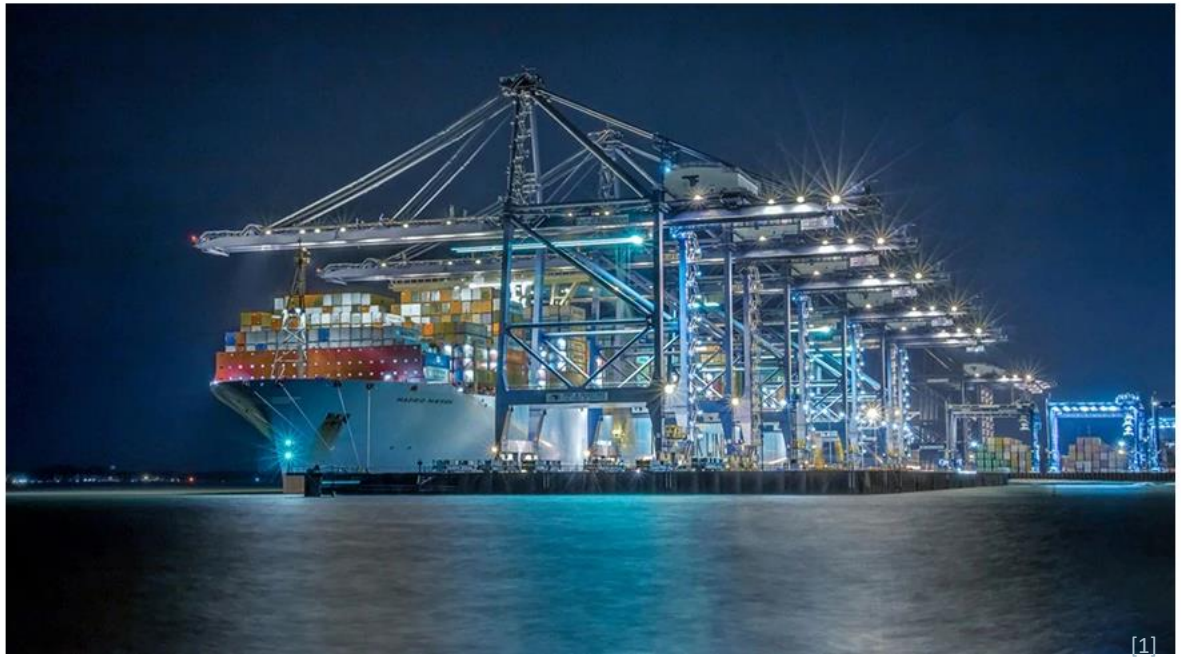
- »… our first carbon neutral vessel on the water by 2023 …
  This vessel will be running on carbon neutral methanol … We consider green ammonia as a promising option for marine fuels and a dual fuel engine for ammonia is under development.«

Maersk backs plan to build Europe's largest green ammonia facility

23 February 2021

Sustainability

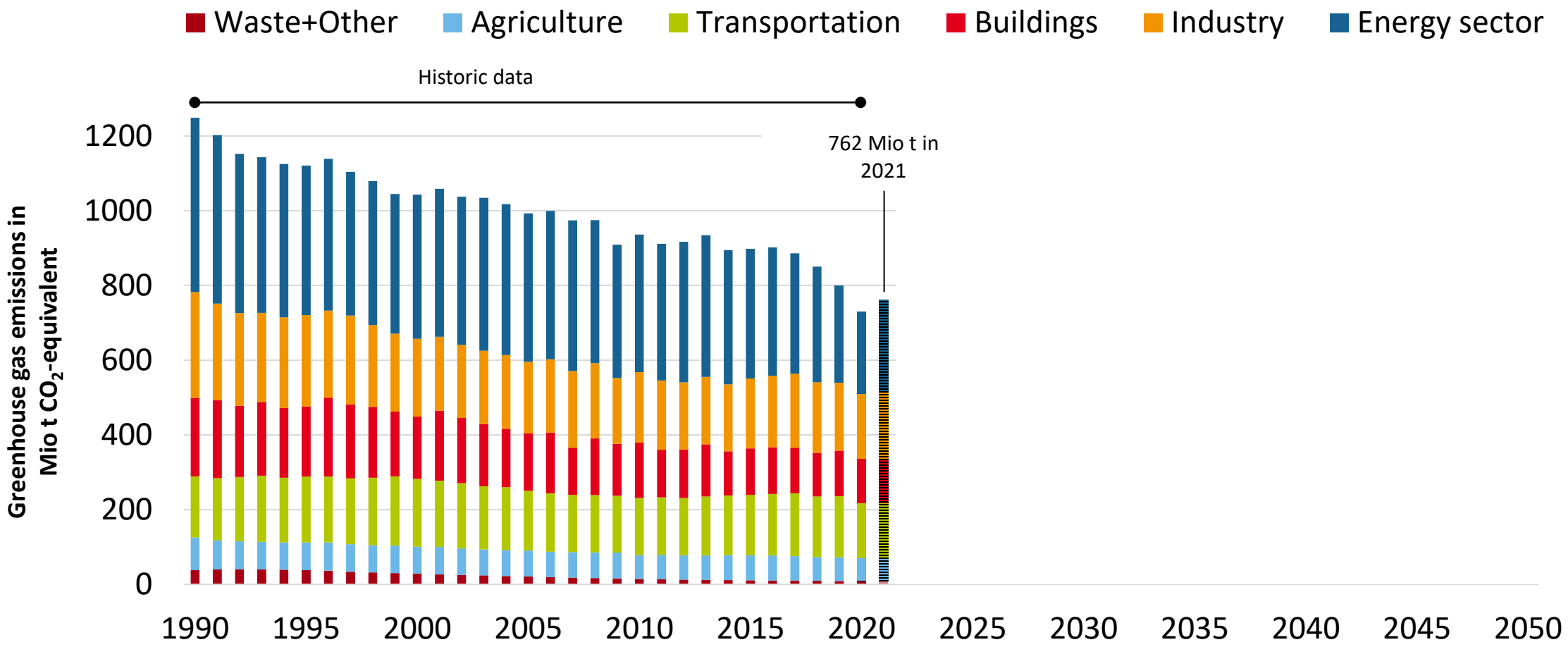
Share



[1]

[1] https://www.maersk.com/news/articles/2021/02/23/maersk-backs-plan-to-build-europe-largest-green-ammonia-facility Maersk – leading container shipping company

Greenhouse Gas Emissions of Germany: History



Historic data and estimate of emissions data for the previous year 2021, German Environment Agency, 15.3.2022

Political Agenda of the Energy System Transformation in Germany

Legal Base of the Energy System Transformation in Germany

Targets of the European Green Deal

- Reducing the Net-Emissions to zero in the EU until 2050
- Fit for 55” legislative package
- Being the first climate-neutral continent in the world

Targets of German Climate Protection Law (est. 01.08.2021)

- Reducing the Greenhouse Gas Emissions at least 65% by 2030
- Climate Neutrality until 2045

For the first time agreed upon by law

- National and european climate targets
- Annual control and obligation of readjustment
- CO_2-targets for all sectors (mobility, buildings, …)
- Climate neutrality of the Federal Administration

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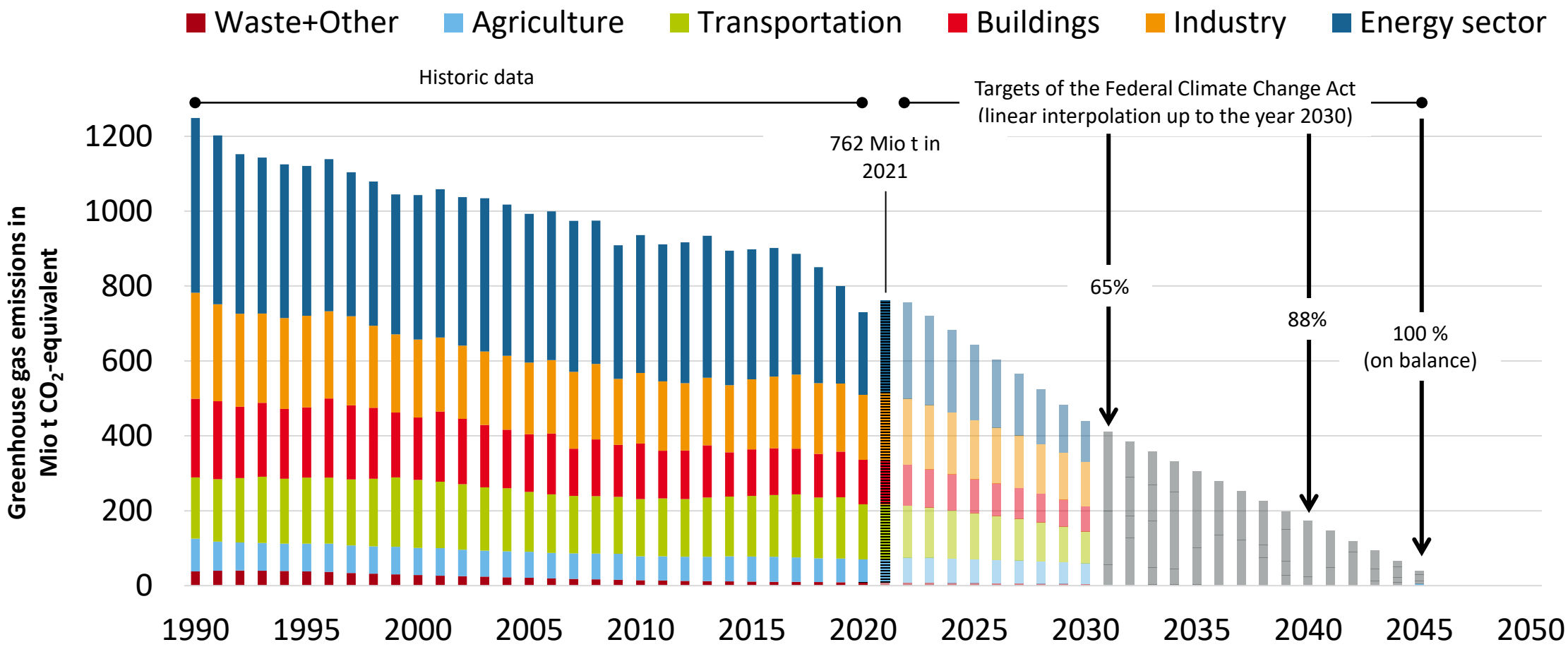
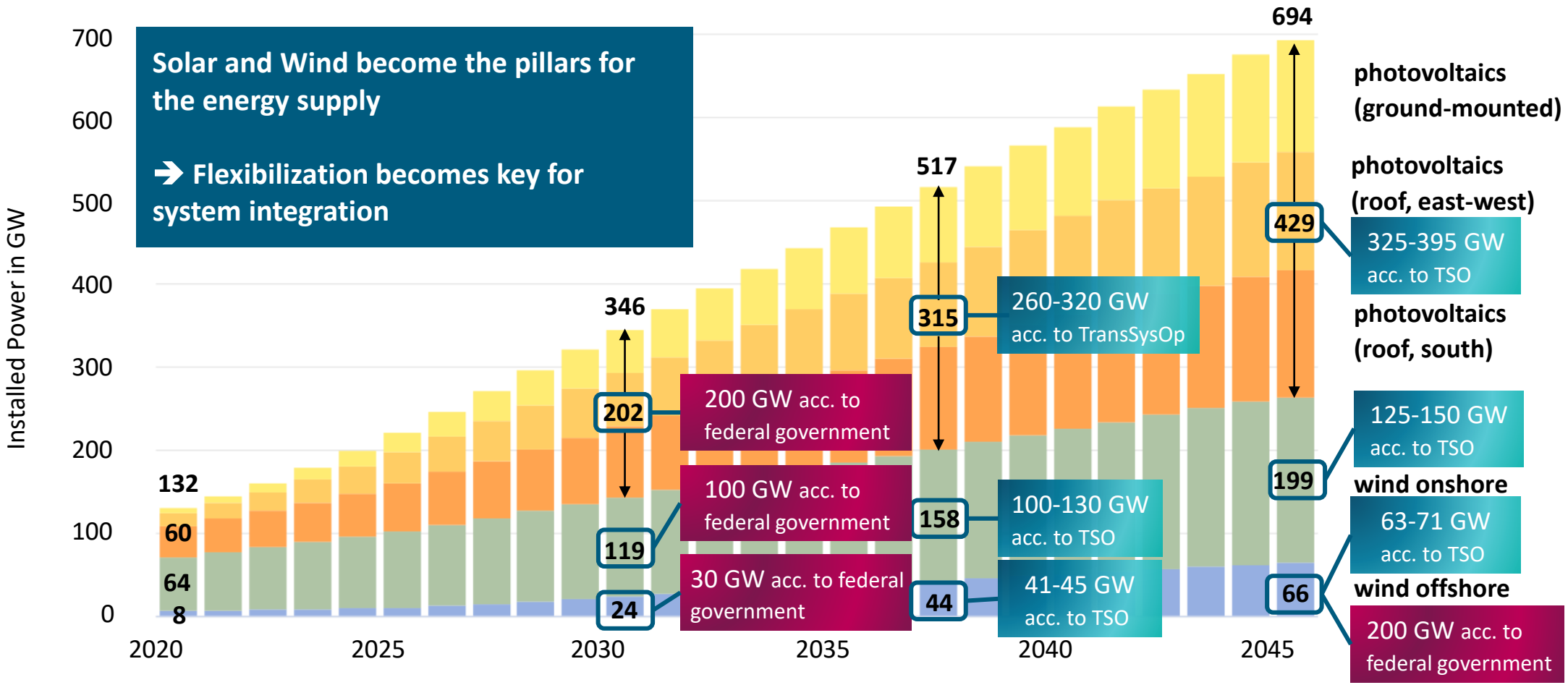
Greenhouse Gas Emissions of Germany: History and Targets



Energy System Analysis - Results

Expansion of solar PV and wind energy converters



Studie: Fraunhofer ISE, Wege zu einem Klimaneutralen Energiesystem – Die deutsche Energiewende im Kontext gesellschaftlicher Verhaltensweisen, Update November 2021: Klimaneutralität 2045. Daten: https://energy-charts.info.
Koalitionsvertrag (November 2021) und Eröffnungsbilanz Klimaschutz des BMWK (13.01.2022).
Szenariorahmen zum Netzentwicklungsplan Strom 2037 mit Ausblick 2045, Version 2023 (Januar 2022).

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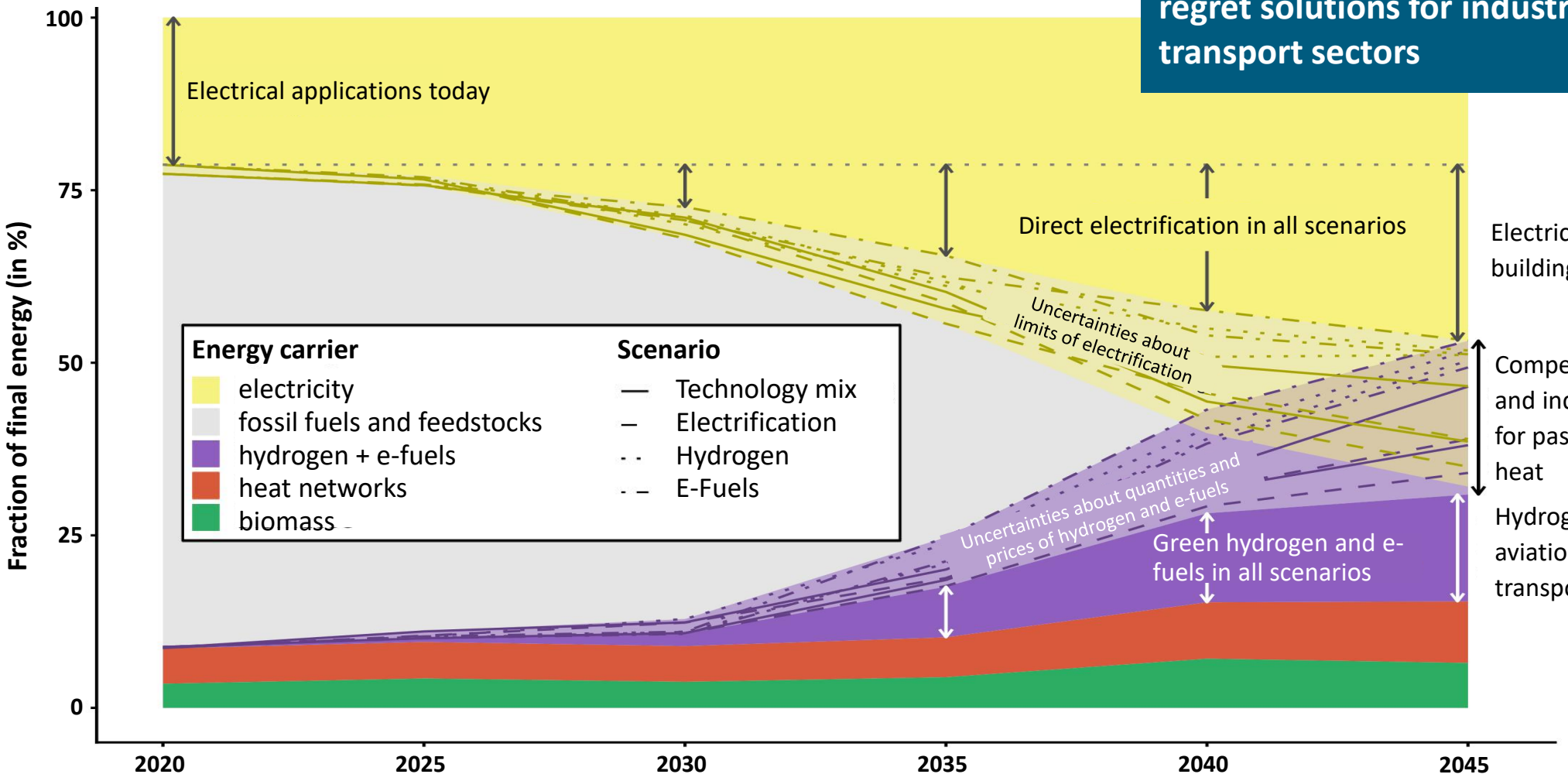
Energy System Analysis – Results

Final energy: Direct vs. indirect electrification

Green hydrogen and fuels are no regret solutions for industry and transport sectors



Electricity mainly in cars and buildings

Competition between direct and indirect electrification, e.g. for passenger cars and process heat

Hydrogen in industry, aviation, shipping and road transport

Figure translated from: Ariadne Kurzdossier 2021: Durchstarten trotz Unsicherheit, 16.11.2021, https://ariadneprojekt.de/publikation/eckpunkte-einer-anpassungsfaehigen-wasserstoffstrategie/

Demand for Hydrogen and eFuels in Germany

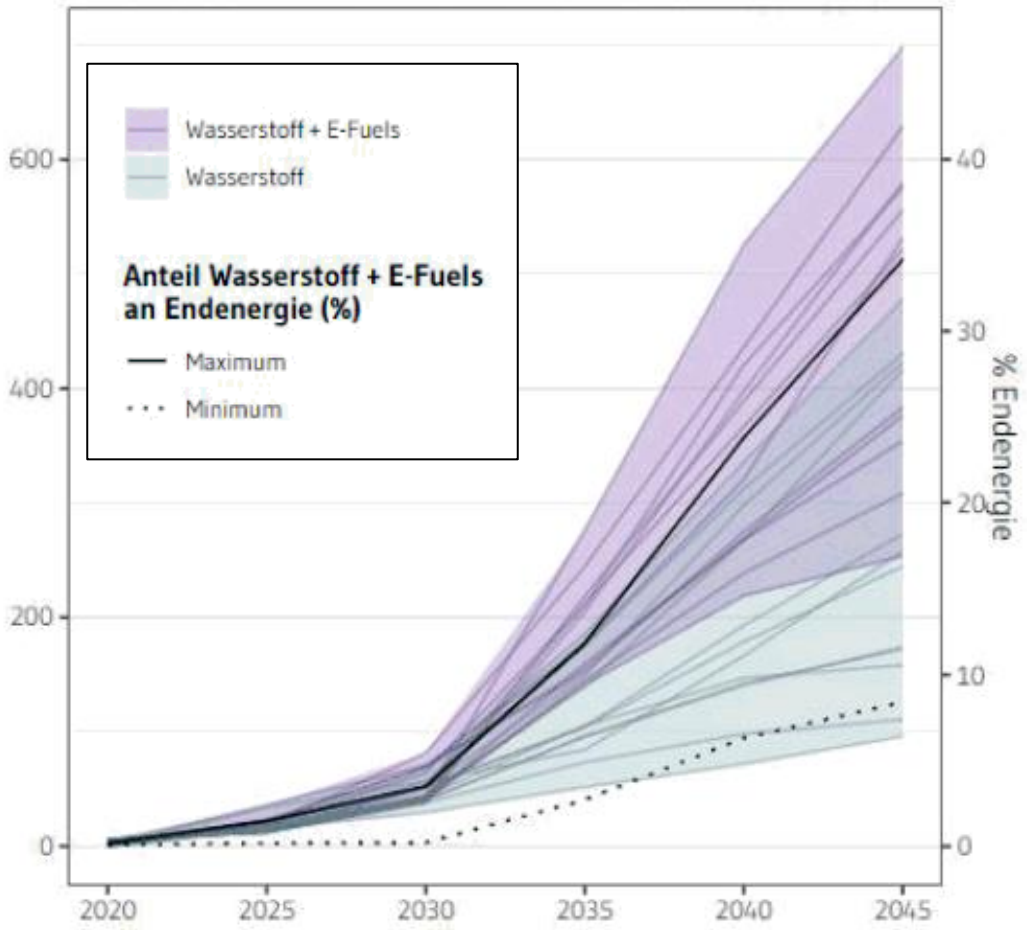
Results Systems Analysis (Ariadne Project)

- Demand of hydrogen and eFuels ranges between **250 and 700 TWh in 2045** (share ranges between **9% and 34% of final energy consumption**)

- The scenario-analysis of Ariadne project illustrates:
  - Until 2030, the use of H2 and eFuels still limited
  - Role of hydrogen and eFuels may vary heavily depending on the future climate change strategy and the extend of electrification measures.

“No-regret”- Options for almost all scenarios are the energetic and material use of H2 and eFuels in the industry (steel, ammonia, petro-chemicals), aviation, shipping and trucks.

Demand for H_2 and eFuels in Ariadne-Scenarios



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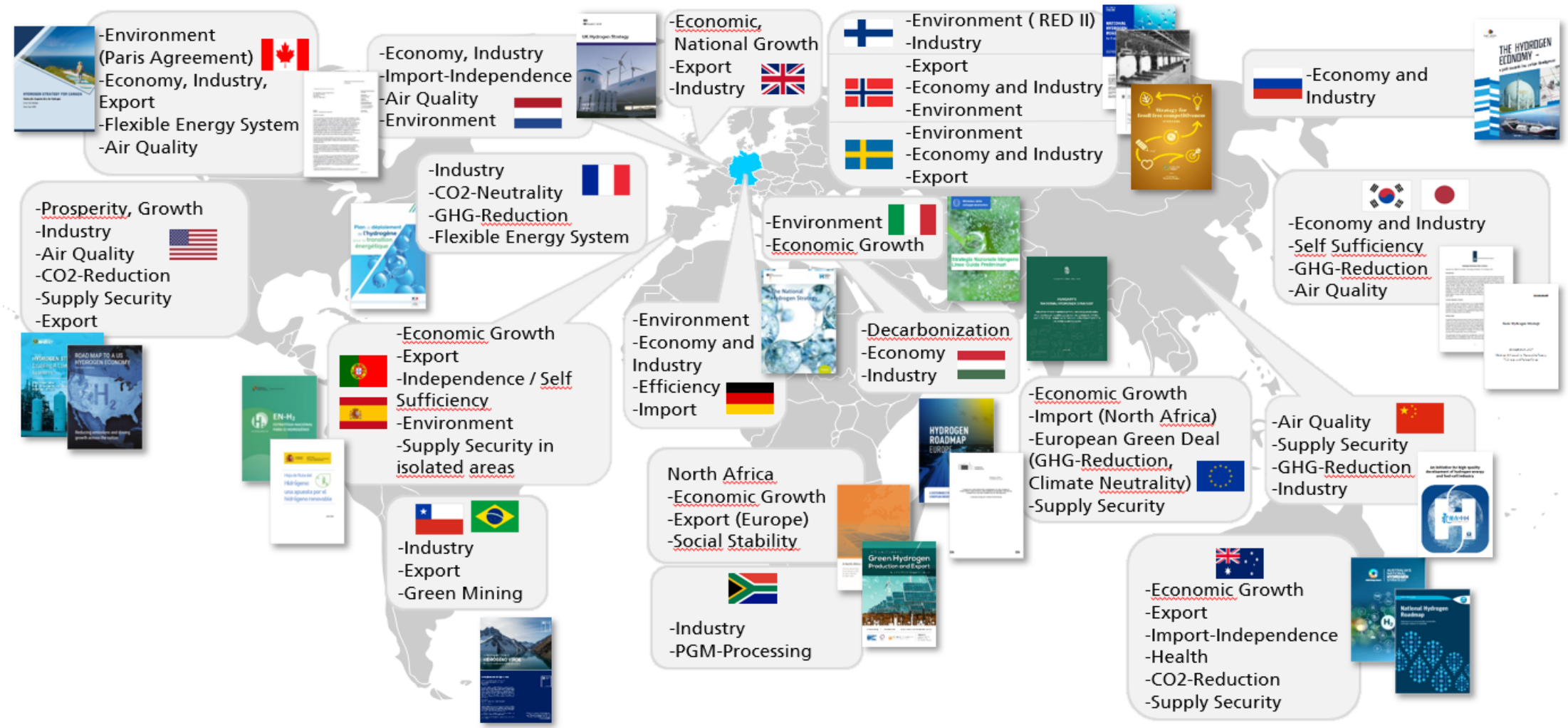
Drivers for a Global Hydrogen Economy

40 National Strategy Papers, Roadmaps, R&D Programms and Vision Papers on Hydrogen



https://de.wikipedia.org/wiki/Datei:BlankMap-World_gray.svg

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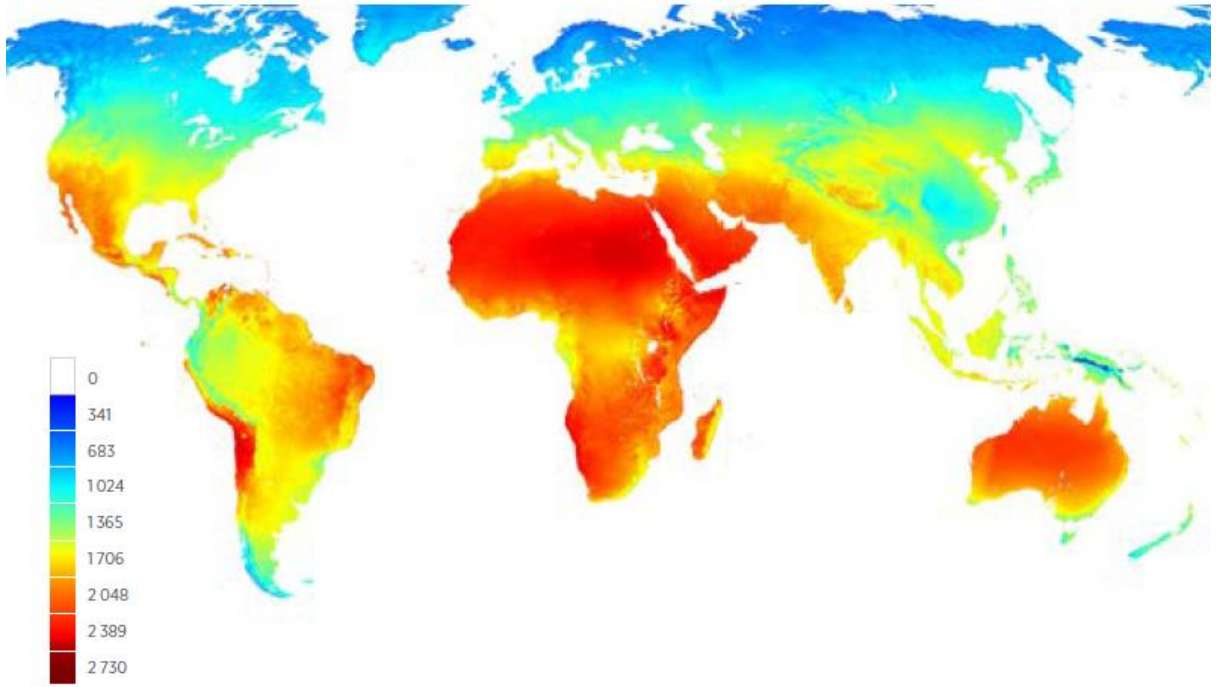
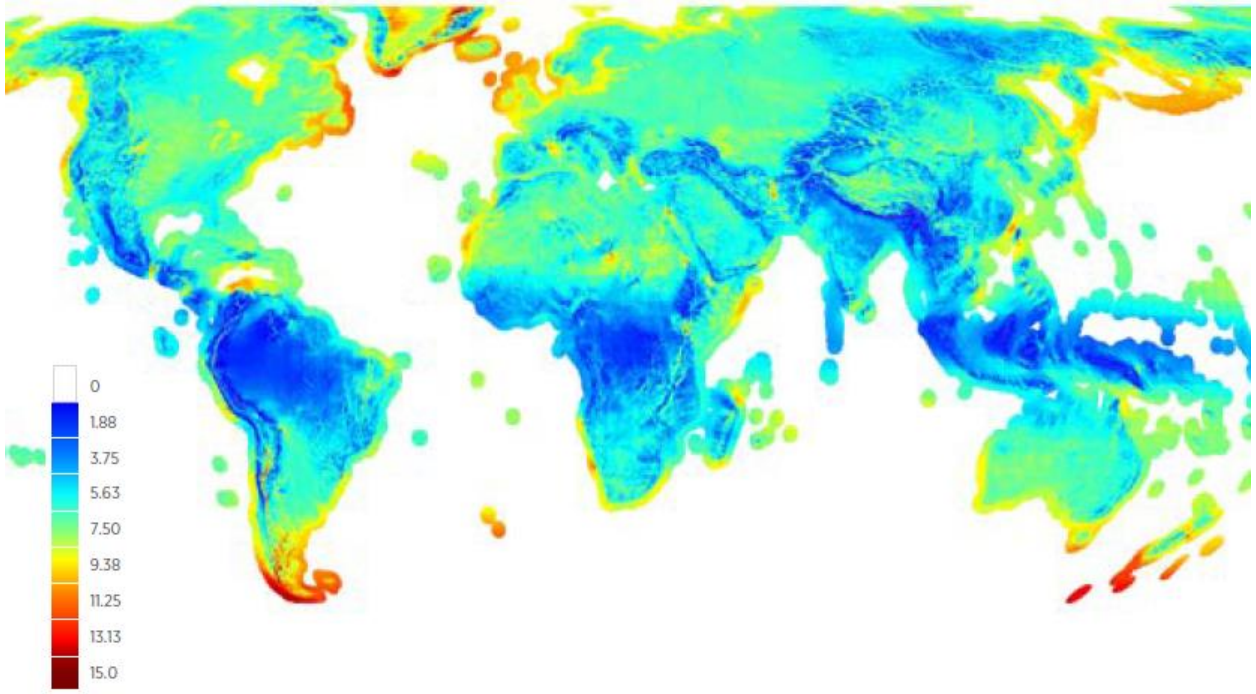
World Renewable Technical Potential

Annual Average Global Horizontal Irradiation (kWh/m2)

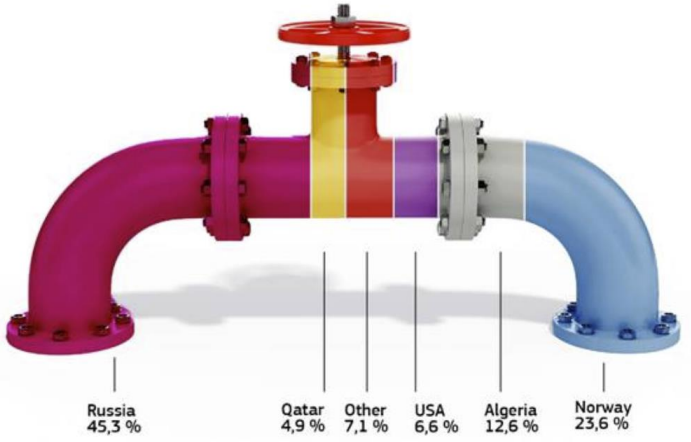


Annual Average Wind Speed at 100 Metres (m/s).



REPower EU

Joint European Action for More Affordable and Sustainable Energy



Hydrogen Accelerator, EC 8-3-2022

- The Commission will further develop the regulatory framework to promote a **European market for hydrogen and support the development of an integrated gas and hydrogen infrastructure, hydrogen storage facilities and port infrastructure**. New cross border infrastructure should be hydrogen compatible. The Commission will assess State aid notification for hydrogen projects as a matter of priority. It commits to complete the assessment of the first Important Projects of Common European Interest on hydrogen within 6 weeks from the submission by the participating Member States of a complete notification. The shared aim should be to enable the assessment to be completed by summer.

- Additionally, the Commission will support pilot projects on **renewable hydrogen production and transport in the EU neighbourhood, starting with a Mediterranean Green Hydrogen Partnership**. It will also work with partners to conclude Green Hydrogen Partnerships and with the industry to establish a Global European Hydrogen Facility, boosting Member States' access to affordable renewable hydrogen.

REPower EU

Joint European Action for More Affordable and Sustainable Energy

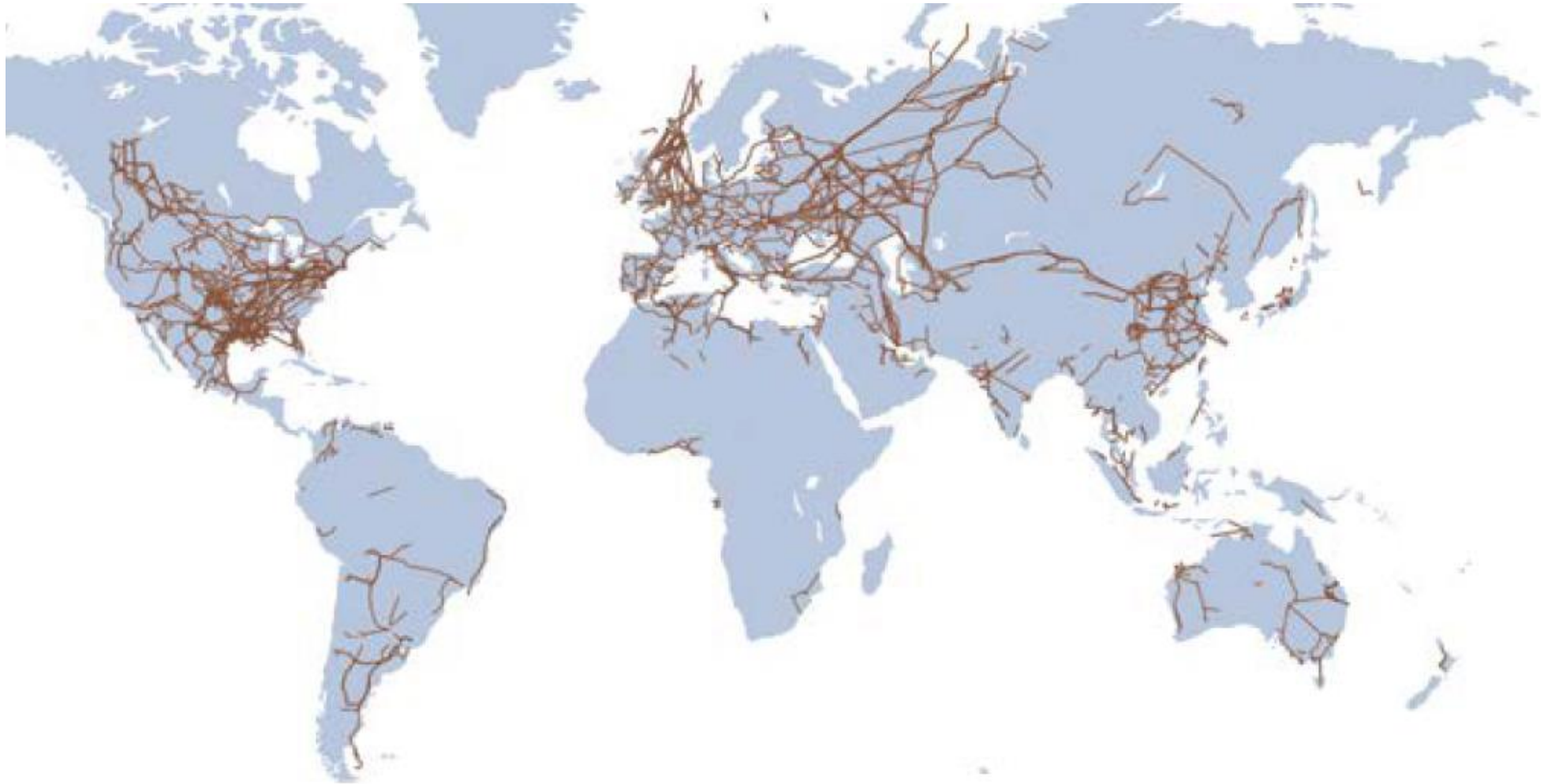
Hydrogen Accelerator, EC 8-3-2022

»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.

This would be made of **additional 10 mt of imported hydrogen** from diverse sources and an **additional 5 mt of hydrogen produced in Europe**«

	2*10 million tons of green hydrogen	**Renewable Resource**			**Electrolyser**		**Hydrogen Production**	
	2030	Capacity	full load hours	Electricity Production	Capacity	full load hours		
		GW	hr/yr	TWh	GW	hr/yr	Million ton	TWh_{HHV}
	EU production							
1	Offshore	25	5.000	125	25	5.000	2,5	99
2	Onshore wind	35	3.570	125	25	5.000	2,5	99
3	Solar PV	150	1.750	263	100	2.500	5	197
	Import							
4	Onshore wind	25	4.000	100	20	5.000	2	79
5	Solar PV	200	2.100	420	150	2.700	8	315
	TOTAL				**> 320**		**20**	**788**

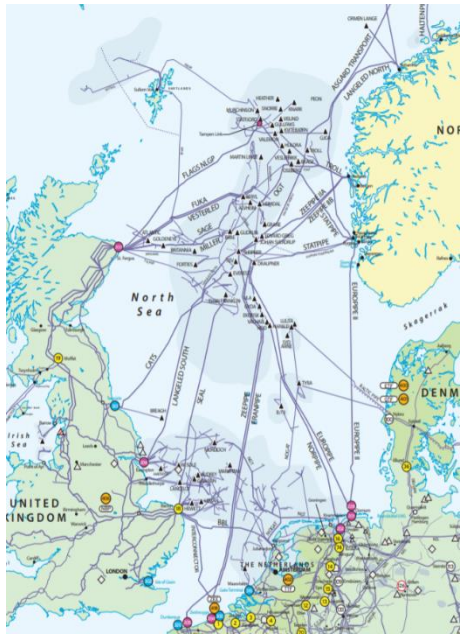
Global map of natural gas transmission pipelines



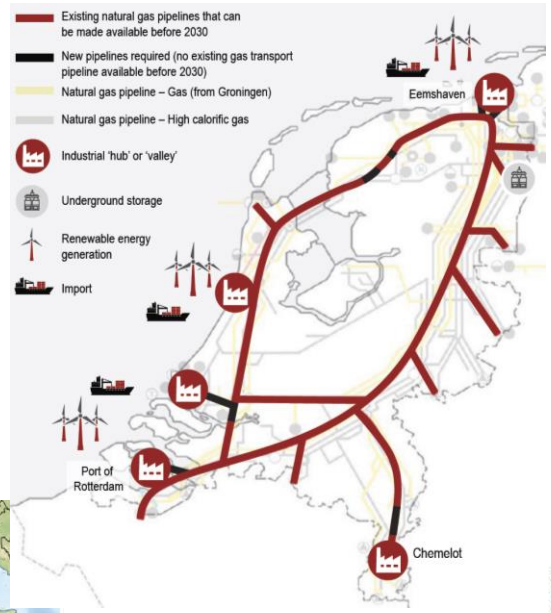
Gas Infrastructure in Europe can be Reused for Hydrogen

Hydrogen and it’s Derivates from the MENA Region

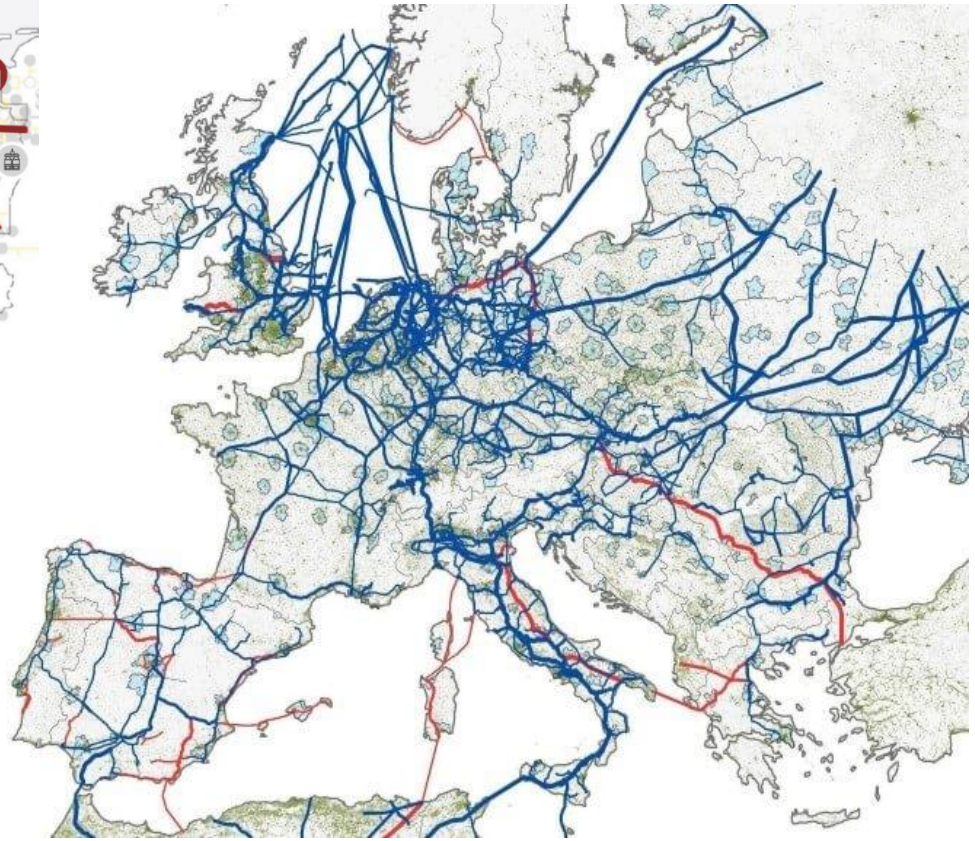
Northern Sea



- Dutch H2 Infrastructure in 2030

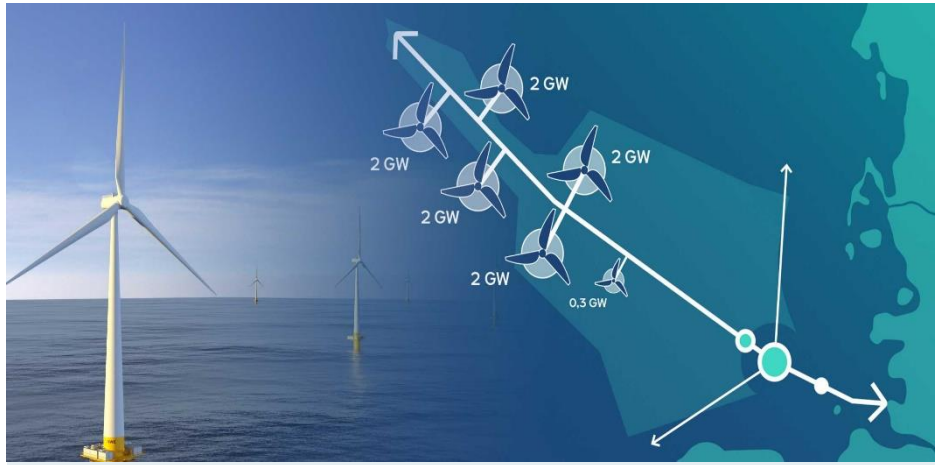


Existing Natural Gas Pipelines



Offshore Wind Hydrogen Projects in Development

Need to be realized much faster



Aquaventus and Aquaductus (Germany)

- 10 GW offshore wind Hydrogen
- 1 million tons of hydrogen (= 5.000 full load hours)
- Fully Operational 2035
- RWE, Equinor, Orsted, Boskalis + others
- Pipeline: Gascade, Gasunie, RWE, Shell
- Pipeline:
  Connect to hydrogen backbone + salt cavern storage

North H2 (Netherlands)

- 10 GW offshore wind Hydrogen
- 1 million tons of hydrogen (= 5.000 full load hours)
- 3-4 GW onshore electrolyser 2030 in Eemshaven
- 6-7 GW offshore electrolyser <2040
- Shell, Gasunie, Groningen Seaports, Equinor, RWE,…
- Pipeline:
  Connect to Hydrogen backbone + salt cavern storage

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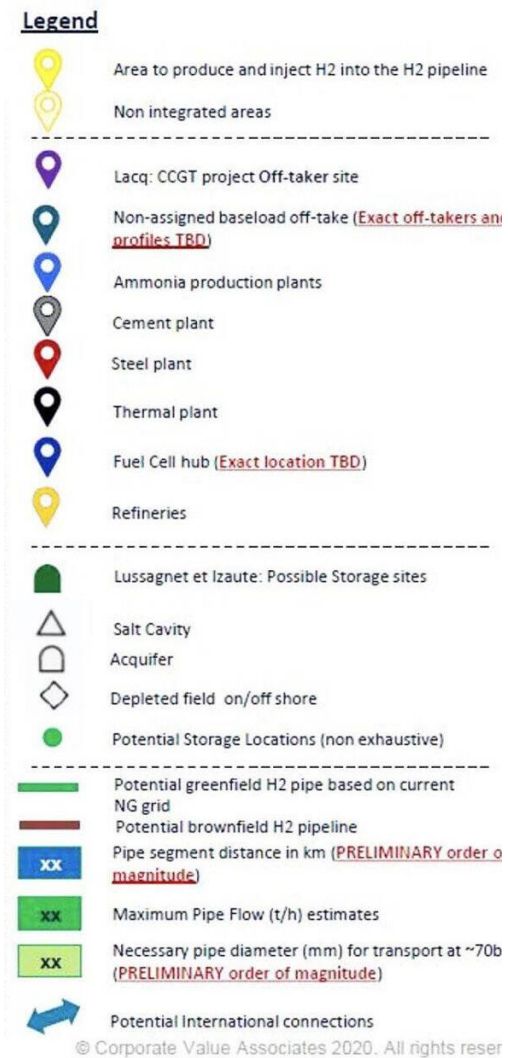
HyDeal – Solar PV to Hydrogen

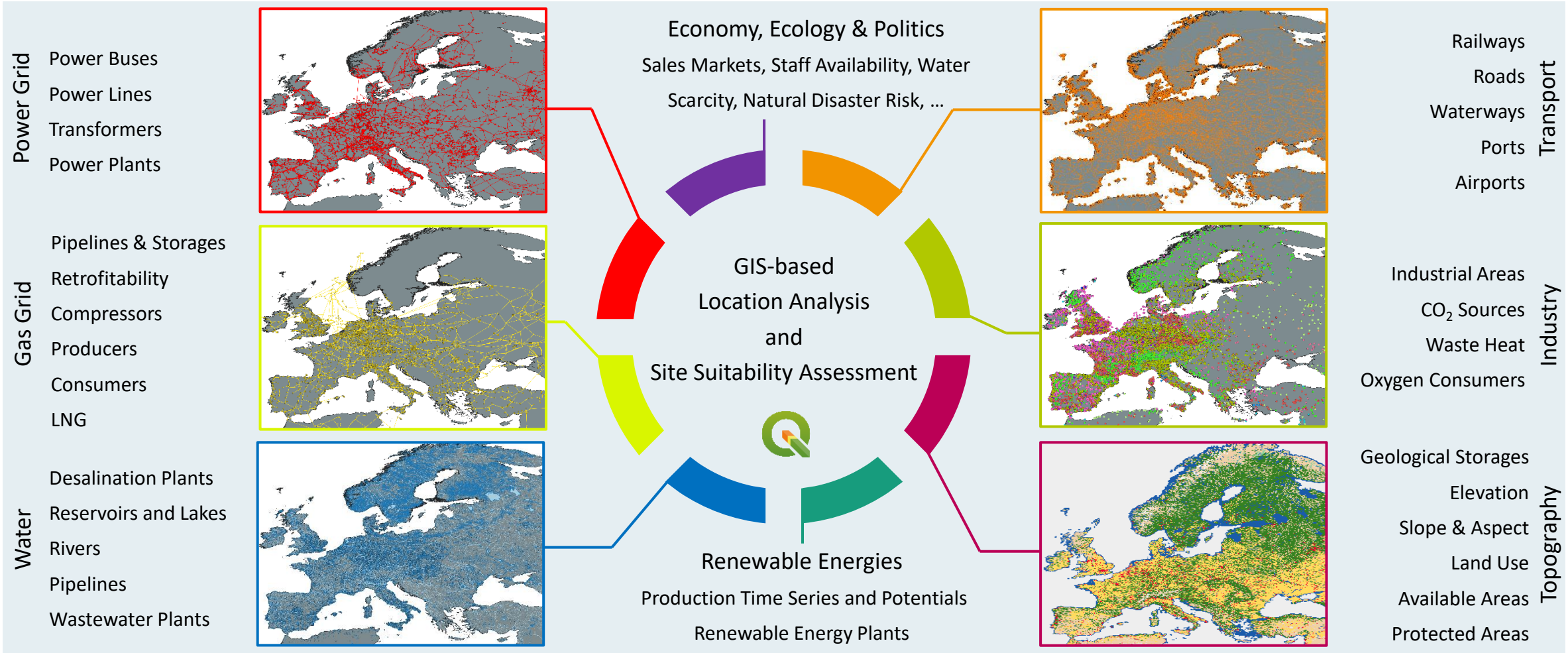
Target by 2030

95 GW Photovoltaic Capacity
67 GW Electrolysis Capacity

3.6 Mt H_2 @ 1.50 €/ kg



GIS Analysis
Methodology



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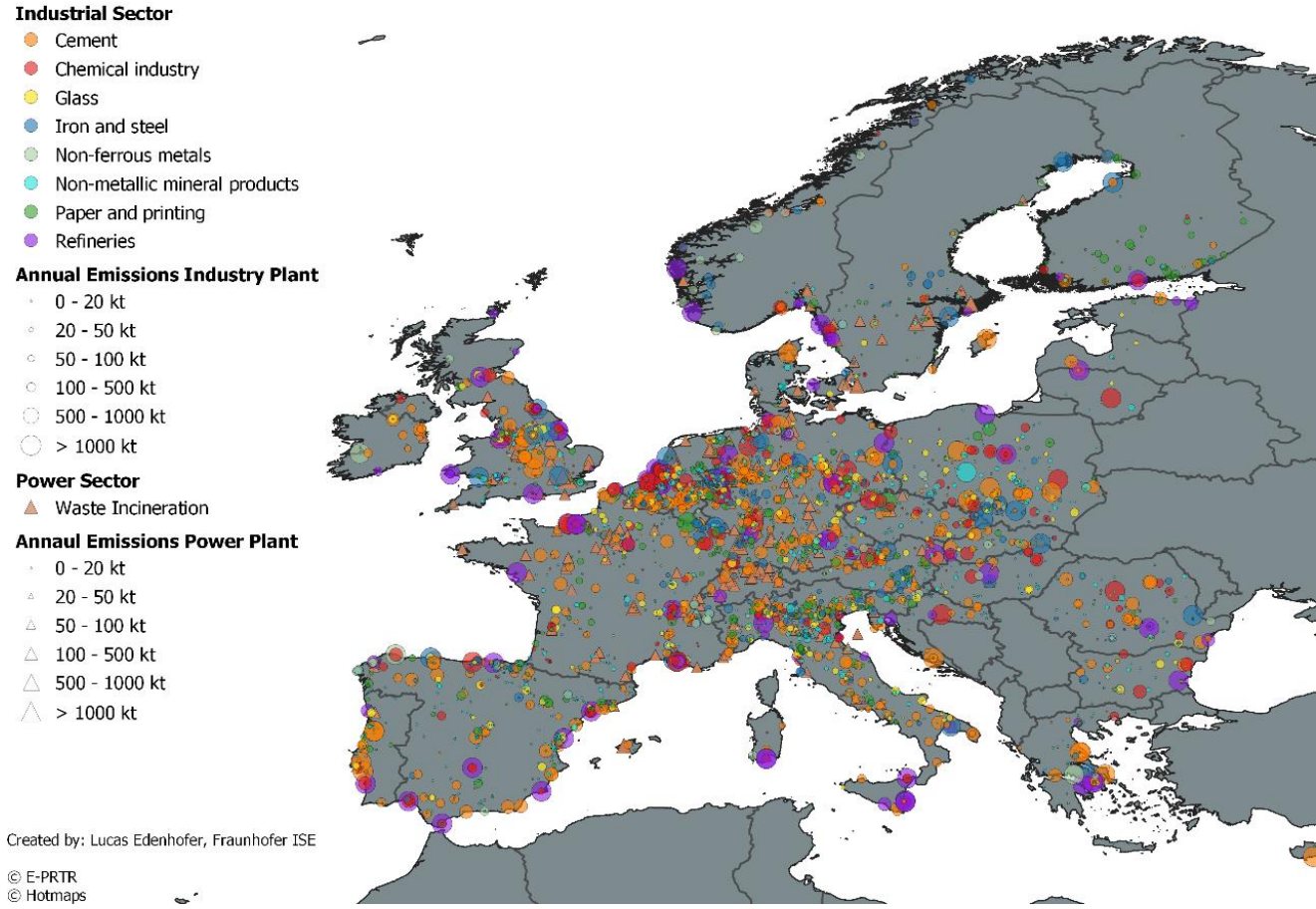
CO_2 Sources

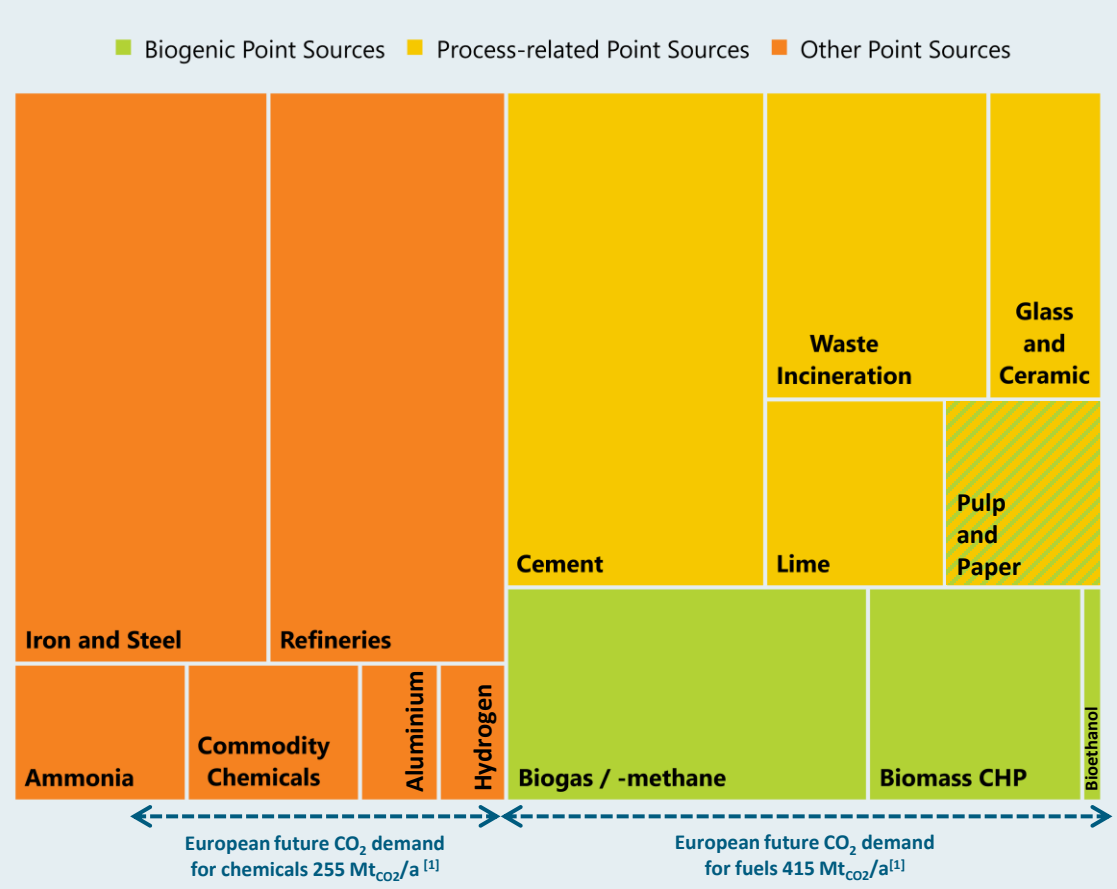
Classification and Availability of CO_2 point sources without fossil power production in Europe, GIS Analysis

- Direct Air Capture (DAC)
- Biogenic sources
  - Biomass
  - Biogas
  - Biomethane
  - Bioethanol
- Point sources with significant process-related emissions
  - Lime
  - Glass
  - Waste incineration
  - Cement
  - Pulp and paper
- Point sources with other appropriate emission reduction strategies or insignificant process-related emissions
  - Iron and steel
  - Chemical Industry
  - Non-ferrous metals
  - Refineries
- Fossil power production is no sustainable carbon source

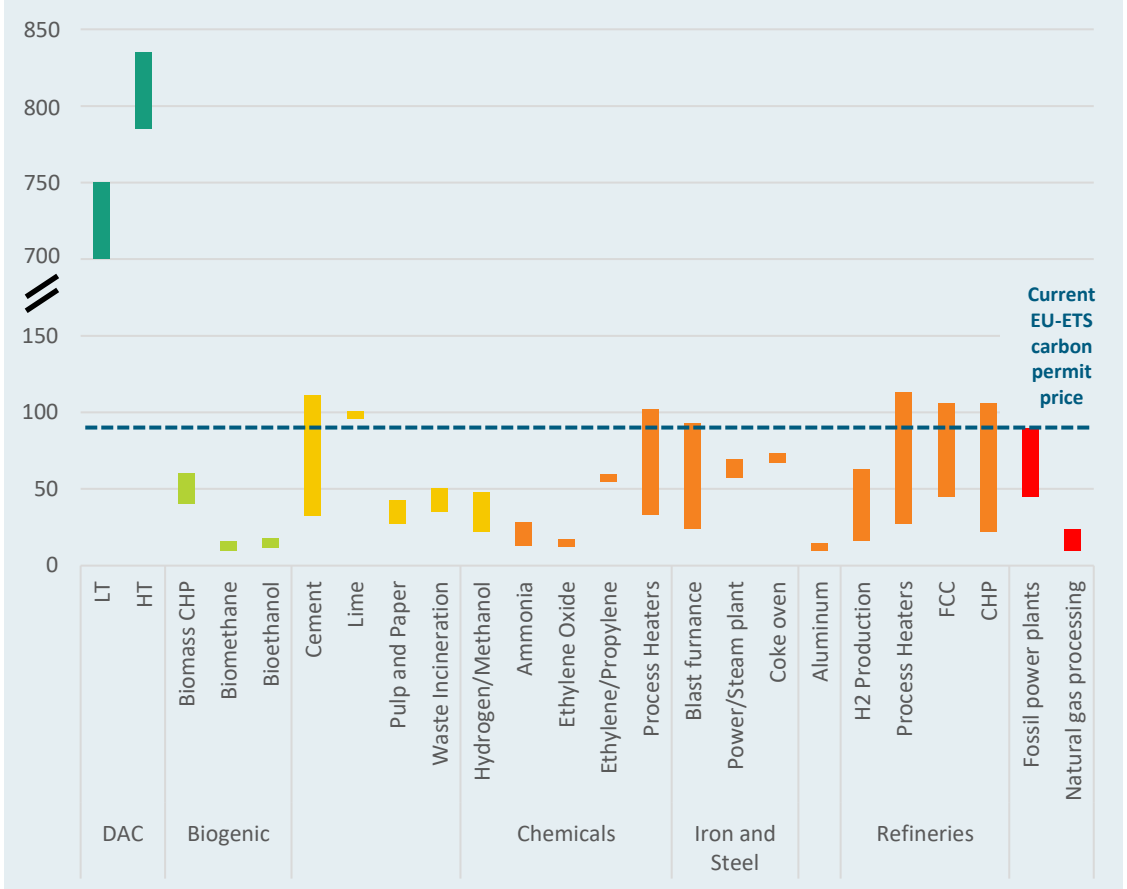


CO_2 Sources
Availability and Capture Costs

Availability of Point Sources EU 2017



Capture Cost 2020 [€/t_{CO2}]



Sources availability
[1]: https://doi.org/10.1039/D0EE01530J
[2]: EU ETS

Sources capture costs
[1]: W. Terlouw et al. (2019)
[2]: https://doi.org/10.1016/j.jclepro..2019.03.086
[3]: https://doi.org/10.3389/fenrg.2020.00175
[4]: https://doi.org/10.3389/fenrg.2021.738791

Abbreviations
CHP | Combined heat and power
LT | Low temperature
HT | High temperature
FCC | Fluid catalytic cracking

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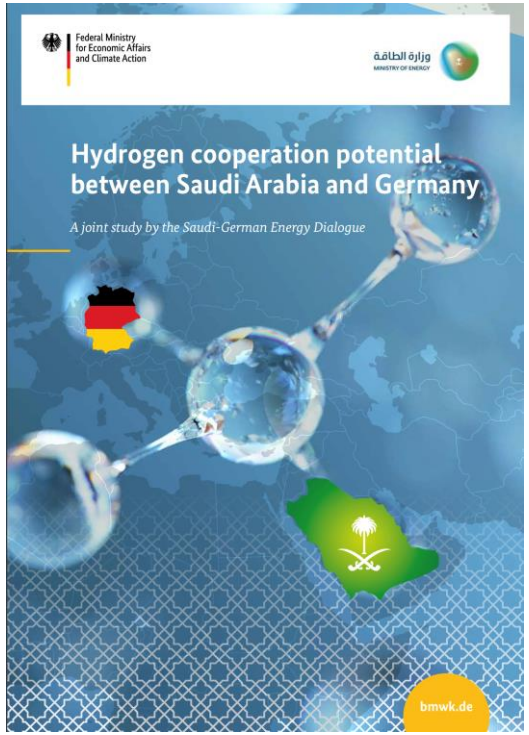
MENA – Middle East and North Africa

Hydrogen cooperation potential between MENA region and Germany



MENA H^2 challenges

Source: Yunus Syed and Jan Frederik Braun (2021).

Production cost and long-distance import of Power-to-X:

Studies performed by Fraunhofer ISE – Central Technical Parameters

Ammonia/ Methanol Synthesis

- Capacities determined by system optimization
- Technical parameters: Kinetic background for assumed parameters based on own ASPEN simulation for representative capacities

H2 Liquefaction

- Improvements in specific energy demand for lique-faction from 8 kWh/kg in 2020 to 6 kWh/kg in 2050
- Downstream processes running continuously; taking specific part load operation into account

- N2 supply for ammonia synthesis with air separation unit
- CO2 from point source (e.g. Waste-to-Energy)
- Transport of products with transport vessel to Brunsbüttel

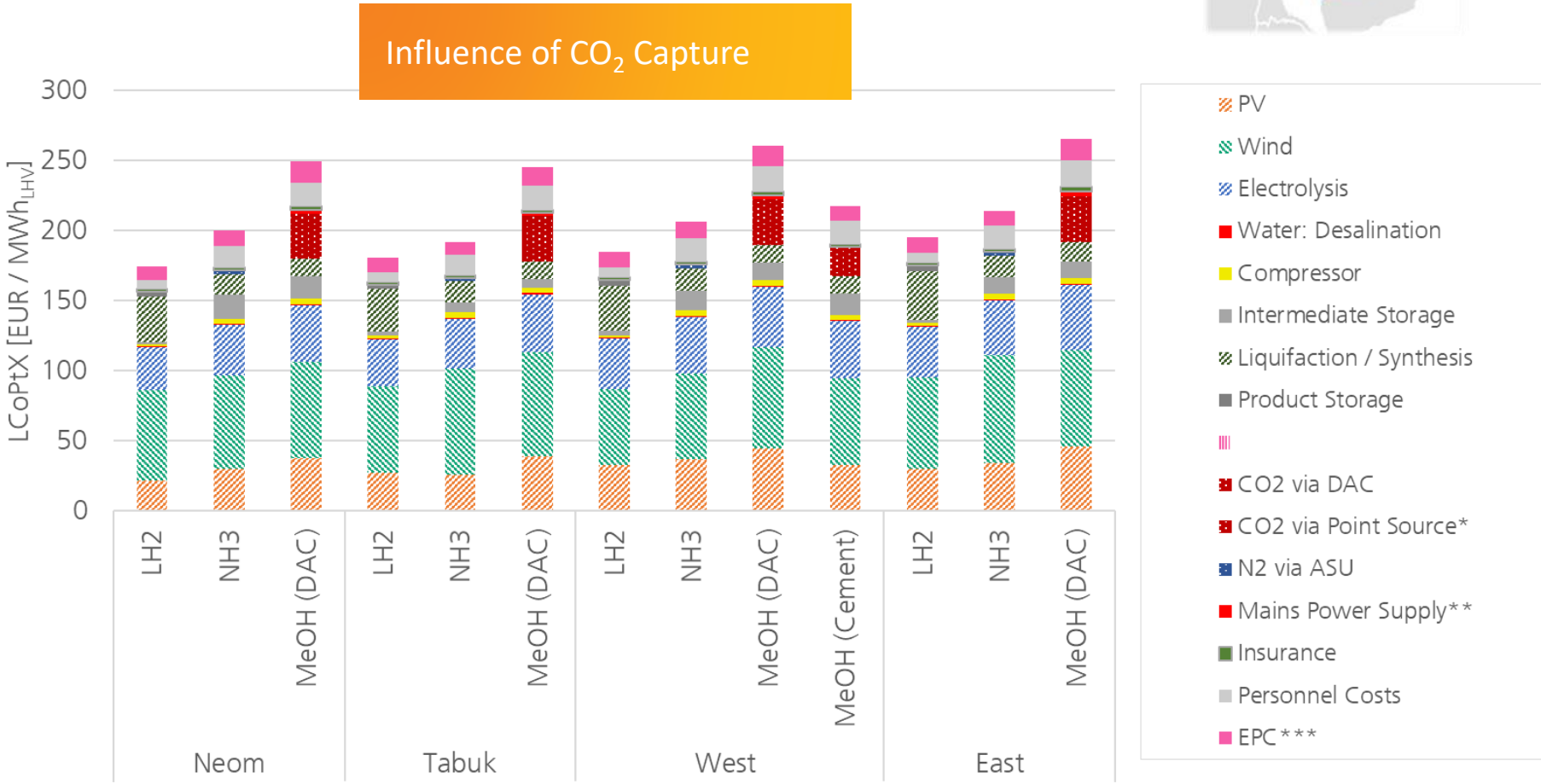
	2020	2030	2050	
H2 liquefaction	25	**25**	25	% of rated cap.
Ammonia	80	**60**	50	% of rated cap.
Methanol	80	**25**	20	% of rated cap.

Project PtX GIZ: Supply Costs of PtX Energy Carriers

Near-Term Case Study for Saudi Arabia

Production in various identified high-potential regions in Saudi Arabia

1. Costs incl. ship transport to Germany
2. Scenario based on near-term production (~2023) with 150 MWel electrolysis as default value from GIZ
3. CO_2 via DAC or capture from cement plant
4. Current methanol price of 570 Euro/t corresponds to 103 Euro/MWh



Preliminary Results – Project on behalf of GIZ GmbH

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Project PtX GIZ: Supply Costs of PtX Energy Carriers

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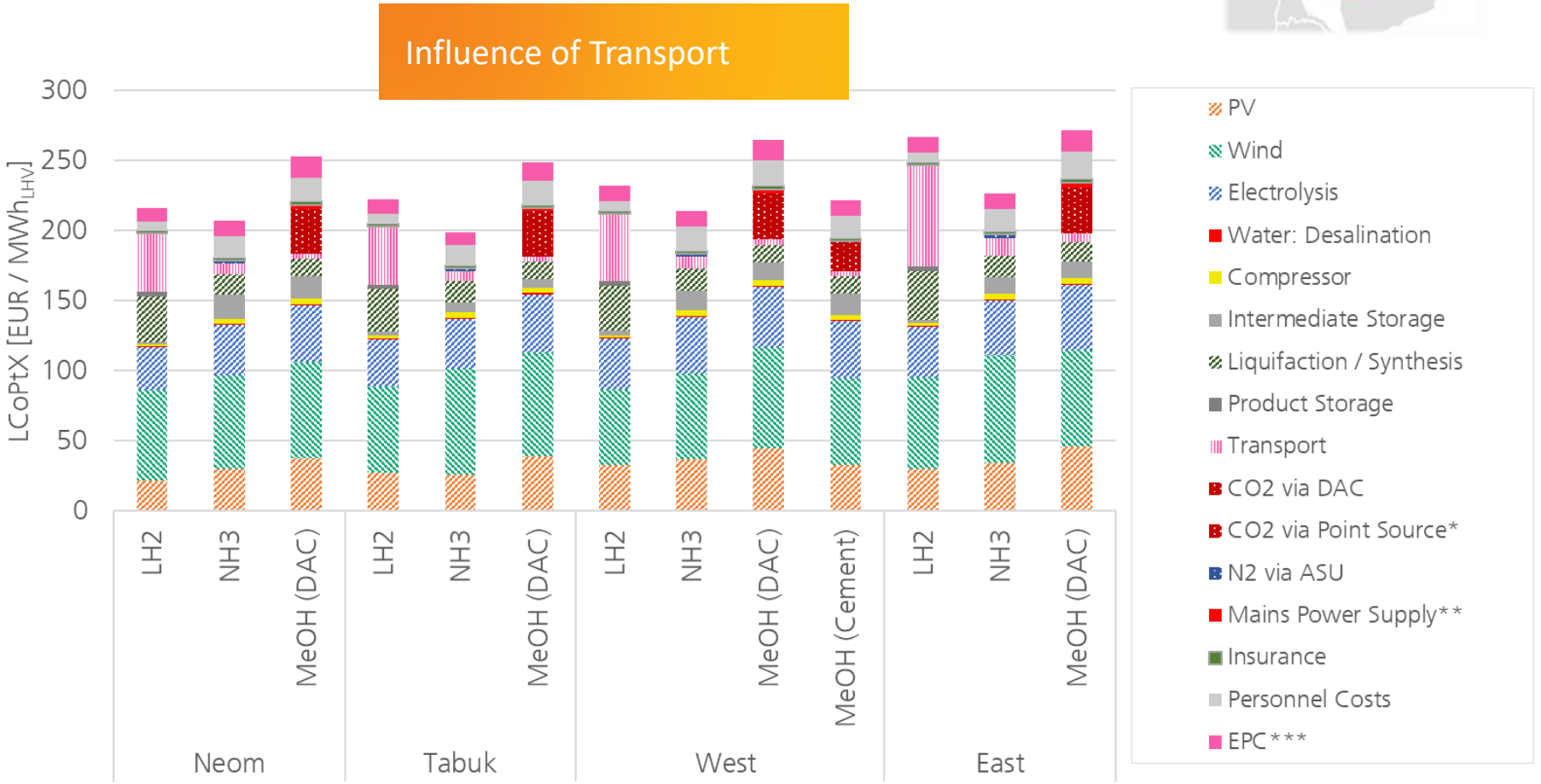

Preliminary Results – Project on behalf of GIZ GmbH

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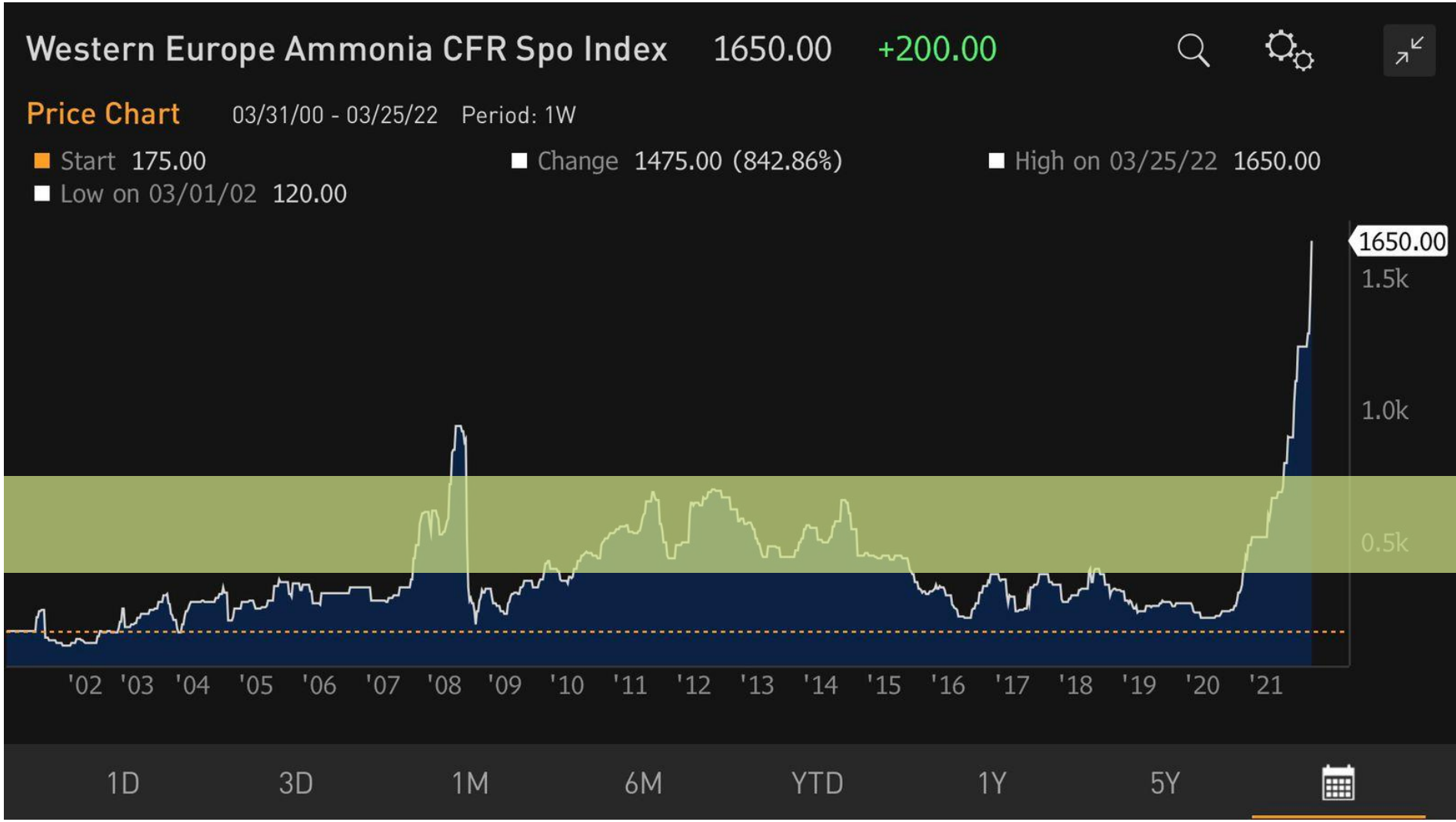
Green Ammonia Currently far Cheaper then Conventional Ammonia

Green ammonia in MENA
from USD 350/ton in Neom to 500-700 in Morocco and 600-800 in Egypt!



Conclusions

- The **global trade** of renewable energy based on hydrogen is beginning now

- EU and national politics must develop **clear pathes and targets for GHG neutrality** and set-up an effective **regulatory framework** (taxes, levies, incentives, etc.) to achieve the targets
- **Remove cost and regulatory barriers** for production and deploy mechanisms to accelerate demand in hard-to-abate sectors
- Accelerate **scale-up of electrolyzer manufacturing** to drive the economics of scale
- The strict constraints of **additionality and unavoidable carbon sources** have to be loosened
- We need a mix of **state funded H2 infrastructure** and **free market elements for private investments**

Speed is crucial now - don’t waste time

International research cooperations and energy partnerships are a prerequisite for faster progress, long term (trading) relationships an d a secure investment environment

Thank you for your Attention!