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The Role of Carbon Capture & Storage (CCS) and Hydrogen in the Energy Transition

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Rice University

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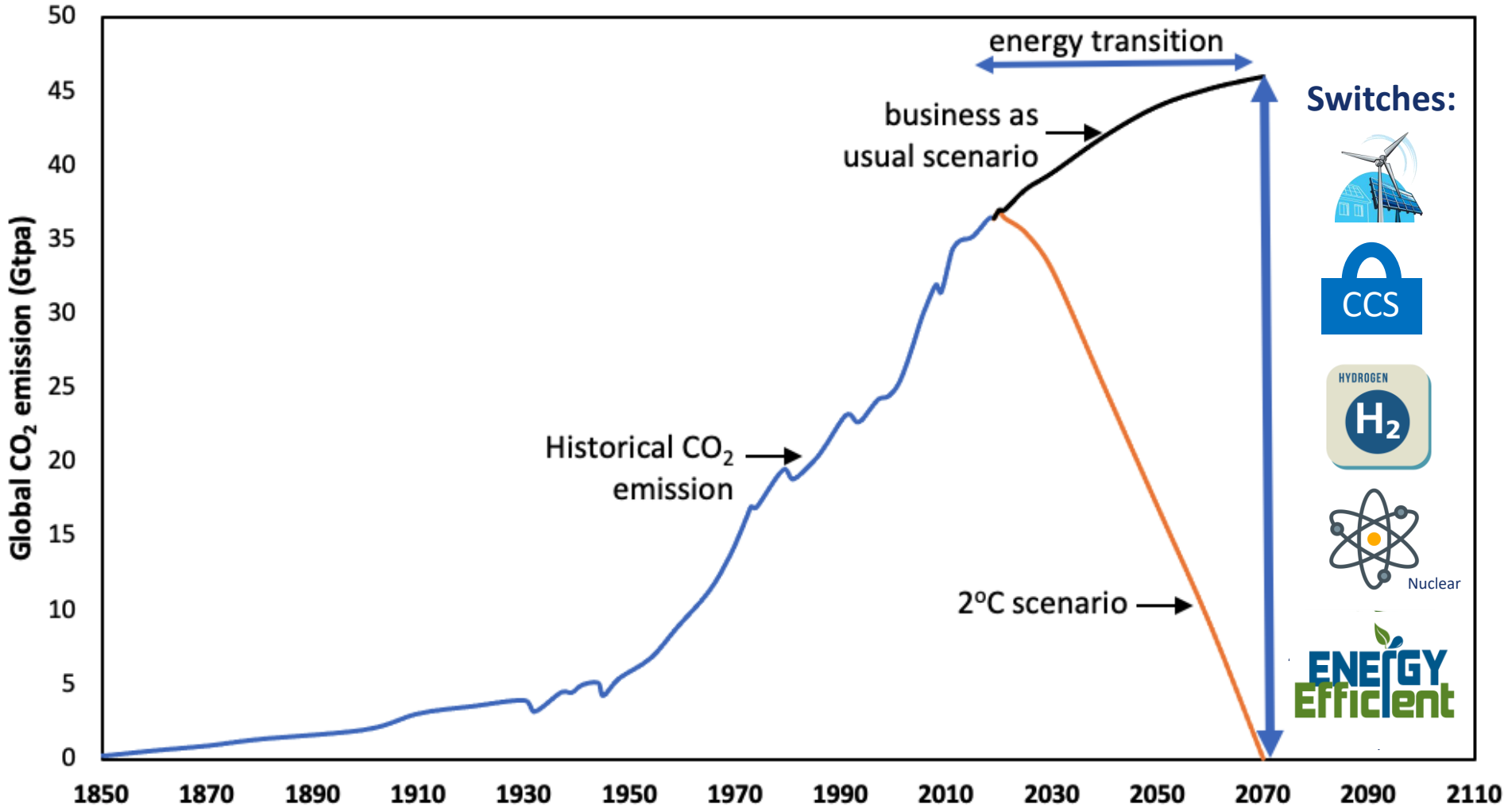
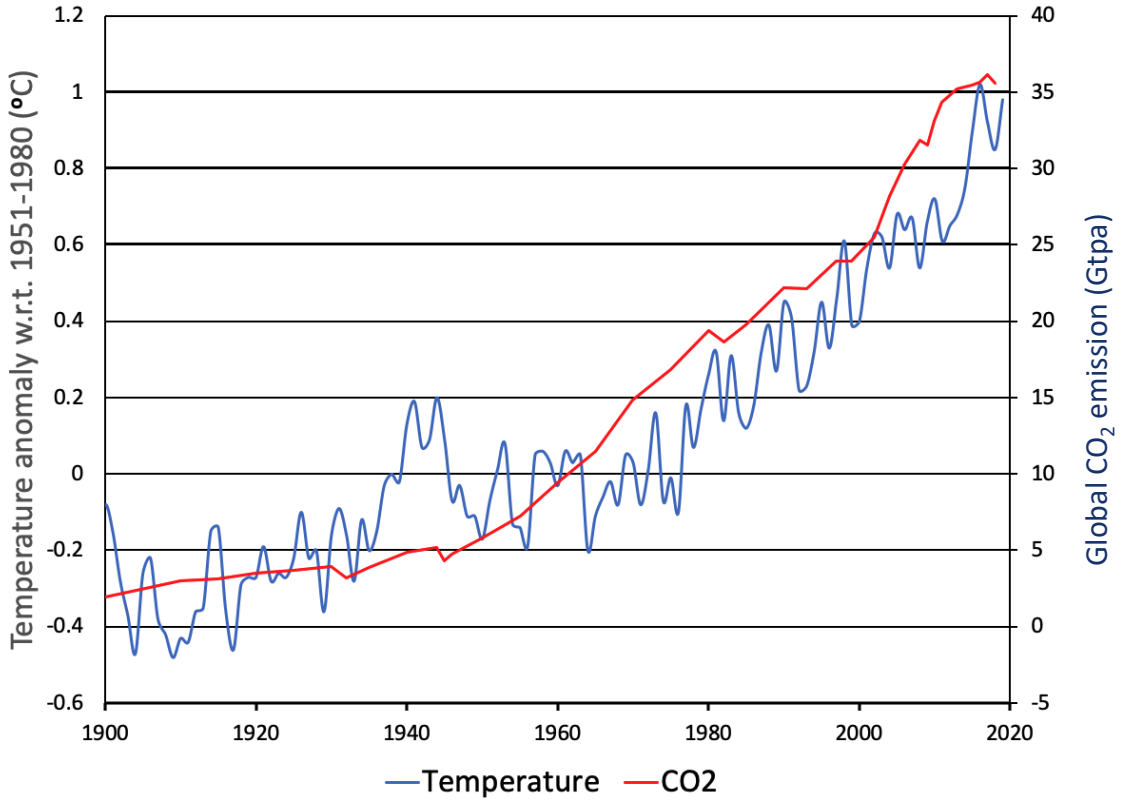
Overall message



Outline of content

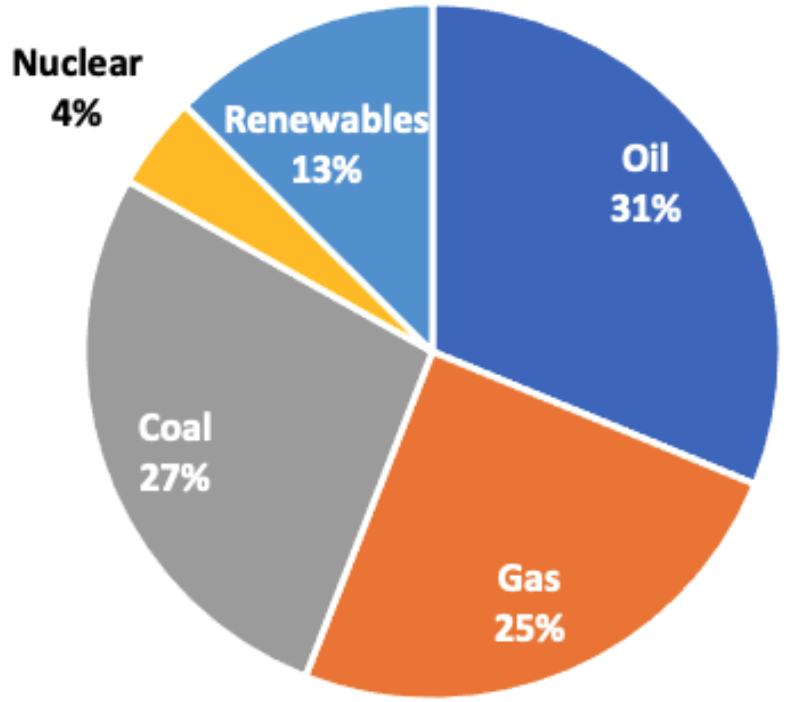
- Role of CCS and H_2 in decarbonizing the power, transport and industry sectors
- CCS case studies
- Way forward for CCS & H_2

A case for action: global temperature rise and fossil fuel consumption



Annual global CO_2 emission and earth's surface temperature rise

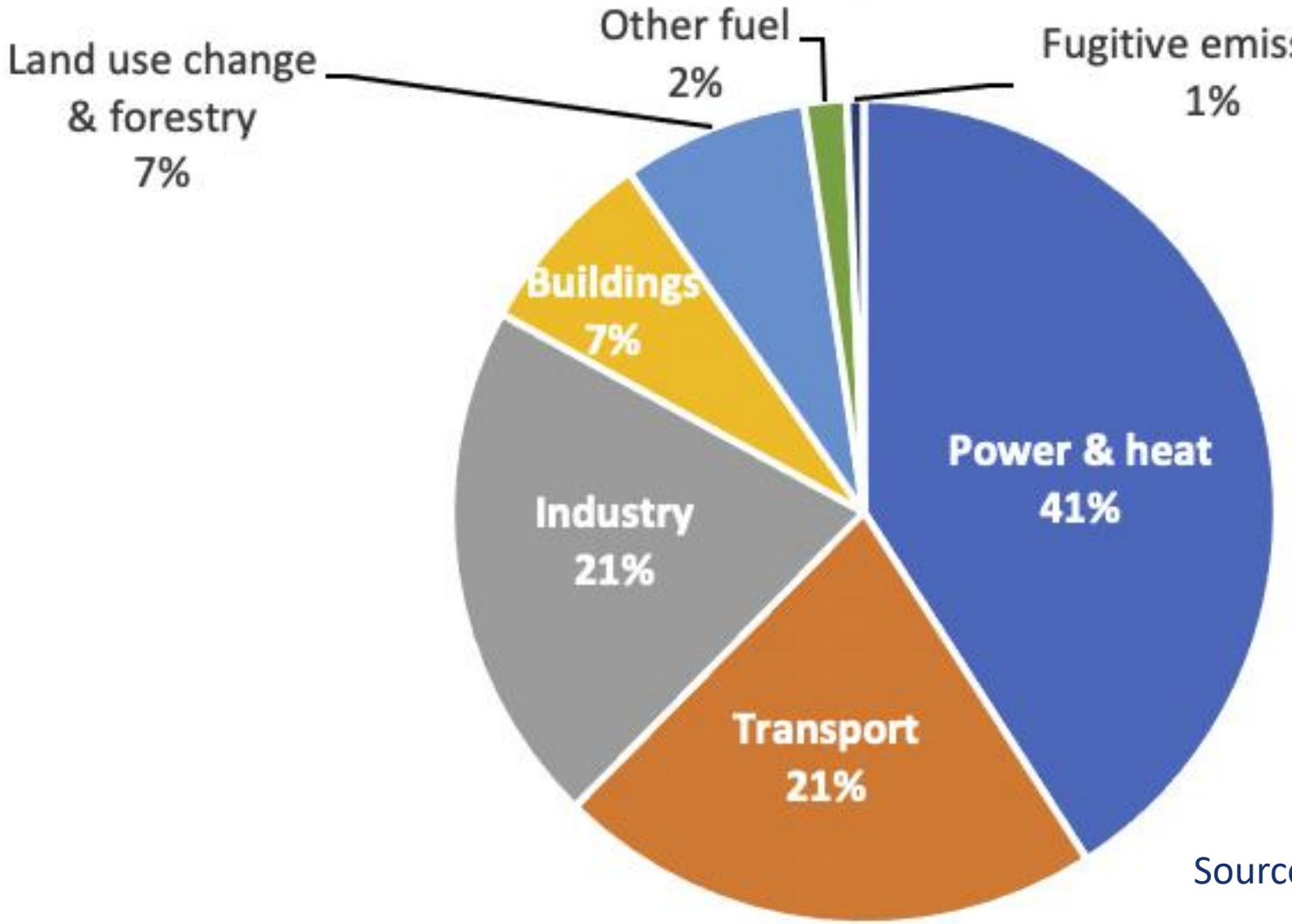
Source: NASA, Our World in Data



Global energy consumption by fuel type in 2020

Source: BP Statistical Review, 2021

Global CO_2 emission by sector



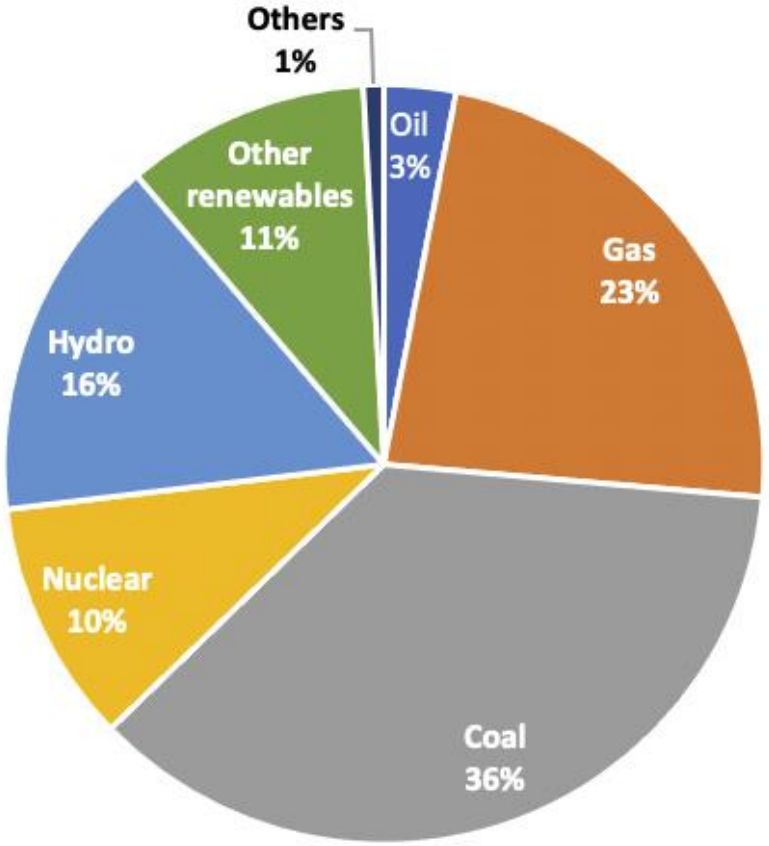
Energy transition requires decarbonizing three energy consumption sectors:

- **Power (electricity)**
- **Transport**
- **Industry**

Source: Our world in data (2016)

Decarbonizing the power sector

Renewables' contribution to power generation: Significant but not fast enough

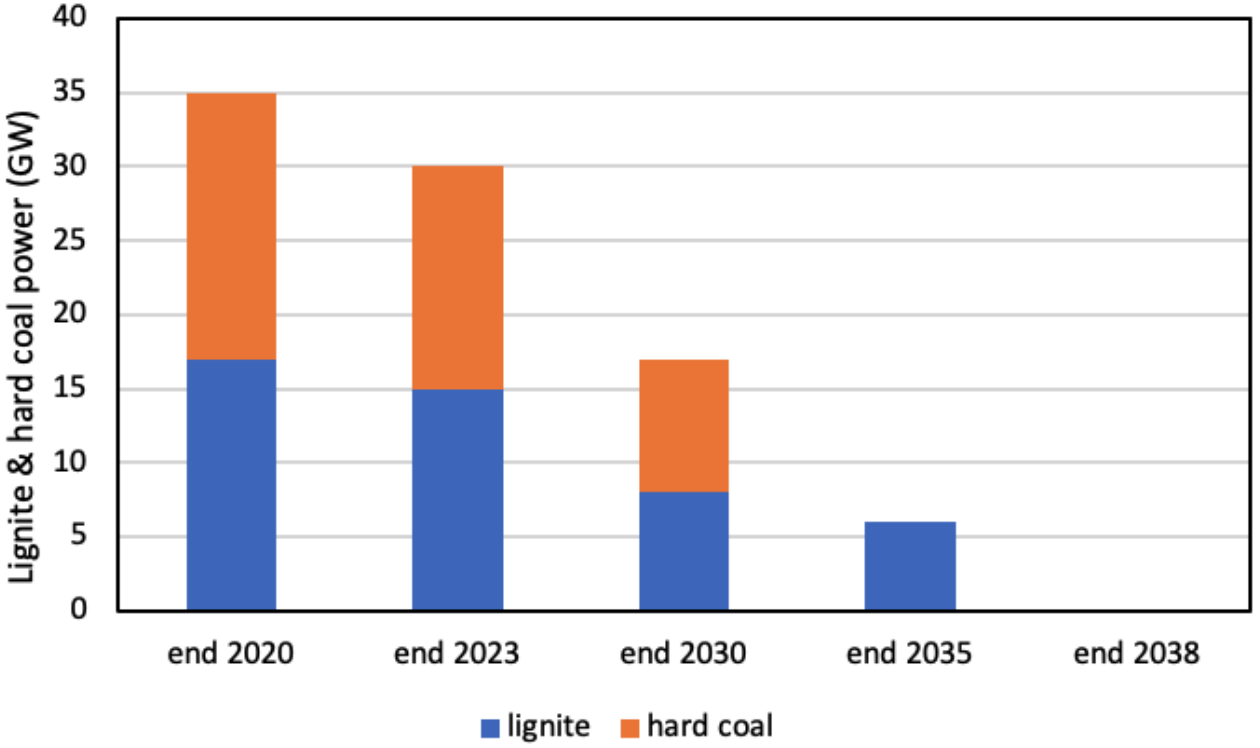


Global power generation by fuel type, 2019

Source: BP Statistical Review, 2020

- Renewables' growth is not fast enough to decarbonize the power sector by 2050, let alone the other sectors.

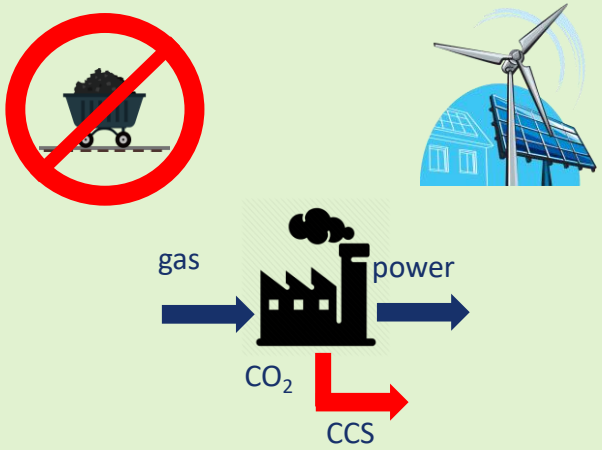
Phase out of coal-fired power plants in Germany



Source: Dickel, 2020

Ways to decarbonize the power sector

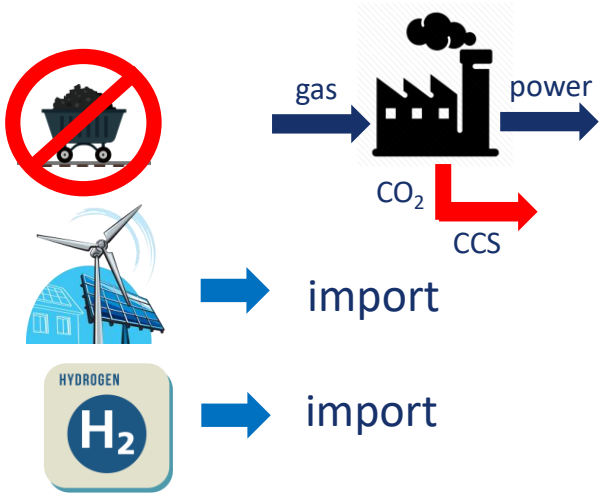
Countries with domestic renewable energies (e.g., Germany, UK, Indonesia):



base load

Nuclear

Countries with limited domestic renewable energies (e.g., Singapore, Korea, Japan):



Nuclear

Decarbonizing the transport sector

Decarbonizing the transport sector

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Facts:

- Transport contributes to 21% of global CO_2 emission.
- Globally, 96% of transport fuels come from petroleum-based liquids (EIA, 2016).

Decarbonization solutions:

Road

EV

HFCV

Aviation

Biofuels

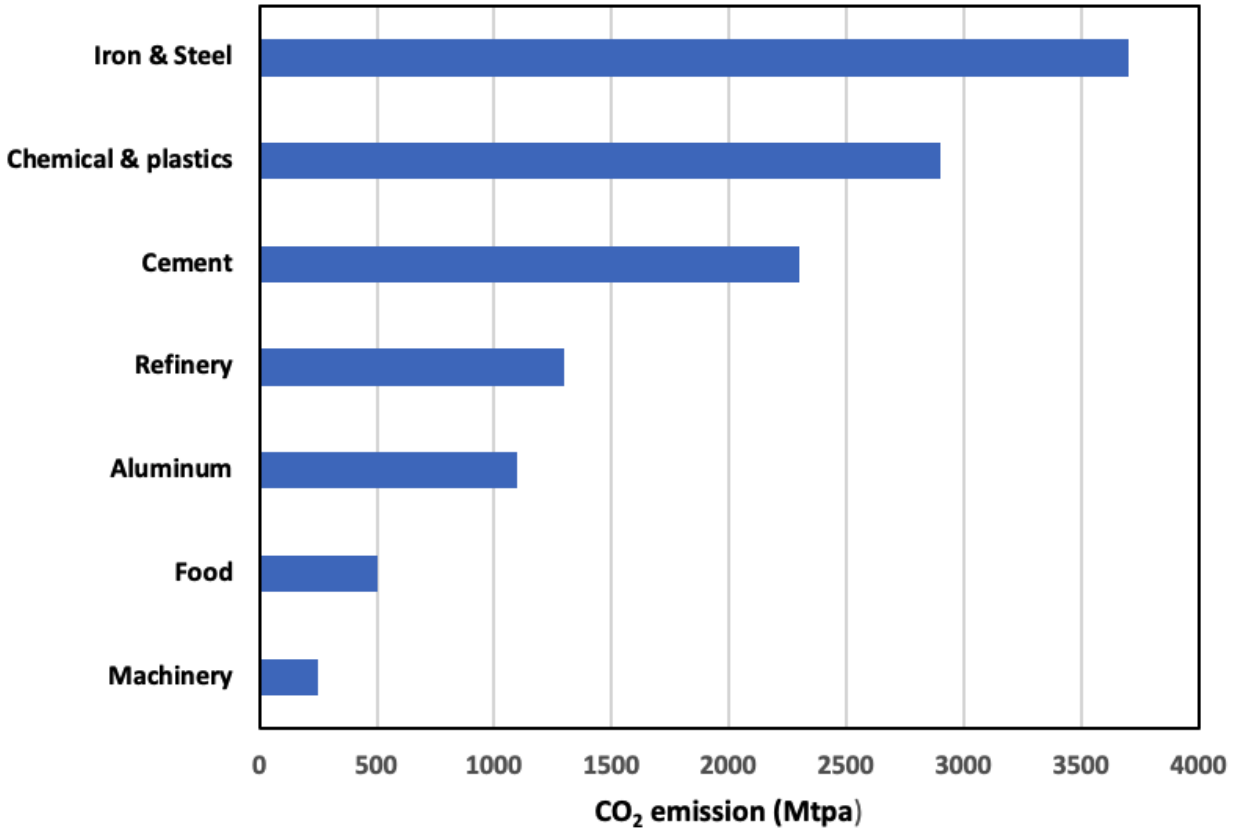
Marine

H_2 or NH_3 vessel

Replace mobile CO_2 emission by stationary emission. Remove CO_2 at source of electricity or H_2 production by CCS.

Decarbonizing the industry sector

Global CO_2 emission by industry



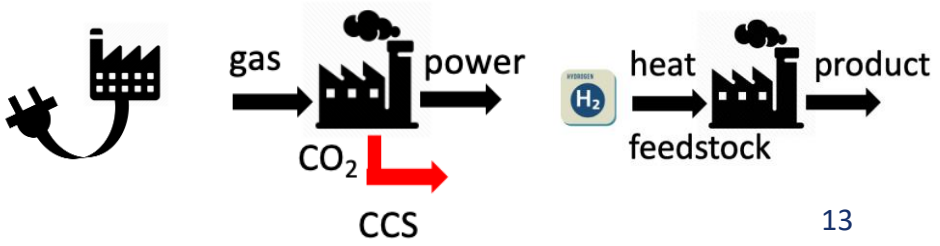
Source: Energy Innovation (2020)

Facts:

- Industry is sector hardest to decarbonize.
- Fossil fuels are used for (1) high-temperature heating, and (2) feedstock.

Decarbonization solutions with increasing impact:

- Electrification of heating.
- Retrofit existing plants with CCS.
- Use hydrogen for high-temperature heating and feedstock.



Five switches of energy transition

	Renewable energies	CCS	Hydrogen	Nuclear power	Energy efficiency
Power	✔	✔	✓	✓	✓
Transport	✔ (power & biofuel)	✓	✔	✗	✓
Industry	✓ (biofuel)	✔	✔	✗	✓

✔ Major contribution

✓ Some contribution

✗ Limited contribution

Importance of hydrogen in decarbonization

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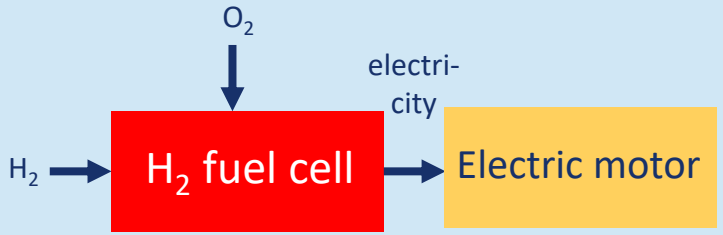
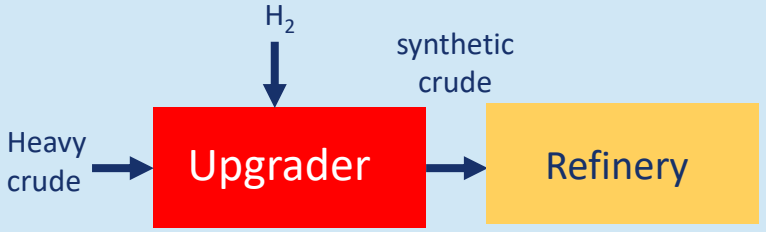
Electricity generation



Heat generation:

$$2H_2 + O_2 \rightarrow 2\ H_2O + \text{heat}$$

Feedstock for industry:



Application

transport/power

industry

industry

Target sectors for H_2 strategy in selected places

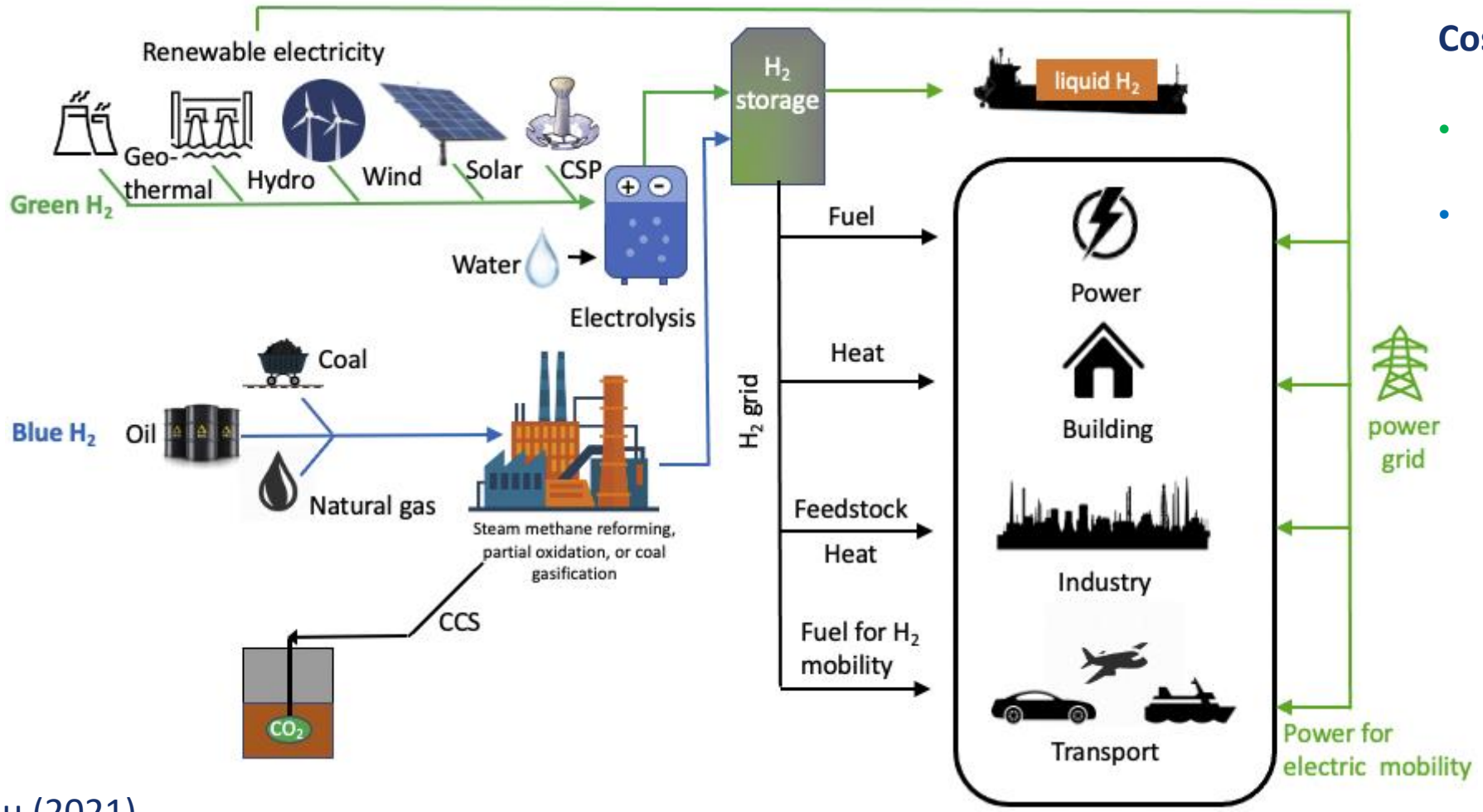
Hydrogen use sectors	EU	DE	NL	FR	ES	IT	UK	NO	CH	UA	RU	JP	KR	CN	AU	CA	MO
Industry	✓	✓	✓	✓	✓	(✓)	✓	✓	✗	✗	✓	(✓)	✗	✗	✓	(✓)	✓
Power	(✓)	(✓)	(✓)	✓	(✓)	✗	✓	✗	✗	✓	✓	✓	✓	✓	✓	(✓)	(✓)
Transport	✓	✓	✓	✓	✓	(✓)	✓	✓	✓	✓	(✓)	✓	✓	✓	✓	✓	(✓)
Buildings	(✓)	(✓)	(✓)	(✓)	✗	✗	(✓)	✗	✗	(✓)	(✓)	✓	✓	✗	(✓)	(✓)	(✓)
Export	✗	✗	✗ [1)]	✗	✓	✗	✗	✗ [2)]	✗	✓	✓	✗	✗	✗	✓	✗	✓

✓ main sector (✓) less relevant ✗ not addressed

1) Hydrogen imports transit to other countries (e.g. Germany) considered.
2) For Norway, hydrogen is not targeted for direct export, but indirectly through the export of NG with local CCS.

Source: World Energy Council, 2020

Production of green and blue hydrogen

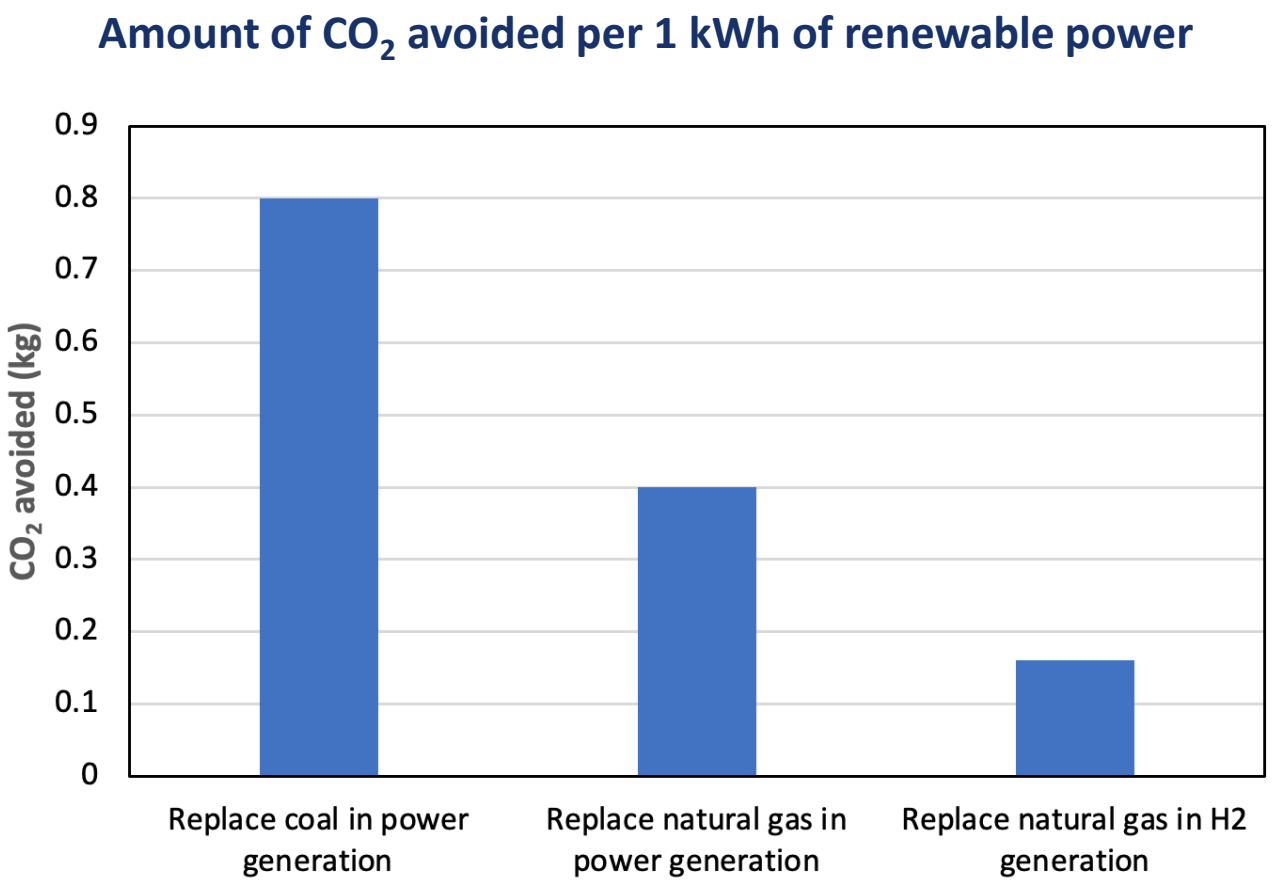


Cost comparison:

- Green H_2 ($3-7/kg)
- Blue H_2 ($1.4-2.4/kg)

Source: Lau (2021)

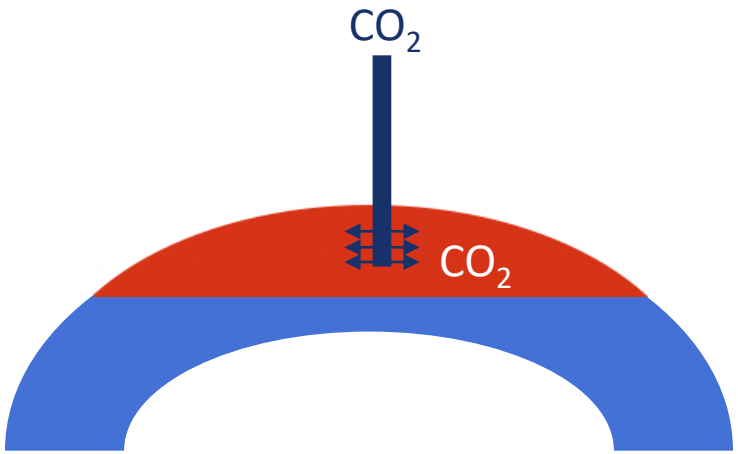
How can renewable electricity be best used?



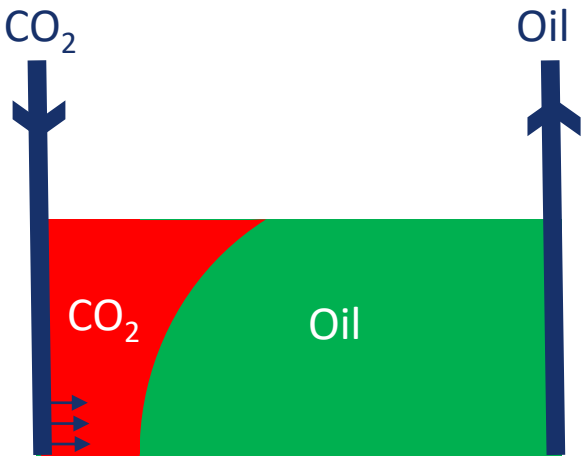
- Replacing fossil fuel to produce power, not producing green H_2.
- Green H_2 (from renewable power) unavailable in large quantities until full decarbonization of power sector.
- Blue H_2 (coal/gas+CCS) needed to decarbonize transport & industry sectors.

Status of carbon capture and storage

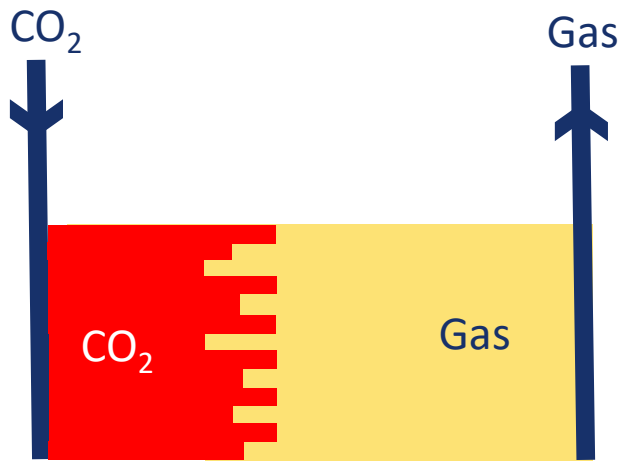
Where can CO_2 be stored permanently?



Saline aquifer



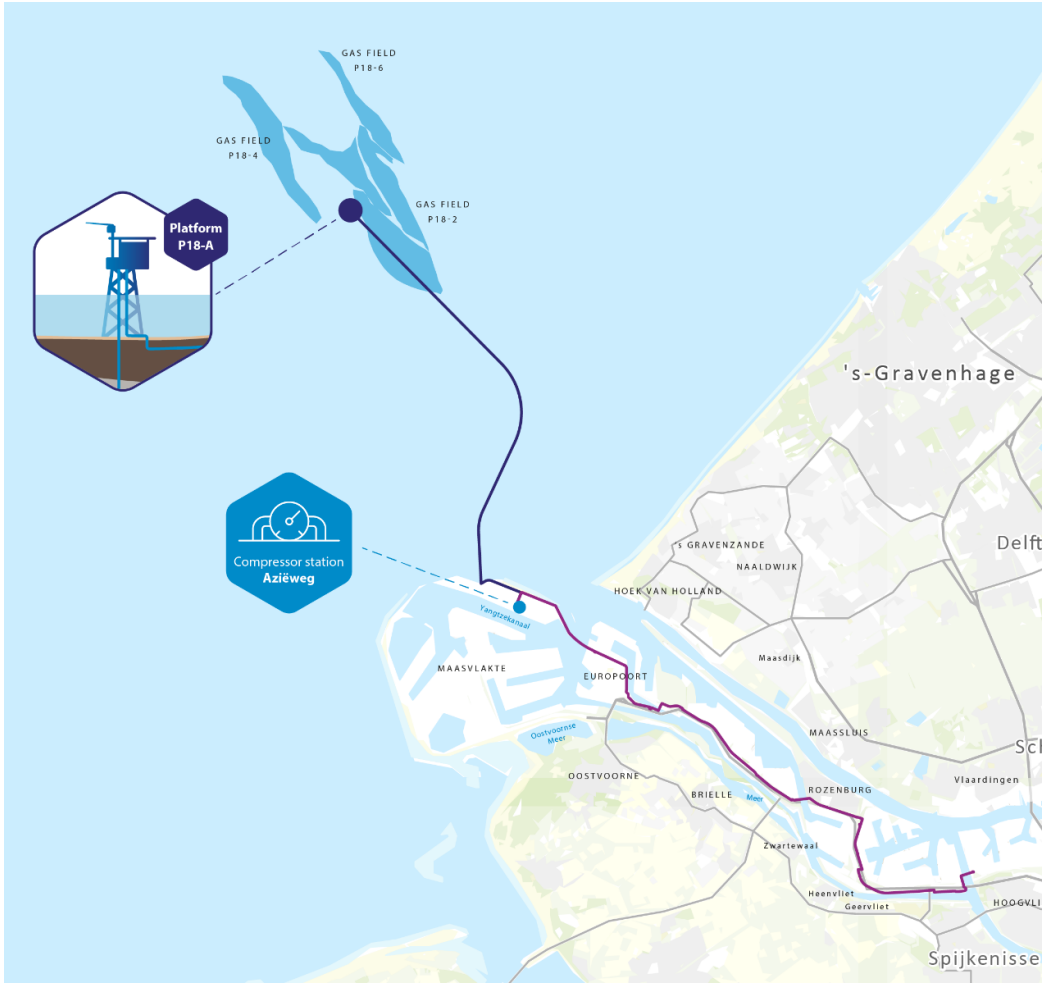
Oil reservoir



Gas reservoir

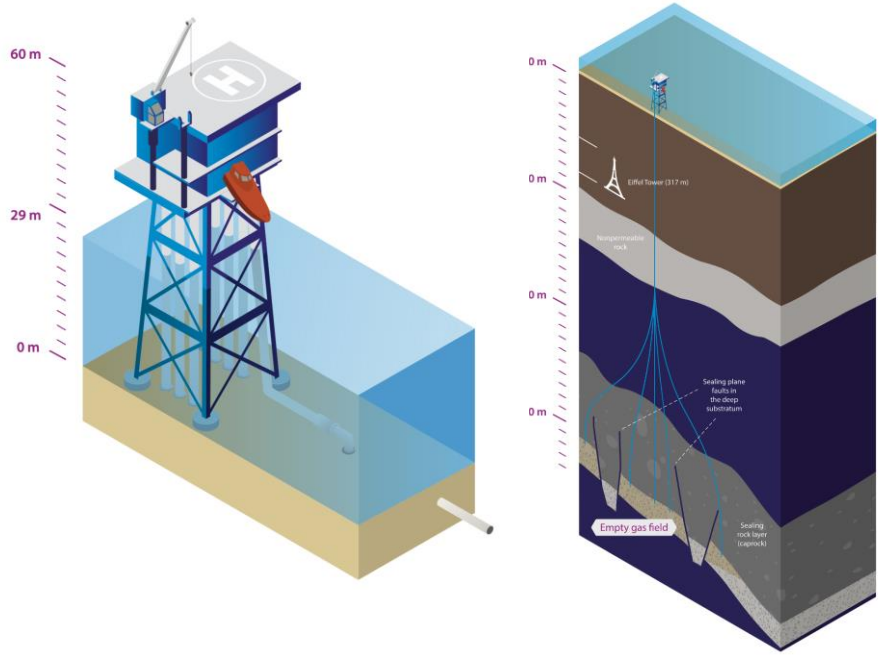
Global CO_2 emission = 35 Gtpa
Global CCS storage = 41 Mtpa

Porthos CCS Project in Netherlands

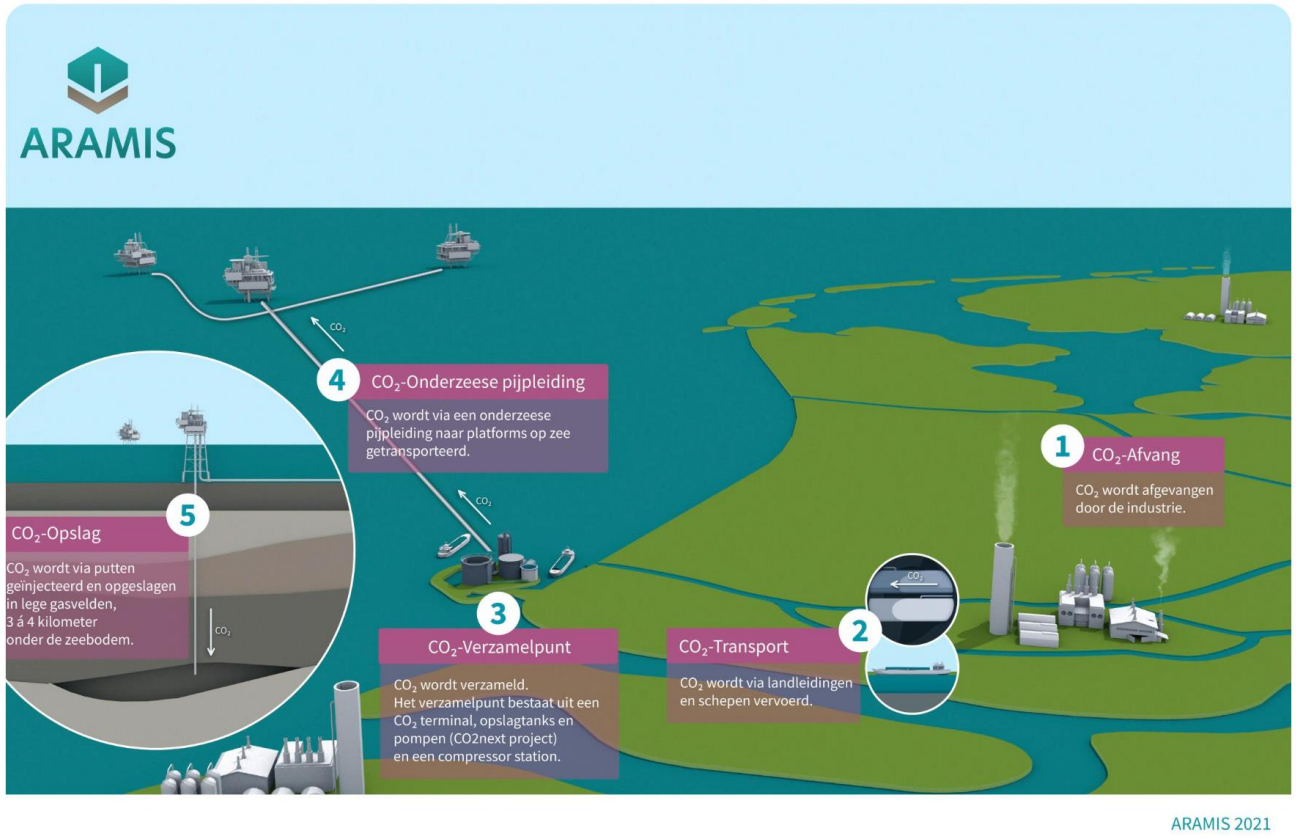


Port of Rotterdam CO_2 Transport Hub & Offshore Storage

- 20 km offshore
- 2.5 Mtpa for 15 years (37 Mt CO_2)
- FID 2022, operational by 2024/2025



Aramis CCS Project & Green H_2 project



5 Mtpa CO_2; FID 2023; operational 2026

'Takes guts' | Shell gives green light to 200MW Dutch green hydrogen project powered by offshore wind

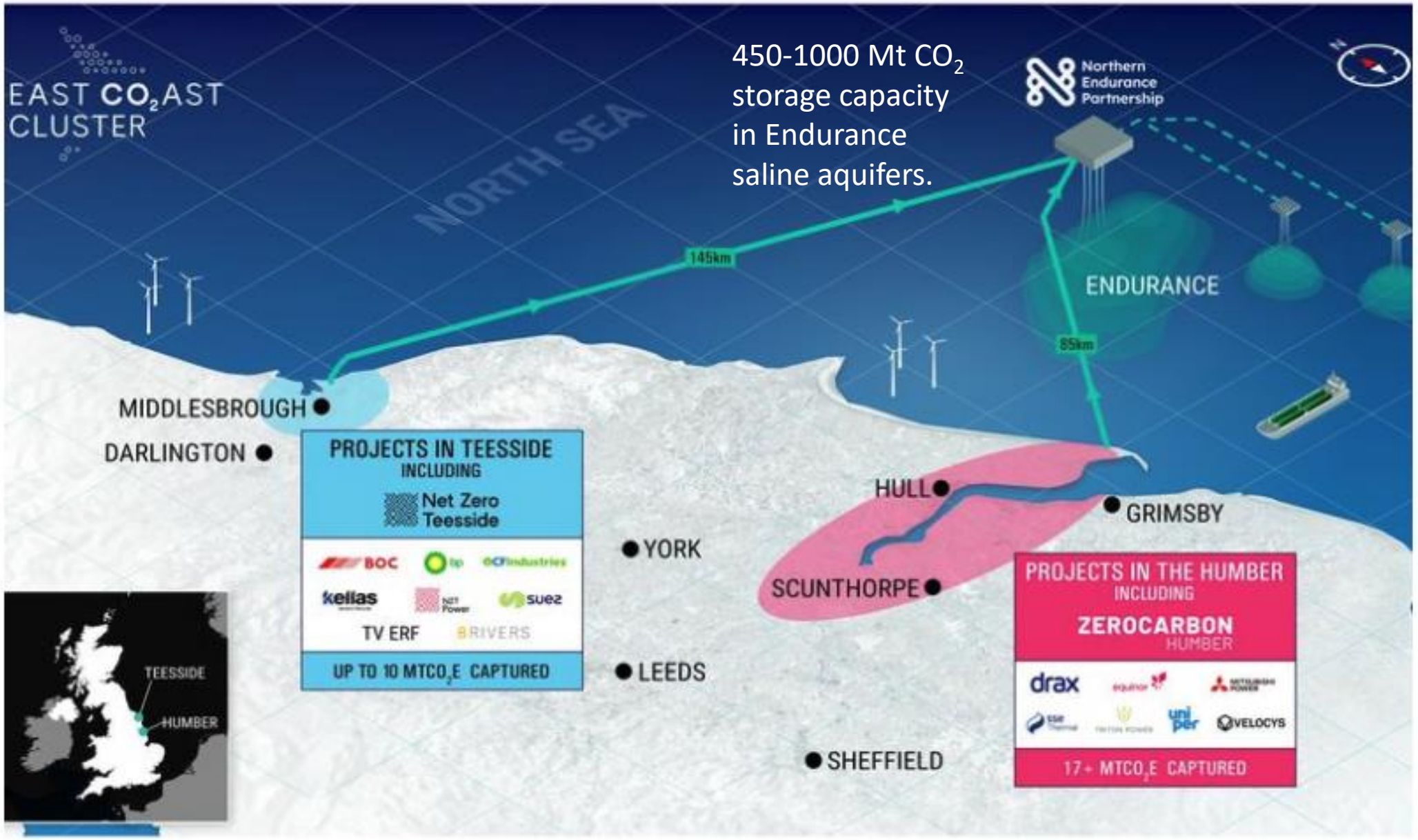
60 tons/day green H_2 to replace grey H_2 in crude refining in Rotterdam.

Case study 1: Longship project – Norway (onstream by 2024)

Illustration of the Northern Lights CCS project (Equinor)

- **Initially capturing & storing 0.8 Mtpa CO_2.**
- **Open to CO_2 from other EU countries later, storing 5 Mtpa CO_2**

Equinor (2020)

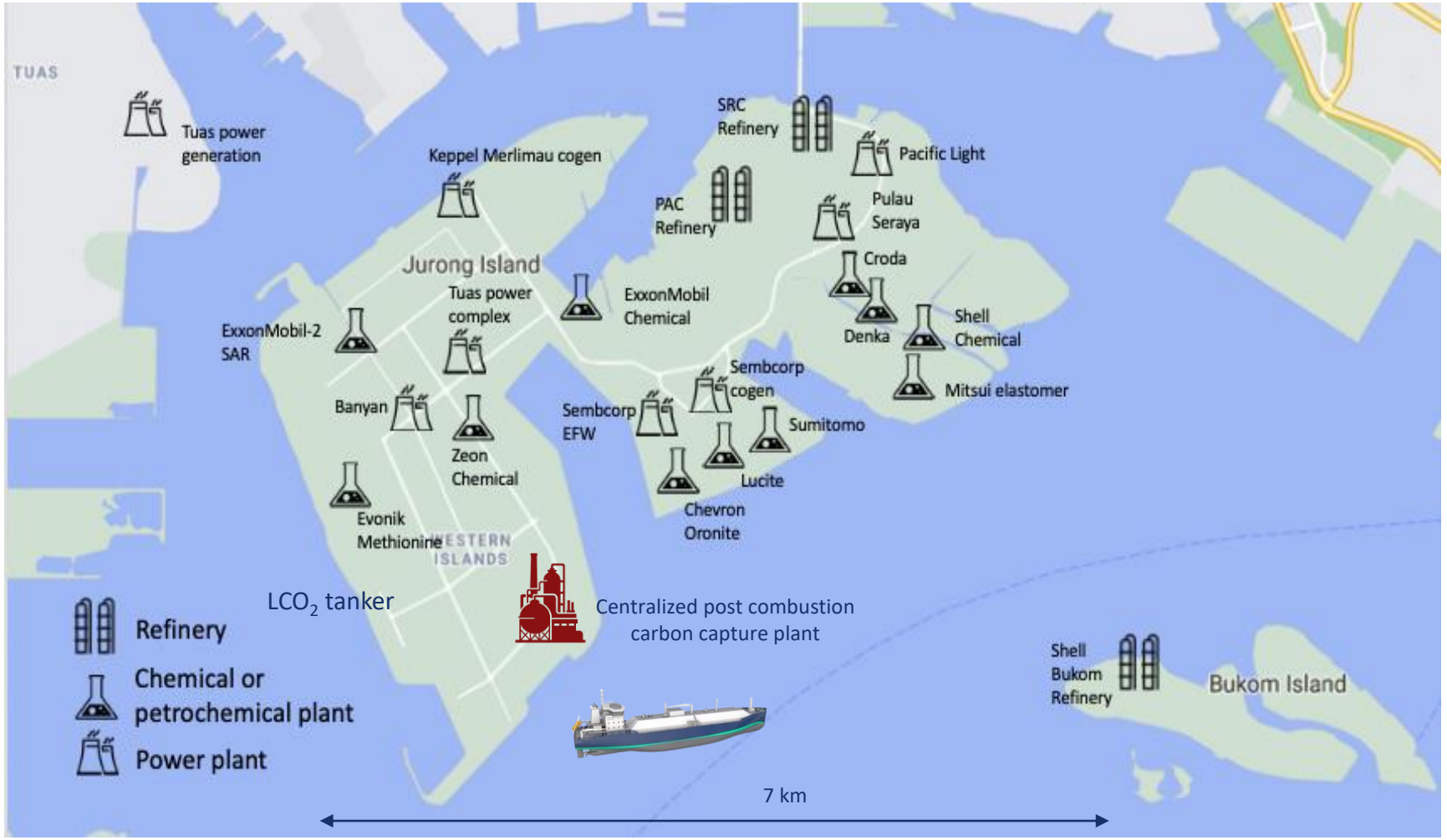


- Stores 27 Mtpa CO_2
- 50% of CO_2 from UK's industry sector
- Operational by 2026.

Source: BusinessLive, 19 Oct 2021

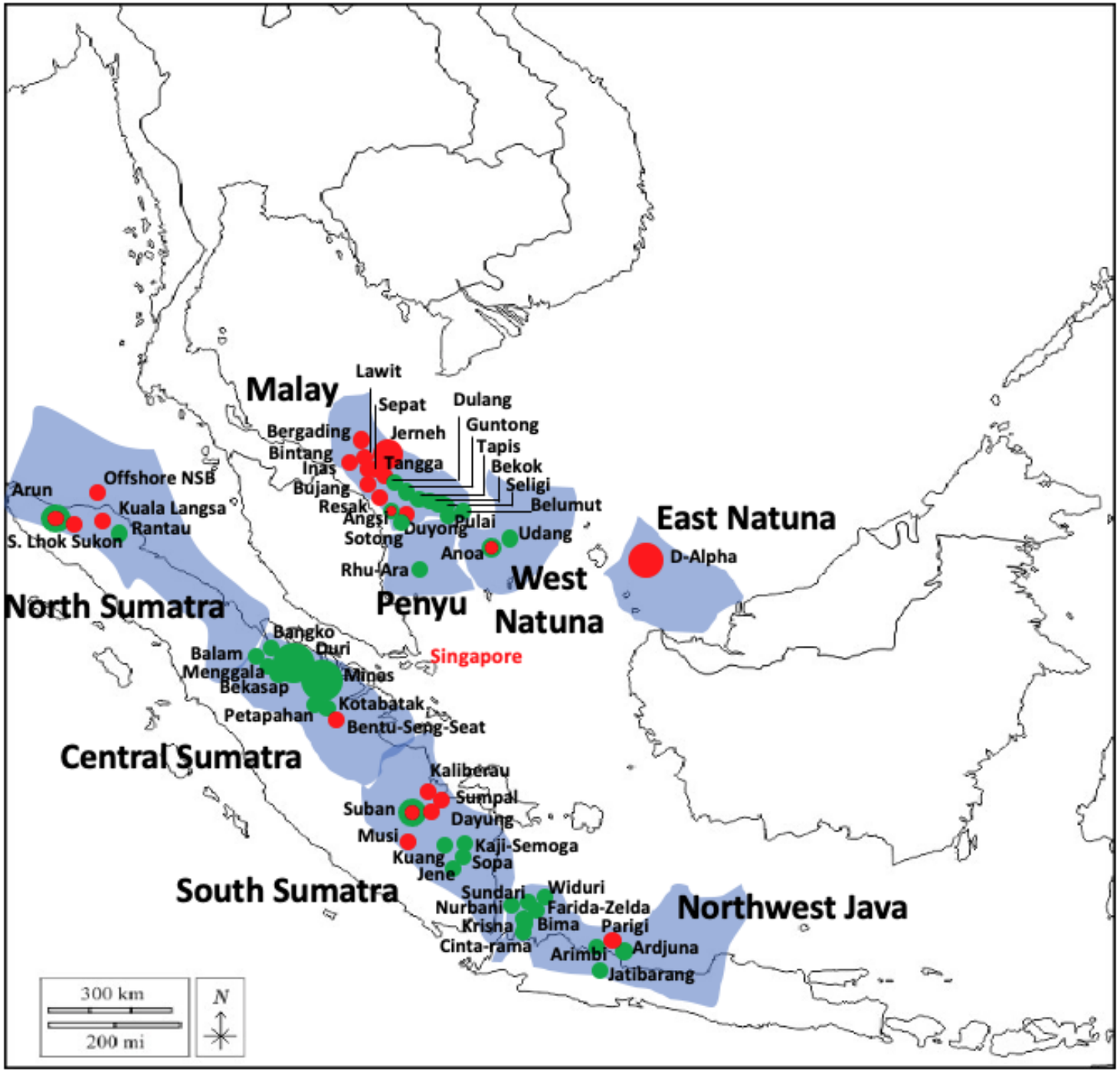
East Coast Cluster bid from Northern Endurance Partnership, uniting Zero Carbon Humber and Net Zero Teesside. (Image: Northern Endurance Partnership)

Case study 3: Southern Lights – Singapore-led ASEAN CCS project



- Centralized post combustion capture capture of 1-5 Mtpa CO_2.
- CO_2 transport by tanker or pipeline to nearby country
- Subsurface CO_2 storage.

Source: Lau et al. (2021b)



Gas

1-5 Tcf

>5 Tcf

Gas condensate

1-5 Tcf

>5 Tcf

Oil

100-3000 MMbbl

>3000 MMbbl

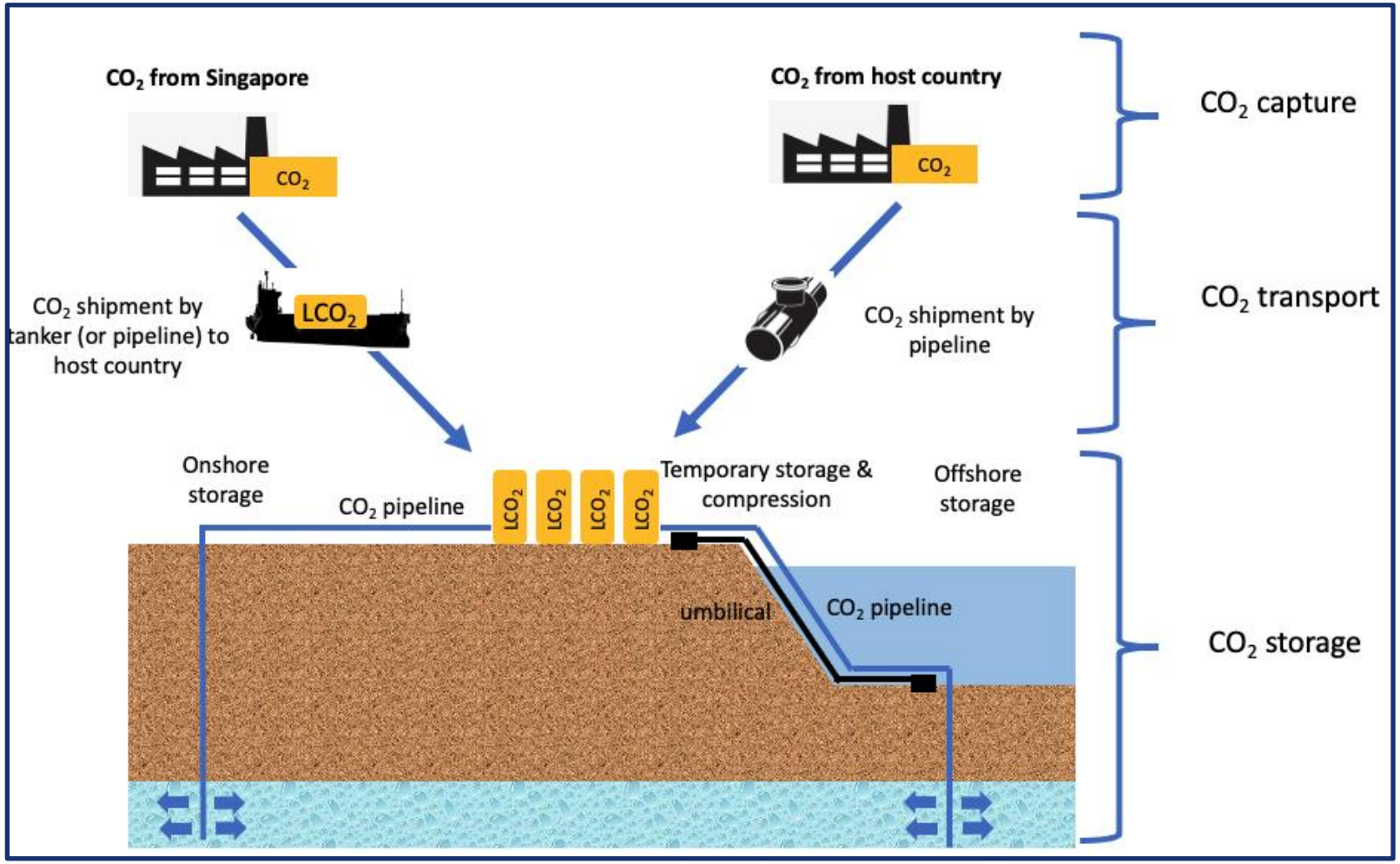
Aquifer

Basin

Case study 3: Southern Lights Project – ASEAN CCS Corridor

Source: Zhang and Lau (2021)

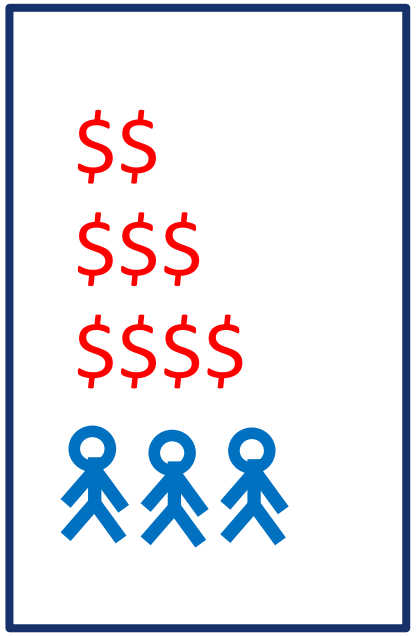
Case study 3: Southern Lights Project – ASEAN CCS Corridor



Source: Zhang and Lau (2021)

Reasons for slow implementation of CCS

1. CO_2-EOR unprofitable at low oil price (<$50/bbl)
2. High capital expenditure
3. Lack of carbon pricing (for most countries)
4. Low public awareness



Source: Lau et al., (2021a)

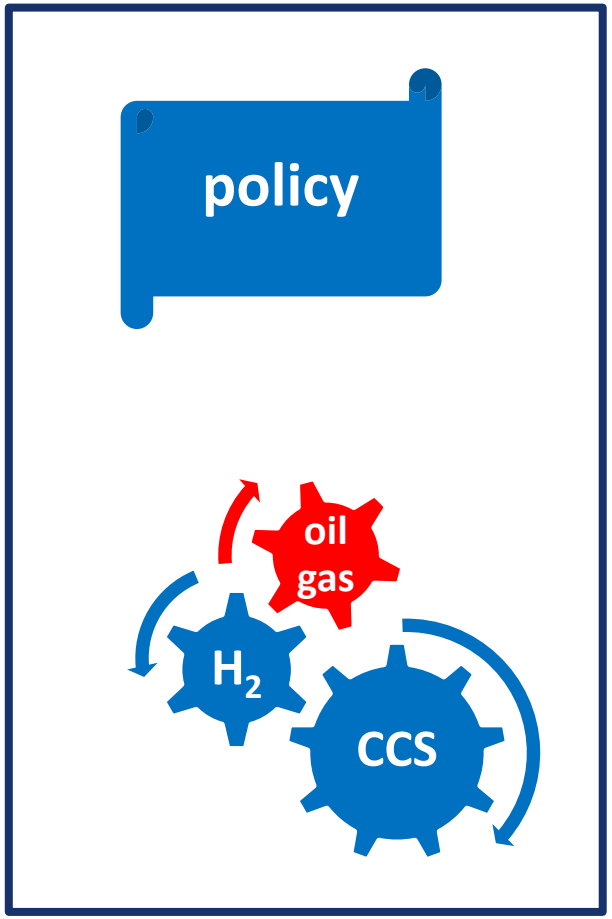
Way Forward for CCS

For national governments:

1. Establish consistent national energy policy
   - Carbon pricing, CCS regulations, regional CCS corridors, public engagement

For E&P industry:

1. A paradigm shift: storing CO_2 as important as producing oil and gas.
2. Re-deploy E&P expertise to implement CCS projects.



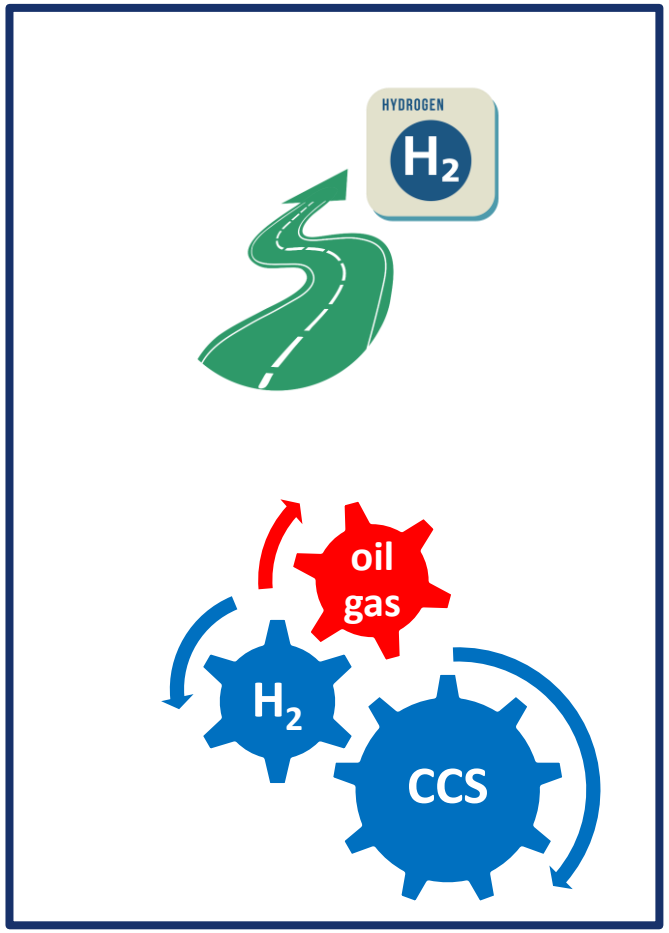
Way Forward for hydrogen

National governments:

1. Develop hydrogen roadmap for nations that do not have one.
   - ➢ hydrogen infrastructure, HSE standards and regulations, etc.

E&P industry:

1. Paradigm shift: regard blue H_2 production from coal and gas as core downstream business.
2. Integrate it with CCS.



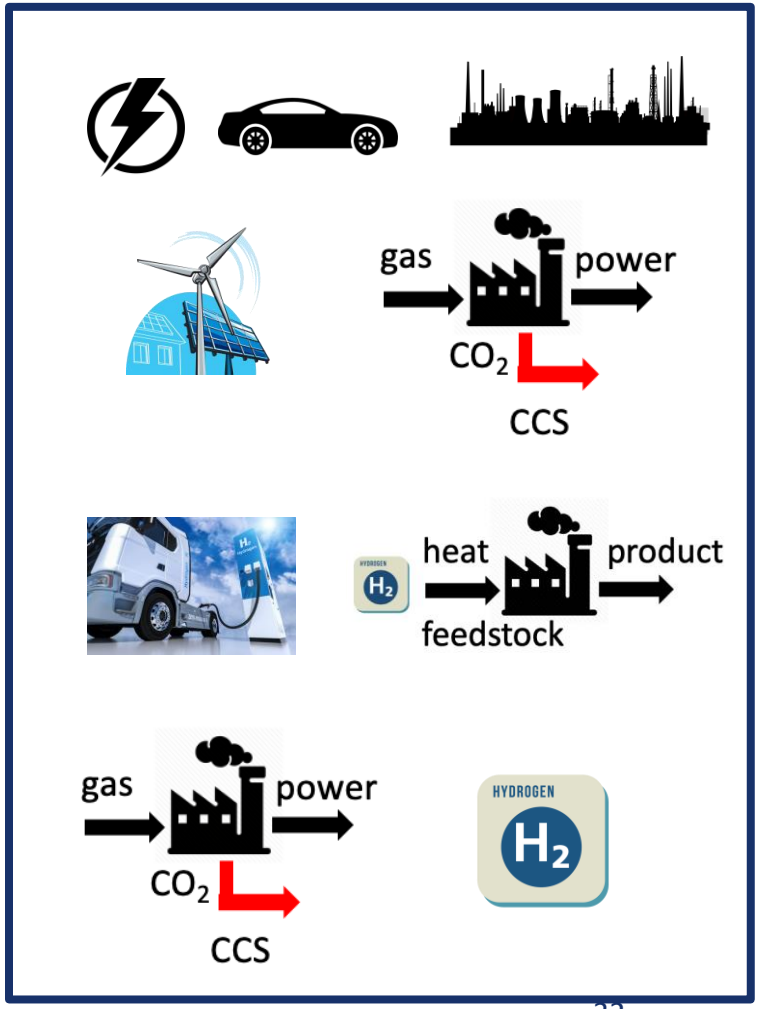
Conclusions

1. Rapid decarbonization of power, transport & industry sectors is needed.

2. Renewable energies are best used to decarbonize the power sector. More CCS is needed to decarbonize fossil fuel power plants.

3. H_2, especially blue H_2, produced by coal/gas and CCS, is needed to decarbonize the transport & industry sectors due to unavailability of green H_2.

4. To regain leadership in energy transition, oil & gas industry needs to treat CCS and blue H_2 production as core business.



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