WHEN TRUST MATTERS

ENERGY TRANSITION OUTLOOK

Hydrogen and CCUS for long term energy security and decarbonization

November 30, 2022

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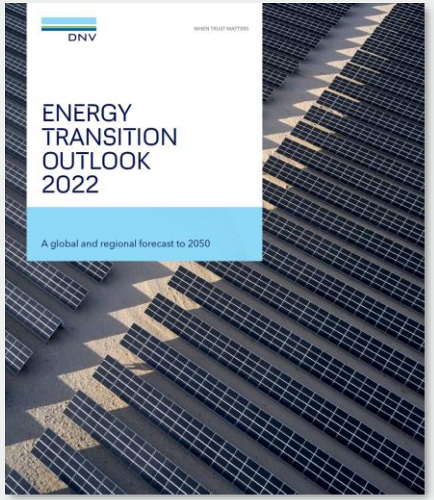
Energy Systems North Europe

Scaling
When, where and how much?

Sectors
With and without uptake?

Transport and trade
How much and where?

Investments
Through to 2050?



Certify, verify and test

against standards, specifications and regulatory requirements

Qualify and assure

new technologies, systems, data, platforms, supply- and value chains

Give expert advice

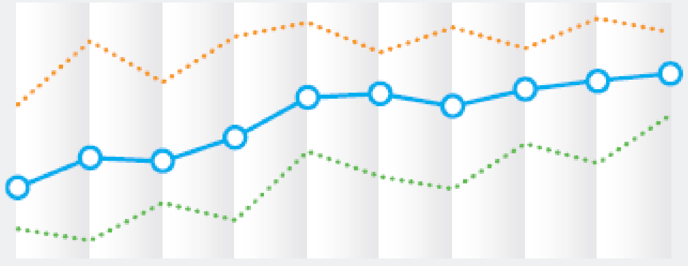
on safety, technology and commercial risk, and operational performance

Co-create and share

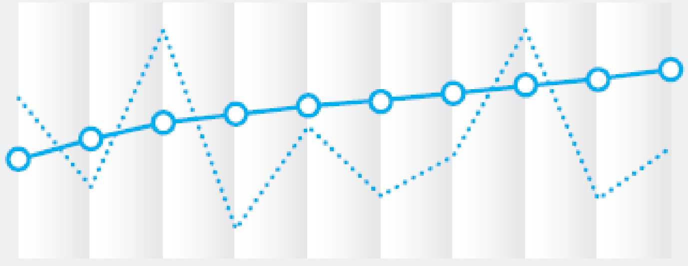
new rules, standards, software and recommended practices

Our approach

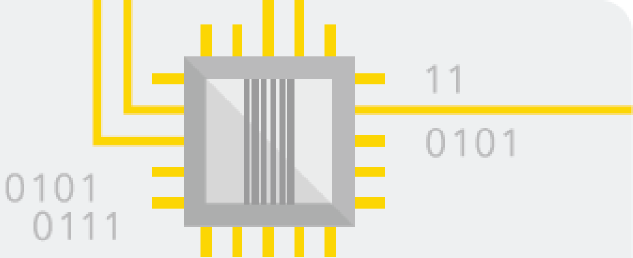
Our **best estimate**,
not the future we want



A single forecast, not scenarios



Long term dynamics,
not short-term imbalances



Continued development of proven **technology**, not uncertain breakthroughs

Main **policy** trends included; caution on untested commitments, e.g. NDCs, etc.

Behavioural changes: some assumptions made, e.g. linked to a changing environment

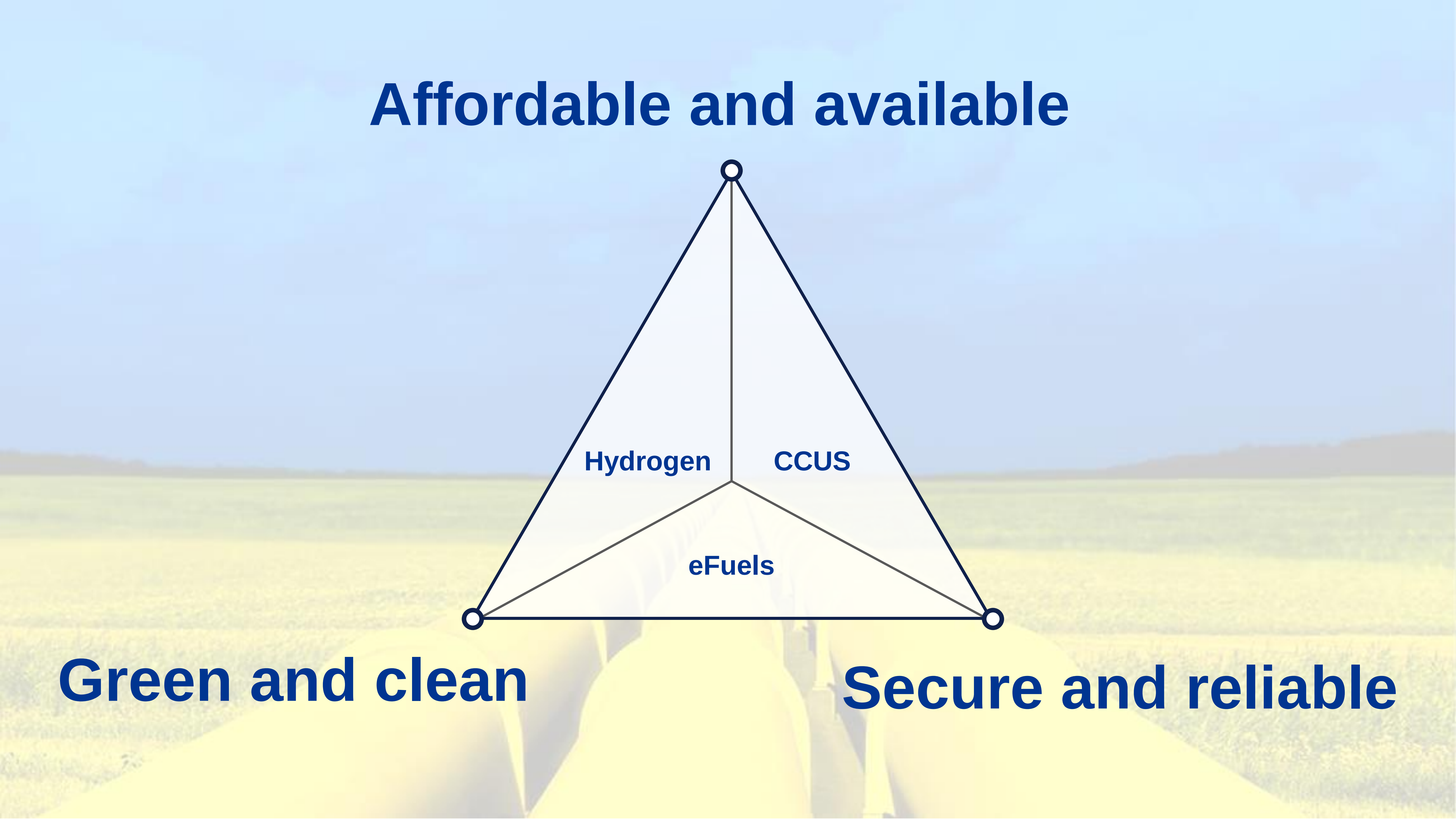
A global and regional forecast

“This is not only a war unleashed by Russia against Ukraine”

“This is a war on our energy, a war on our economy, a war on our values and a war on our future.”

*“And hydrogen can be a game changer for Europe.
We need to move our hydrogen economy
from niche to scale”*

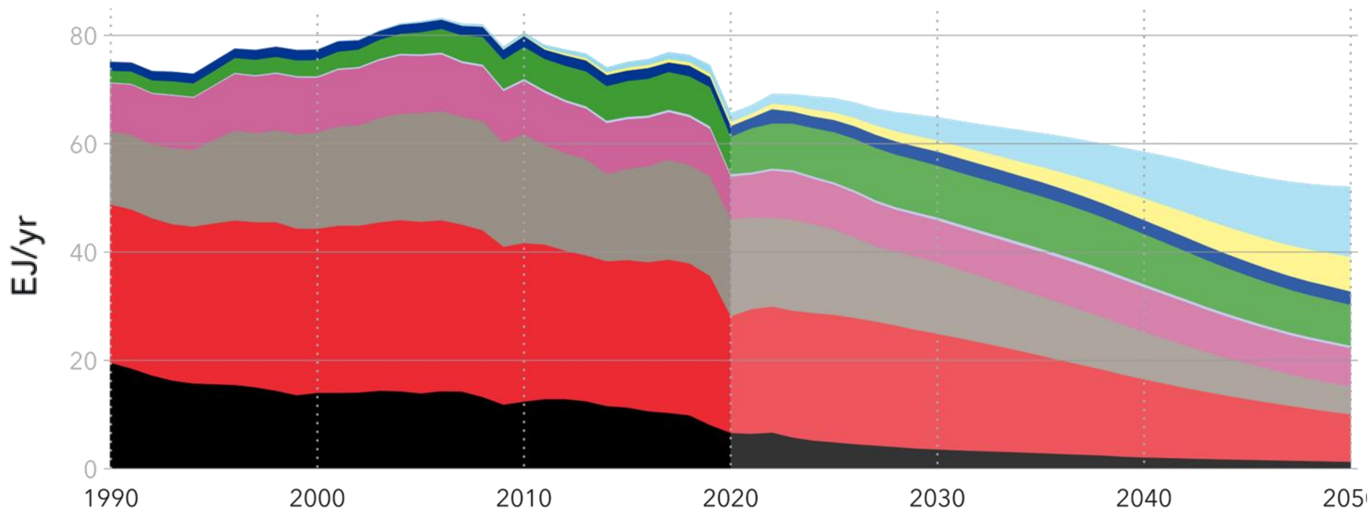
- Ursula von der Leyen
State of the union, Sept.14 2022


Affordable and available
Hydrogen
CCUS
eFuels
Green and clean
Secure and reliable

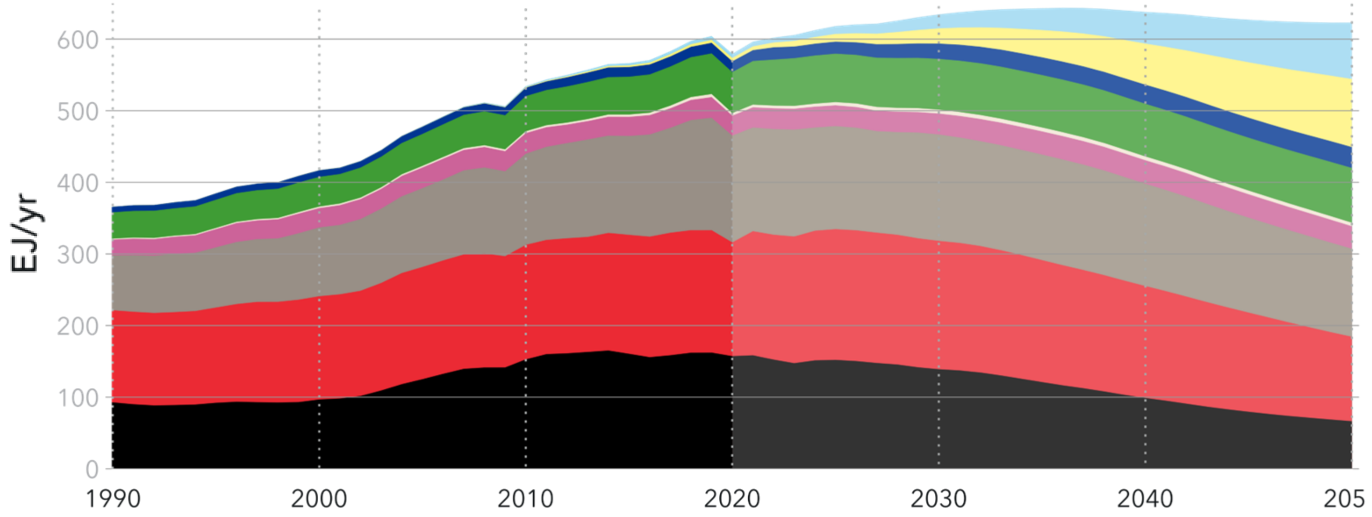
Primary energy consumption by source

- Europe consumes about 10%
- Global primary energy supply peaks in 2036
- European consumption reaches 50% renewable share by 2050

European primary energy consumption by source



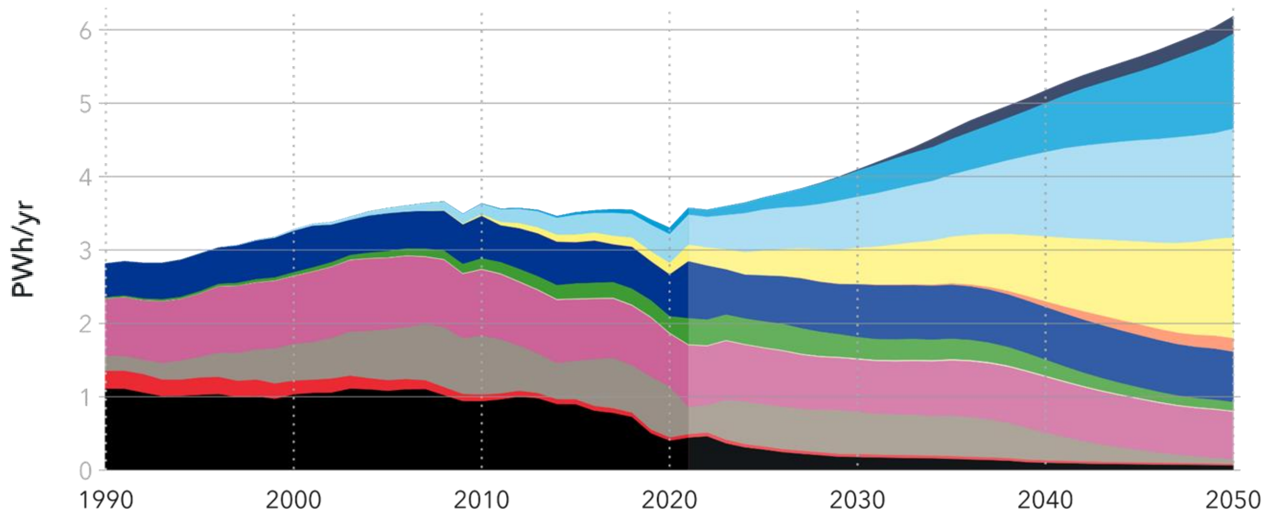
Global primary energy consumption by source



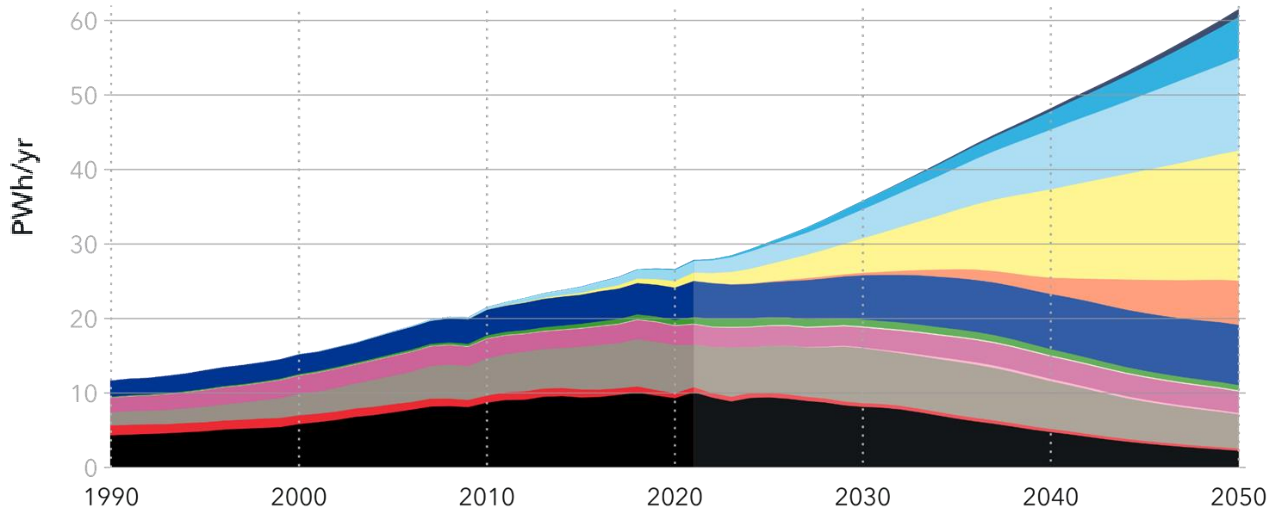
Historical data source: IEA WEB (2022)

DNV

European grid connected electricity generation



Global grid connected electricity generation



70% of renewable power will come from solar and wind

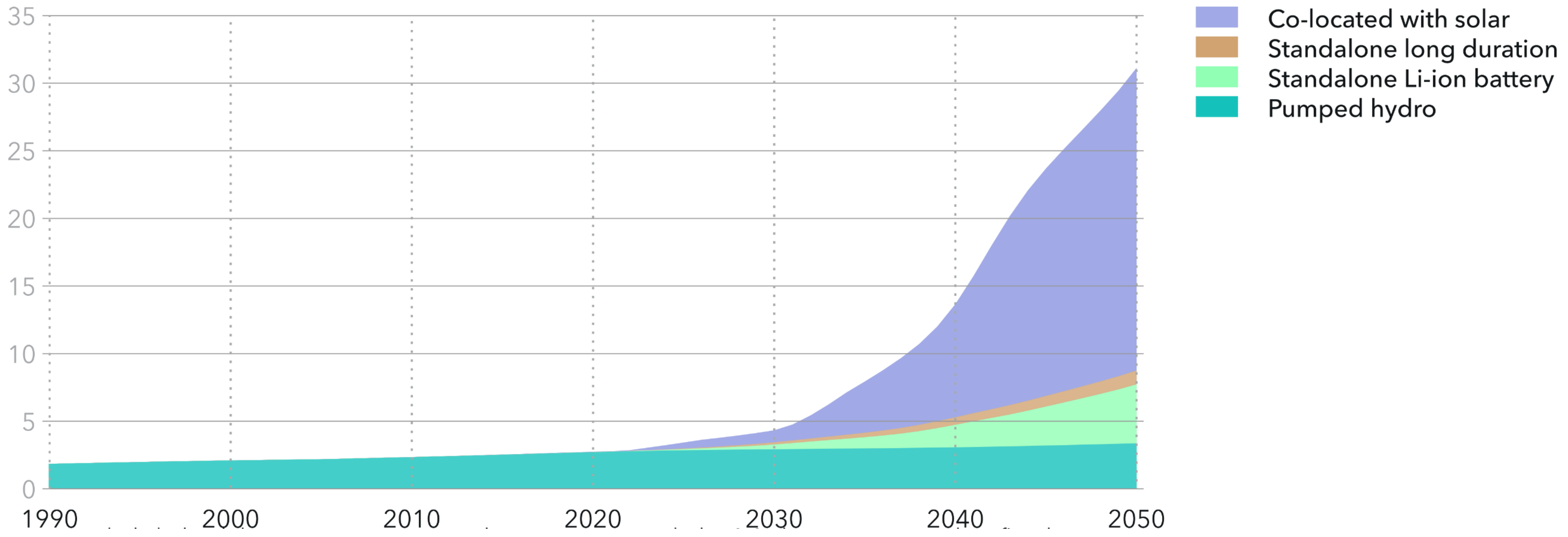
- Offshore power in 2050 amounts to 8000 TWh worldwide, and 1300 TWh in Europe
- Offshore PtX in 2050 is forecasted to 6 Mtpa in Europe, 15 Mtpa worldwide

DNV

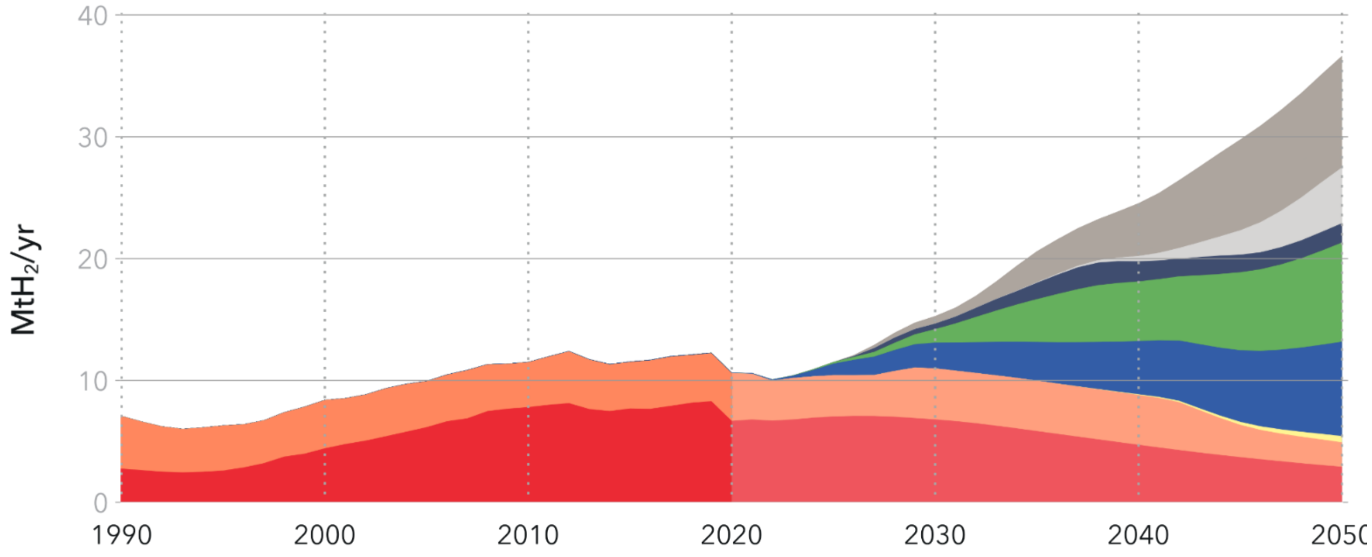
Storage is essential for the inclusion of variable renewables in electricity

World utility-scale electricity storage capacity

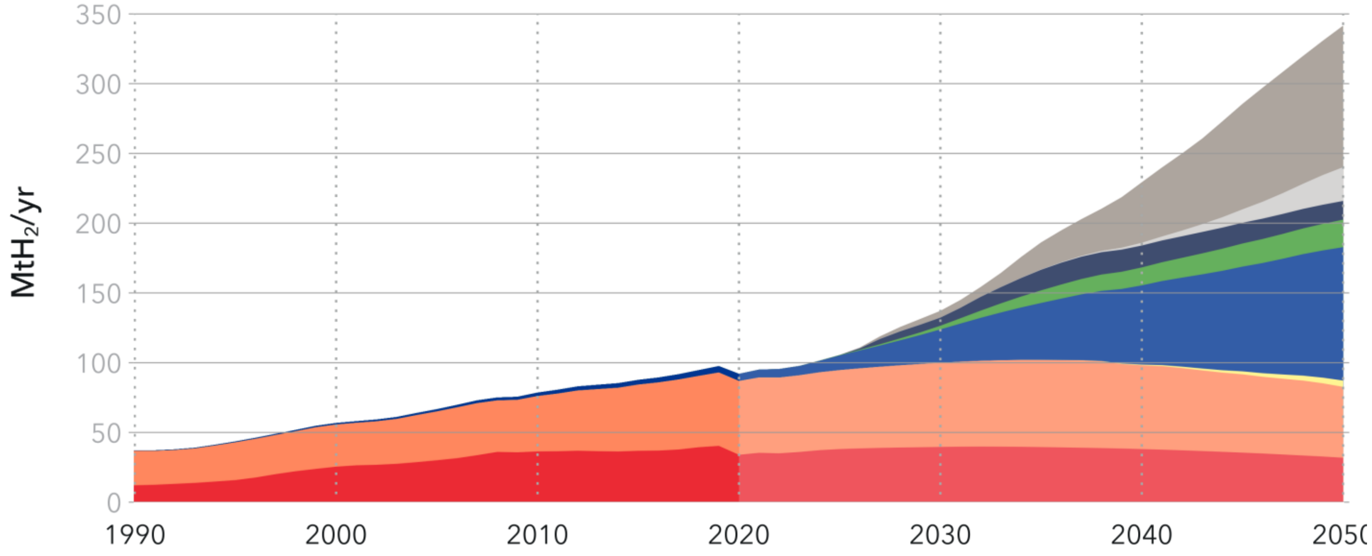
Units: TWh



European demand of hydrogen by sector



Global demand of hydrogen by sector



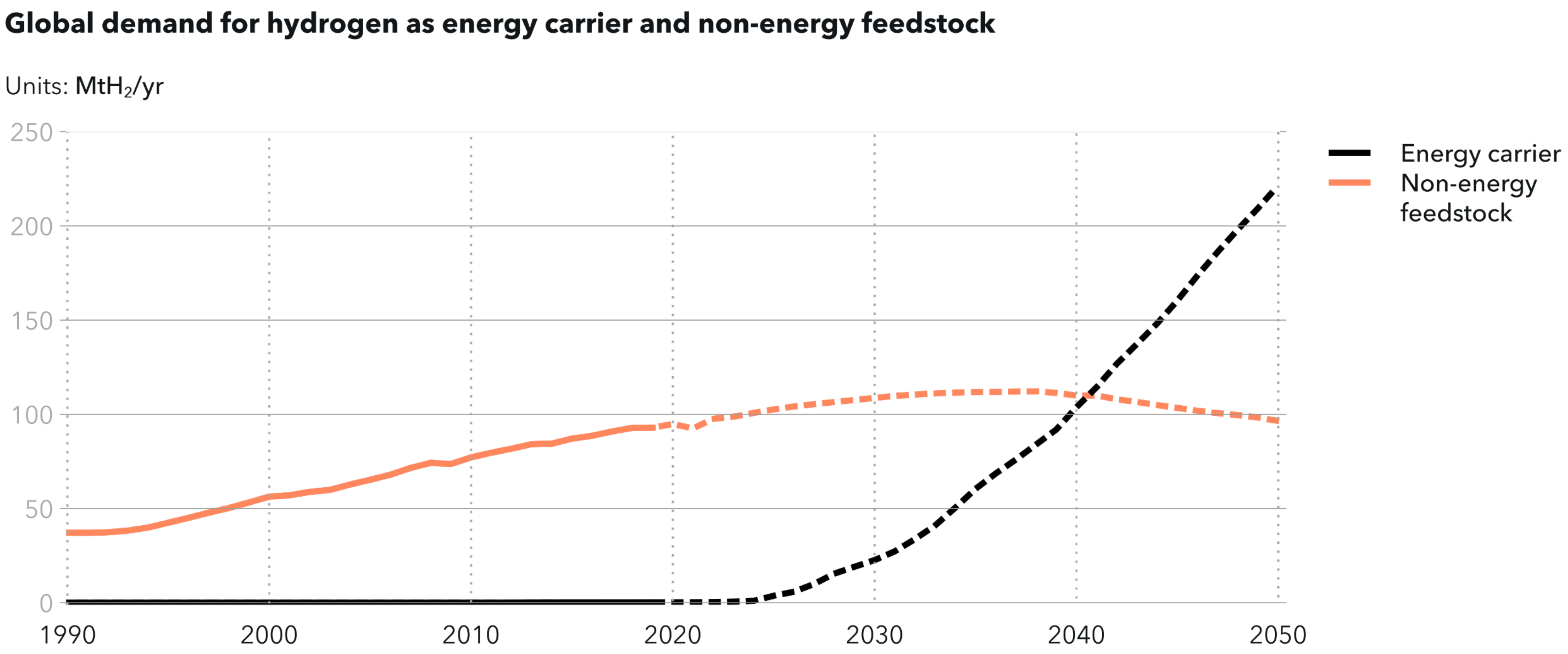
Hydrogen demand
- late but strong growth

- Global and European demand increase threefold by 2050
- Europe does *not* reach targets for 10 Mtpa renewable H_2 in 2030
- Manufacturing and transport ammonia and efuels dominate

- Transport - NH_3 & e-fuels
- Transport - hydrogen
- Electricity generation
- Buildings
- Manufacturing
- Other energy uses
- Ammonia production and other chemical processes
- Refineries

DNV

Energy use of hydrogen will overtake feedstock use in 2040



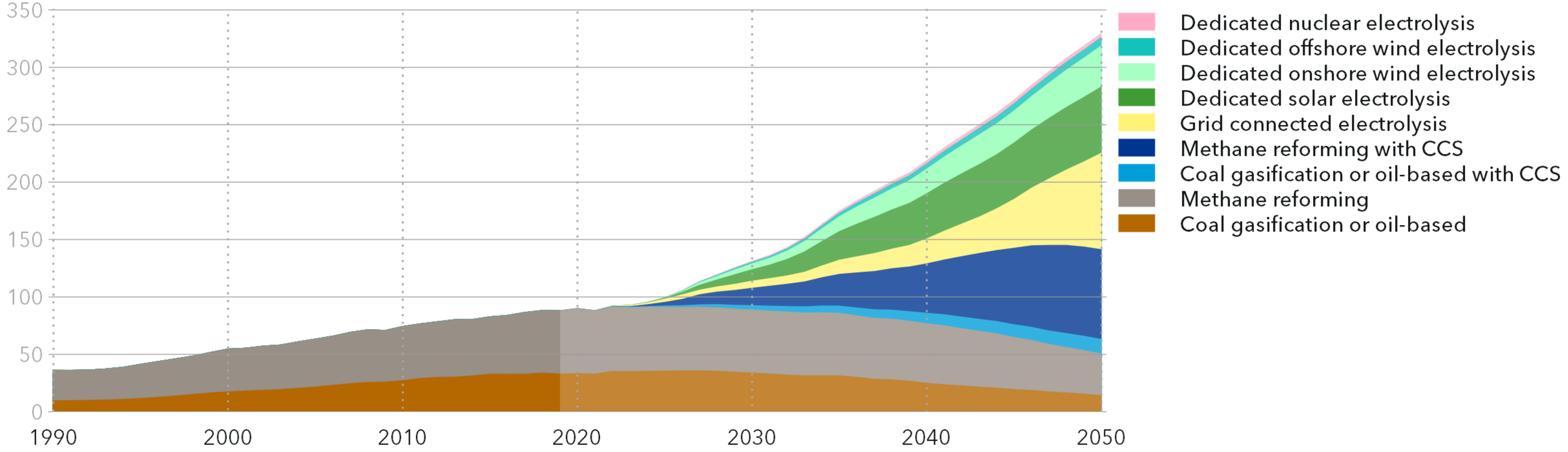
In 2050, 85% renewable and low-carbon hydrogen

3	6	4.9
EU	USA	China

$kgCO_2/kgH_2$

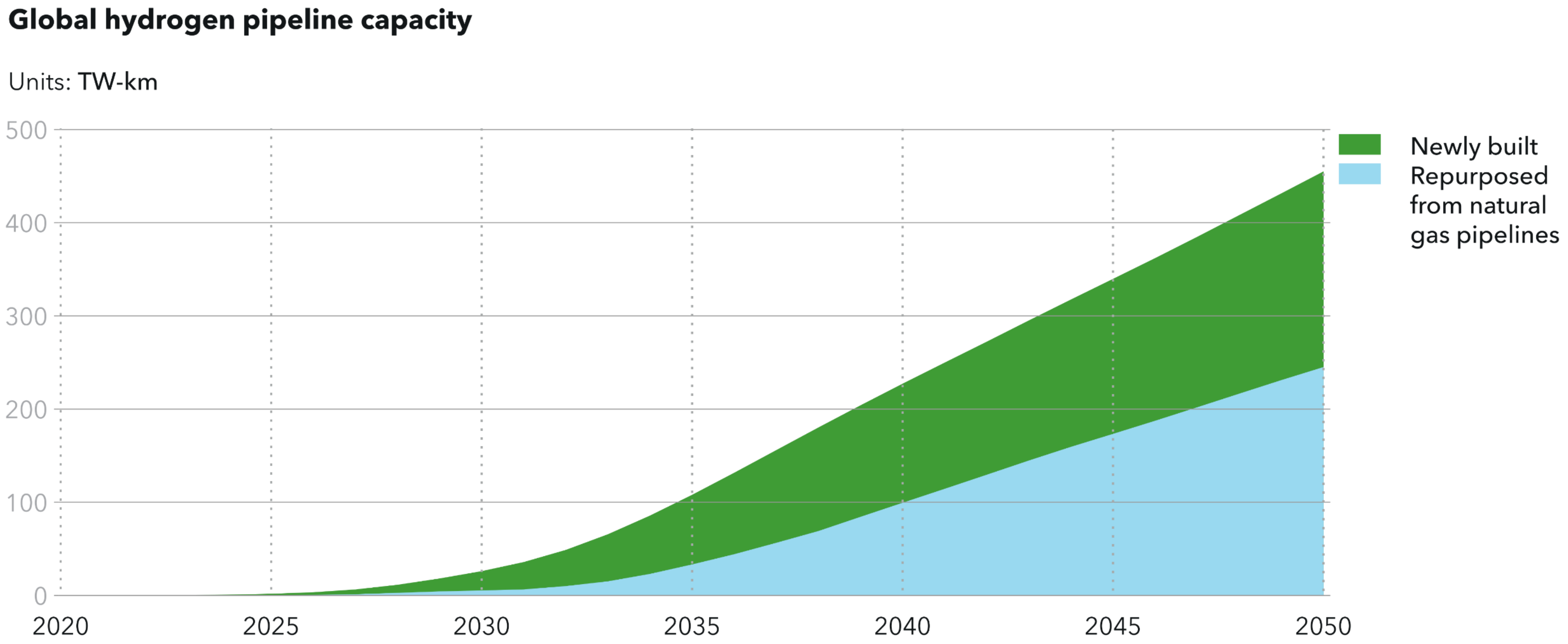
World hydrogen production by production route

Units: MtH_2/yr



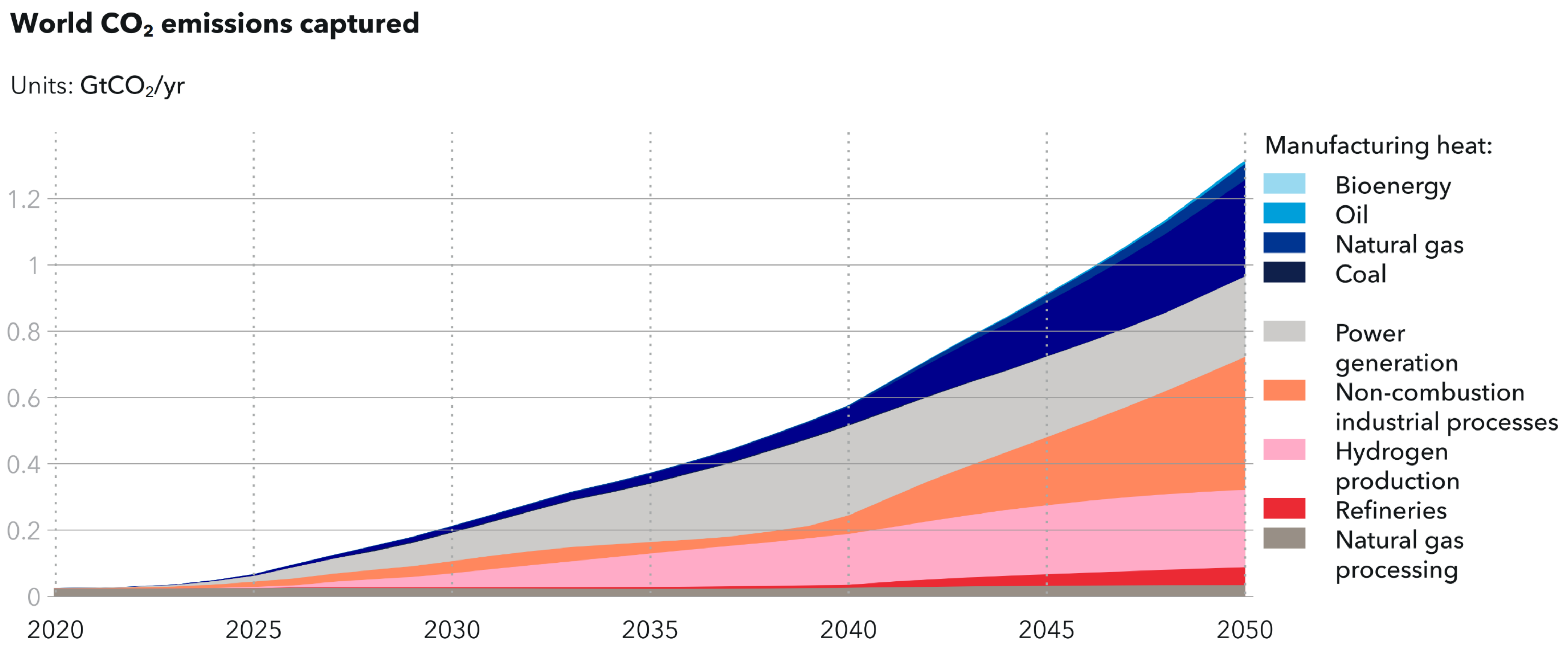
Historical data source: IEA Future of Hydrogen (2019), IEA Global Hydrogen Review (2021). Does not include hydrogen use in residual form from industrial processes.

More than 50% of global hydrogen pipelines will be repurposed from natural gas pipelines

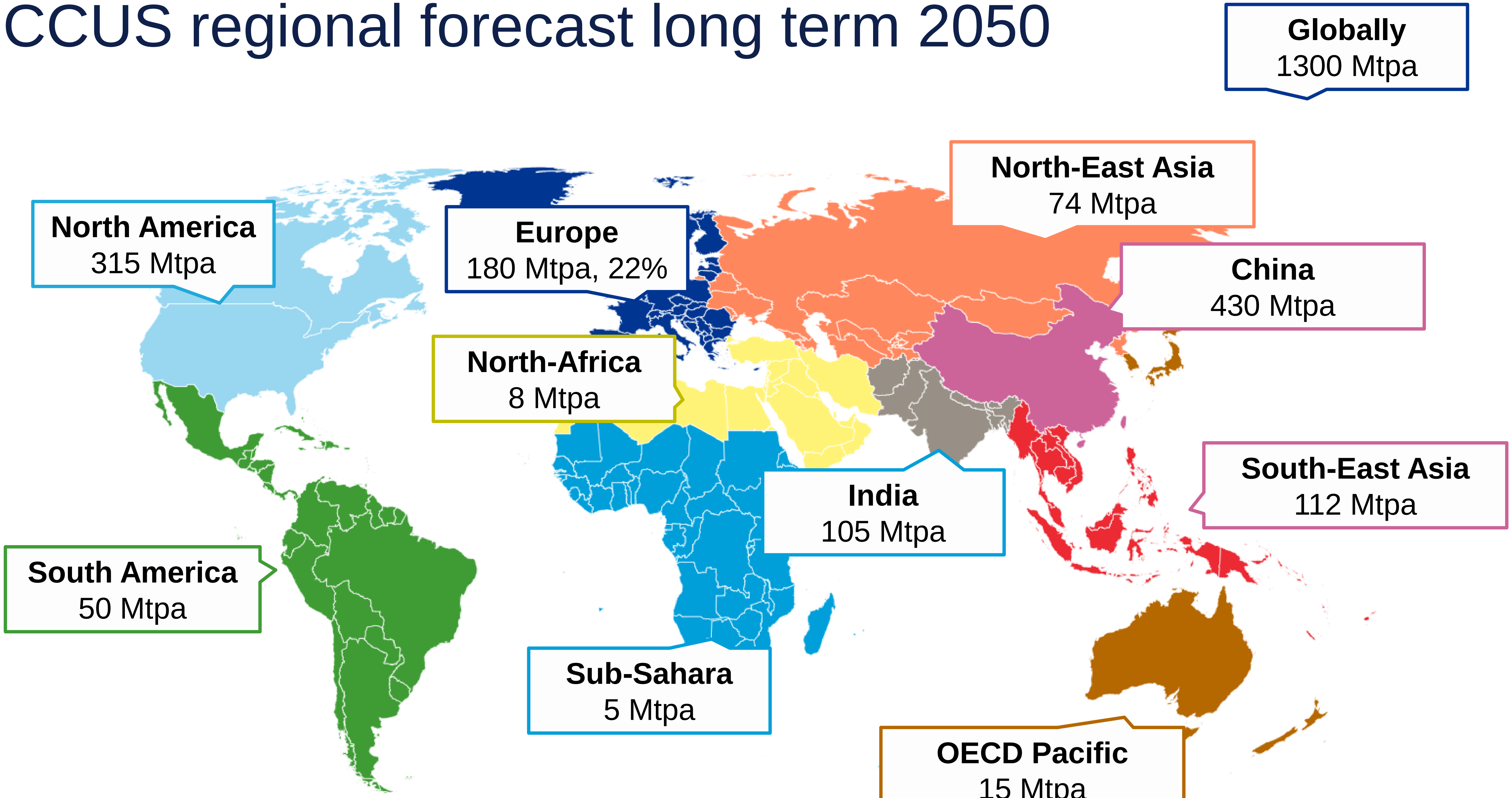


Includes transmission, distribution and trade pipelines.
TW-km – territorial waters kilometers

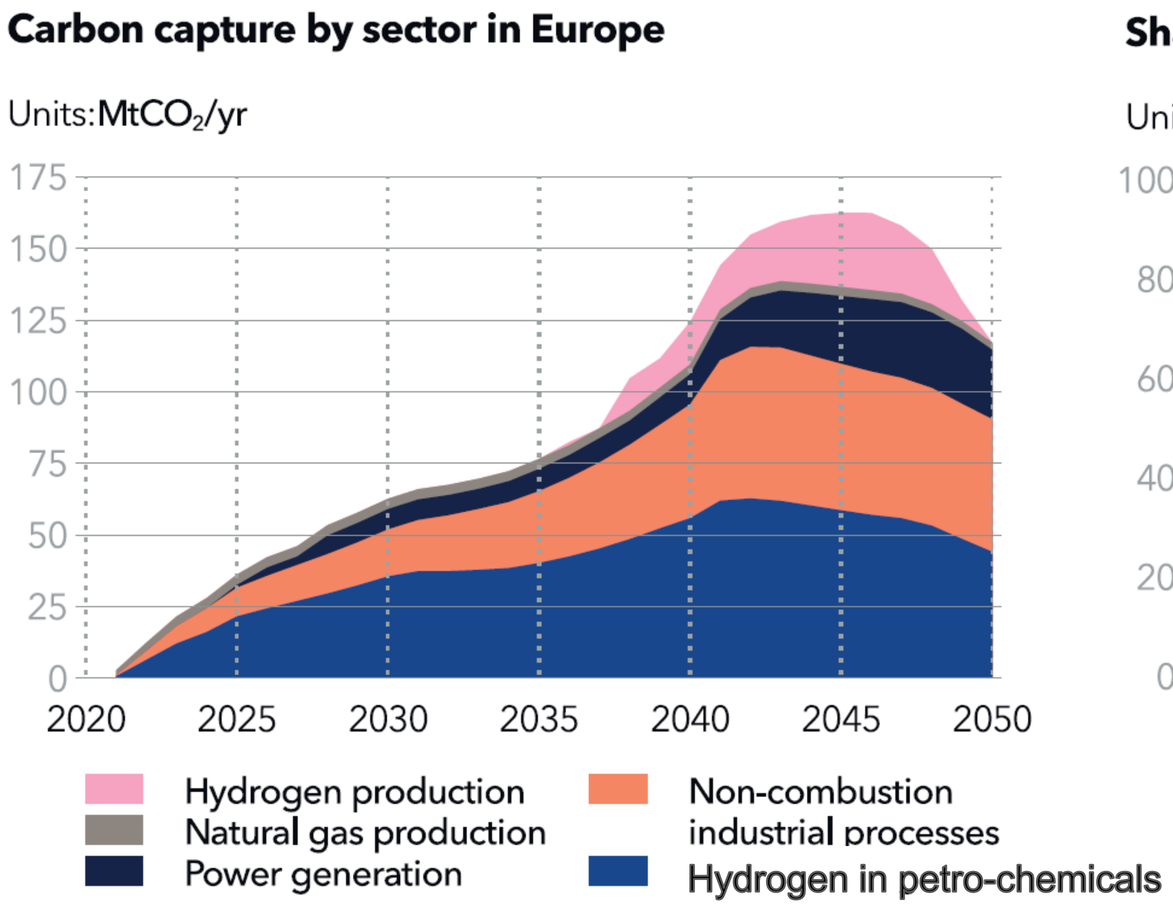
CCS picks up in 2040s – too little too late

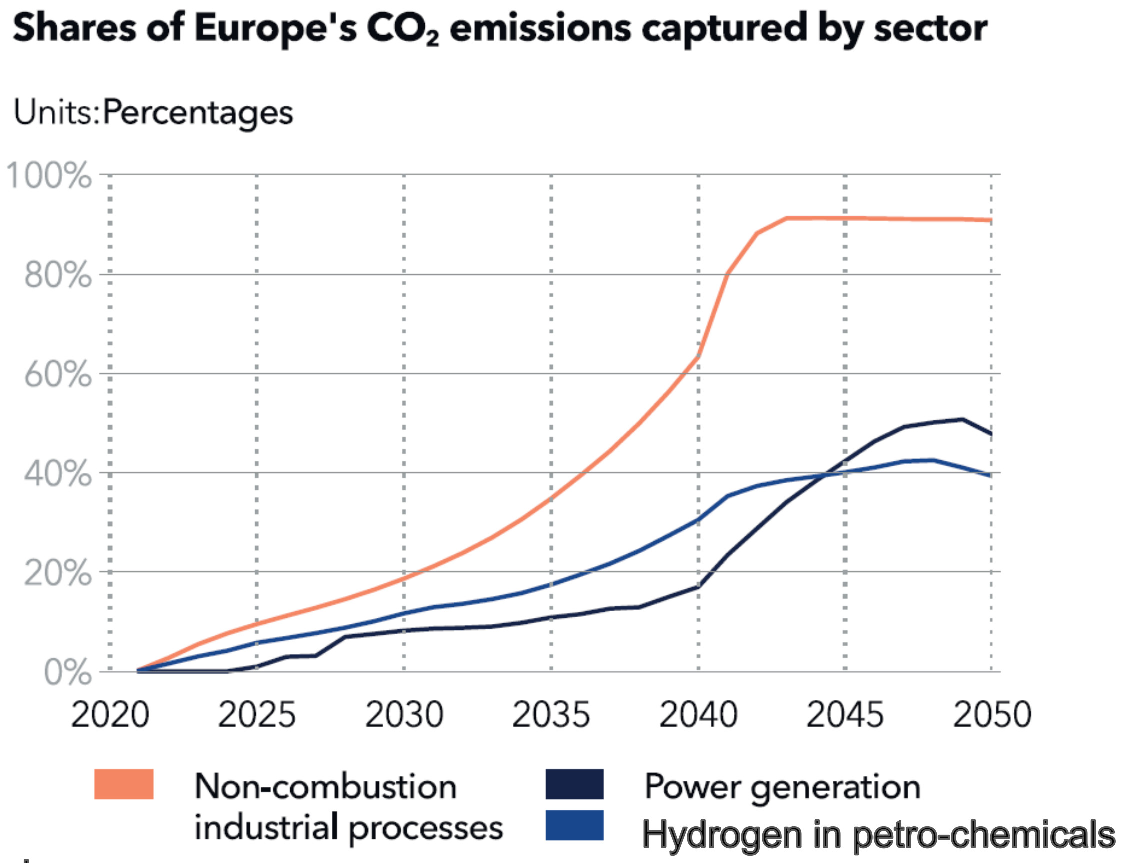


CCUS regional forecast long term 2050



CCS in Europe

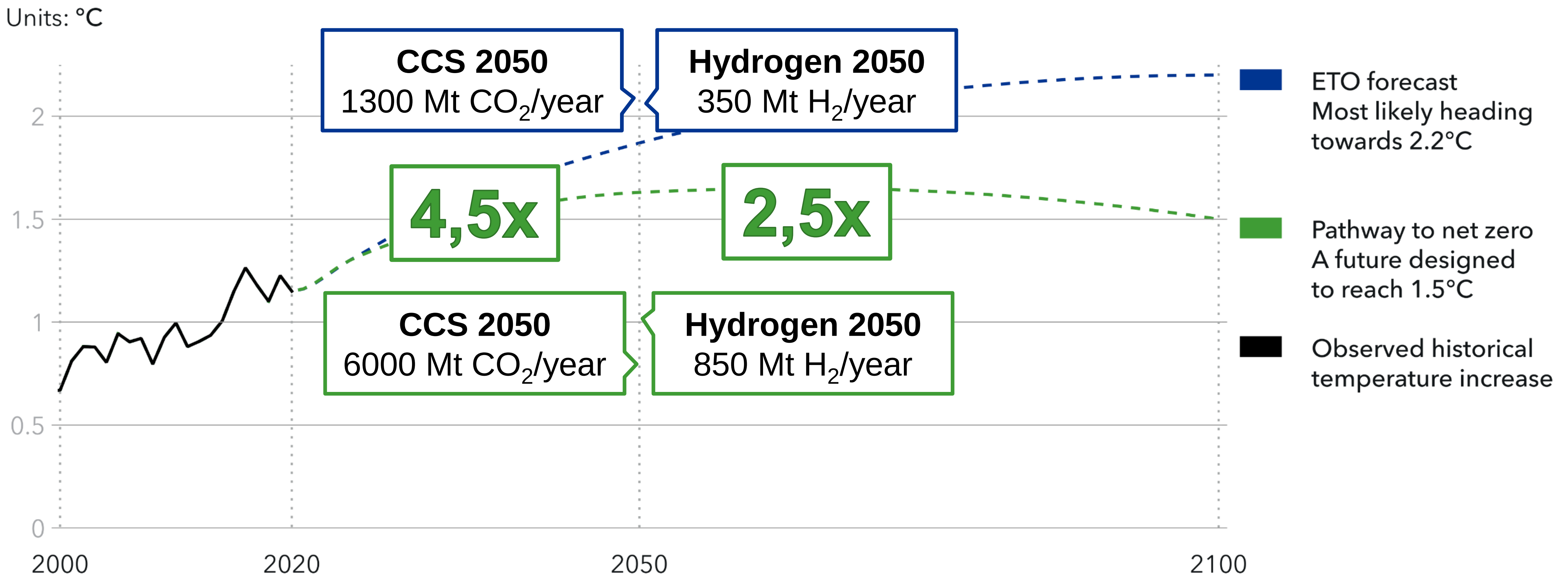




The two futures

Closing the gap to 1.5°C

Change in global surface temperature relative to 1850-1900



Historical data source: IPCC AR6 WGI (2021)

Offshore renewable green hydrogen production

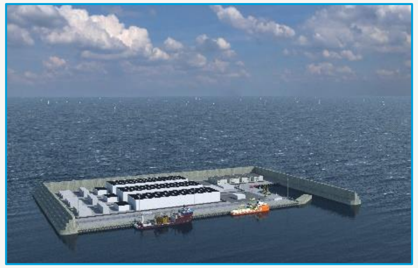
– Power and or gas grid connected, or off-grid?

Centralized

De-centralized

Bottom fixed

Energy island



Platform / Hub

Attached

Integrated

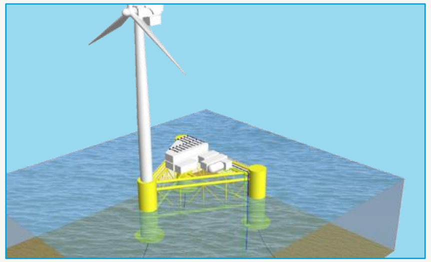
Gas and/or power grid connected

Floating

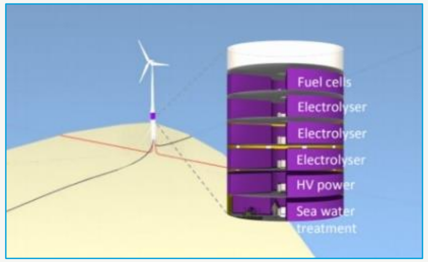
FPSO

Platform / Hub

Attached



Integrated



Off gas grid

Shipped to shore, secondary ship

Hydrogen carrier for global commodity trade

Off gas grid

Direct use bunkering, with medium scale storage


P2XFloater

Otimizing offshore wind power-to-gas

Maximizing H2-output, energy efficiency, scalability, costs with LCOH, and impact of the maritime environment

Partial internal grid

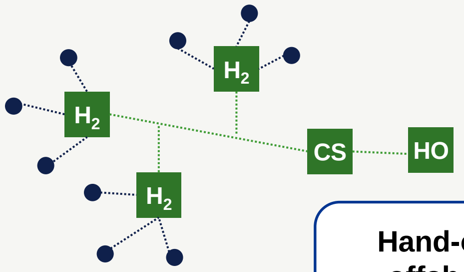
before compressor station, has to be optimized

All internal grid

Power grid

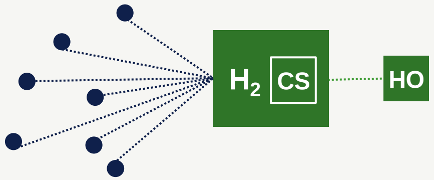
Several small H2 hubs

Wind farm design: e.g. ¼, ½ or ⅓ of turbines connected to each electrolyser "mini-hub"



One main hub

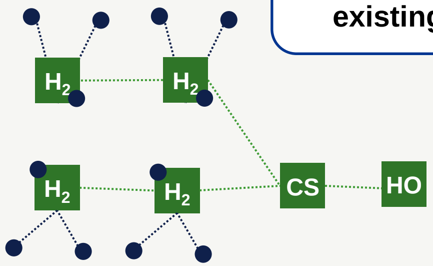
Wind farm design: one large hub with all the electrolysers, all wind turbines connected with power cables



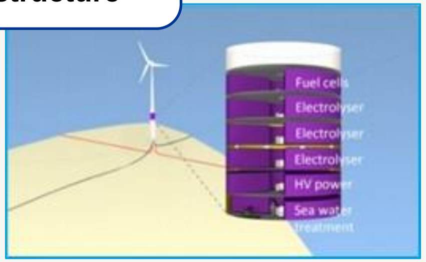
Hand-over onshore or offshore with new or existing infrastructure

Gas grid

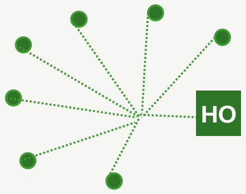
Attached and shared



Wind farm design: optimized H2 shared electrolysers, by 2-3 wind turbines to one which has the attached platform



Integrated electrolyser



Pressurized PEM to compressor substation or directly to common connection point for pipelines

CS Compressor station | HO Hand-over point | Gas pipeline | Wind-turbine | Power grid

DNV

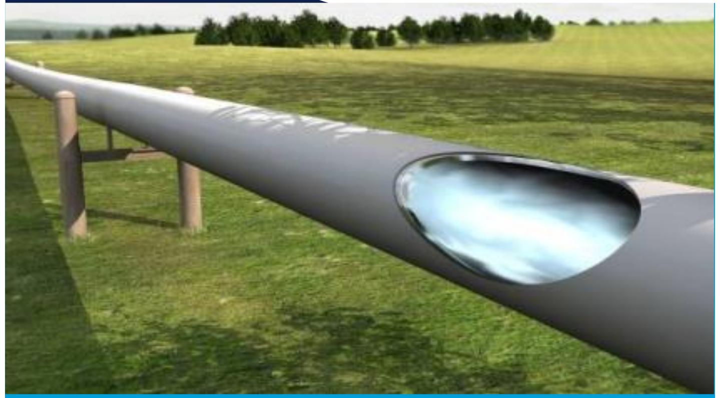
Scaling CCUS – a lot of practicalities!

CAPTURE

- Fossil power plants
- Natural gas CO_2 reduction
- Other industrial processes

- Cost efficiency capture rates
- Introduction of new technologies
- Technology review and benchmarking
- Up-scaling risk assessment
- HSE risk assessment
- Accidental release and dispersion
- Use of CO_2 for efuels
- Value of avoided CO_2

TRANSPORT



- Temporary storage
- Pipelines
- Ships

- Corrosion
- Material selection and structural design
- Flow assurance and operational issues
- Accidental release and dispersion
- Concept design for CO_2 ships
- Requalification of infrastructure

STORAGE

- Depleted oil or gas reservoirs
- Saline aquifers
- Onshore and offshore

- Verification of storage sites
- Permanence of storage
- Risk management
- Monitoring and verification
- Public concern
- Transfer of responsibility

Driving development of first international CCUS standards

DNV	**DNV-RP-J201** Qualification procedures for carbon dioxide capture technology	**DNV-RP-F104** Design and operation of carbon dioxide pipelines	**DNV-RP-J203** Geological storage of carbon dioxide
INTERNATIONAL STANDARD	**ISO 27919-1** Carbon dioxide capture – Performance evaluation methods for post-combustion CO_2 capture integrated with a power plant	**ISO 27913** Carbon dioxide capture, transportation and geological storage – Pipeline transportation system	**ISO 27914** Carbon dioxide capture, transportation and geological storage – Geological storage

Carbon capture and removal is essential to net zero

From energy and process industry

5.8 Gt CO_2

Direct air capture

1.6 Gt CO_2

From land use changes (nature-based solutions)

1.1 Gt CO_2

*2050 figures

Development of categories for CO_2 shipping
Temperature and pressure regimes

Medium pressure (15-20 barg, -30Cº)

- Mature technology - Decades of operational experience
- Limitations to cargo tank size
- Selected regime for northern light initial phases

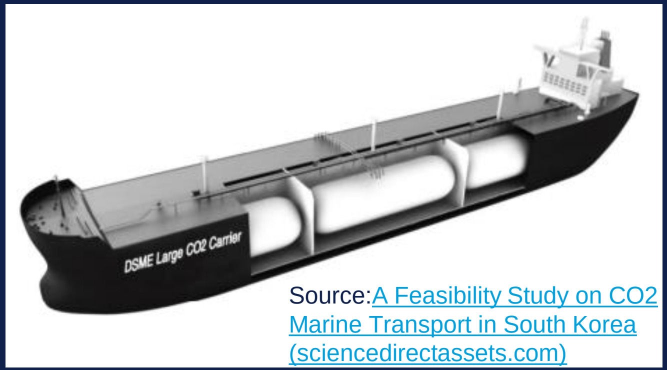
Low pressure (7-10 barg, -50 Cº):

- Novel operation
- Allow larger cargo tanks and reduced cost for shipping
- Increased cost for liquefaction and conditioning

Ambient temperature (40-50 barg, >0 Cº):

- Novel design
- Scalable and flexible design
- Reduced cost for liquefaction and conditioning

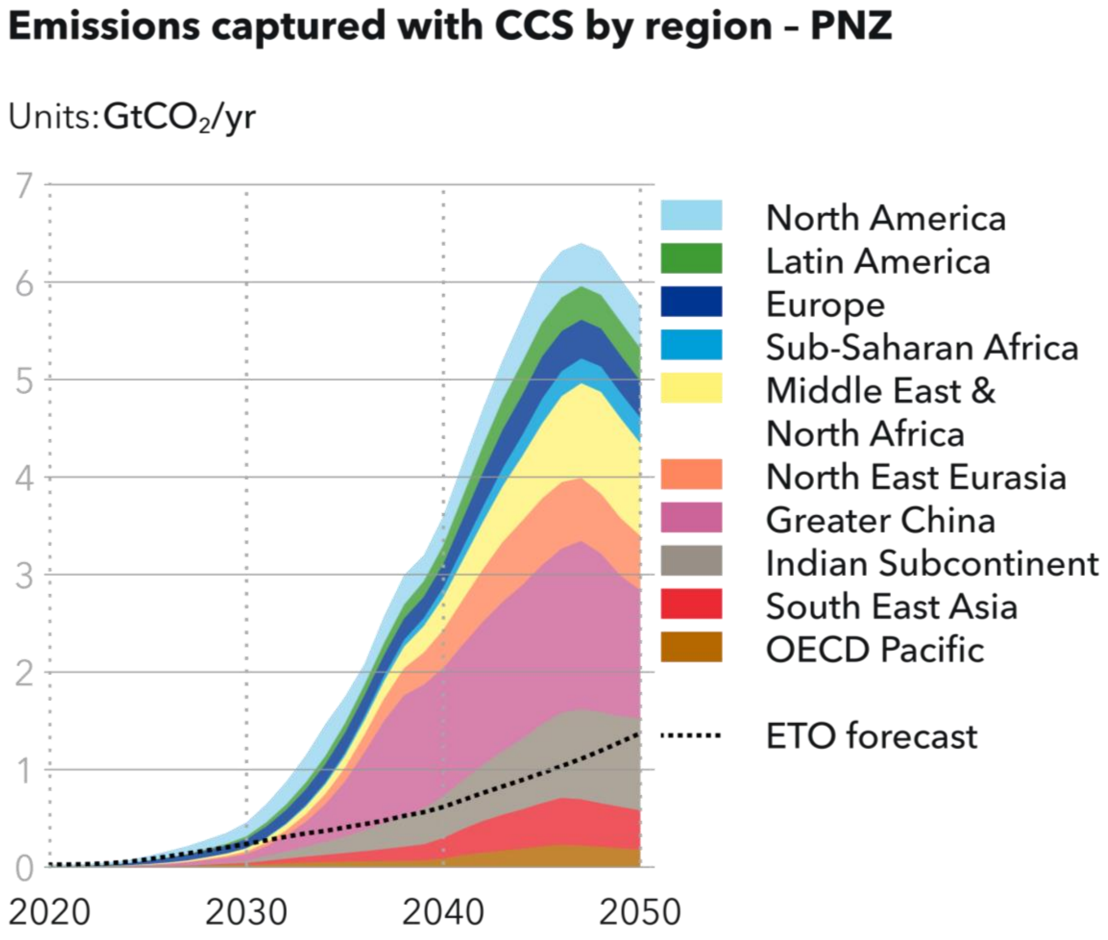
Source: Yara International ASA



Source: A Feasibility Study on CO2 Marine Transport in South Korea (sciencedirectassets.com)

Source: KNCC (kn-cc.com)

What is needed of CCS in the regions for net zero?



- Emissions captured from ~0 Gt to 5.8 Gt

- **Technologies**
  - ‘Point-to-point' CCS facilities vs. ‘hub and cluster’ networks
  - Establishing CCS hubs will help accelerate deployment by reducing costs
- **Key policies:**
  - Higher carbon prices incentivizing CCS deployment
  - Mandates requiring CCS in natural gas-fired power generation
  - CAPEX/OPEX support and policies promoting value chain/infrastructure development enable CCS and direct air capture capacity ramp up

WHEN TRUST MATTERS

Highlights

"Short term delay, long term acceleration"

High energy prices and energy security focus due to the war in Ukraine

We forecast global warming at 2.2°C by 2100

Despite urgency of action, global CO_2 emissions remain at record levels.

83% renewable share in 2050 electricity mix

Electricity is growing and greening everywhere

Hydrogen reaches 5% of the 2050 global energy mix – a third of needed in a net zero future

CCS needs to reach >6 Gtpa by 2050, up from forecasted 1,3 Gtpa worldwide

Thank you for your attention!

Reach out for further details and discussions

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