



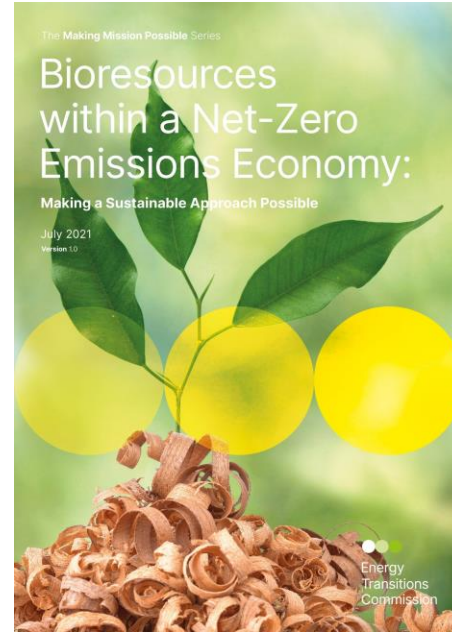
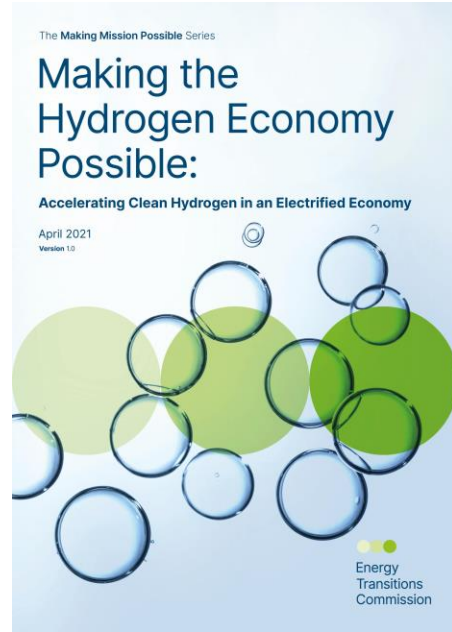
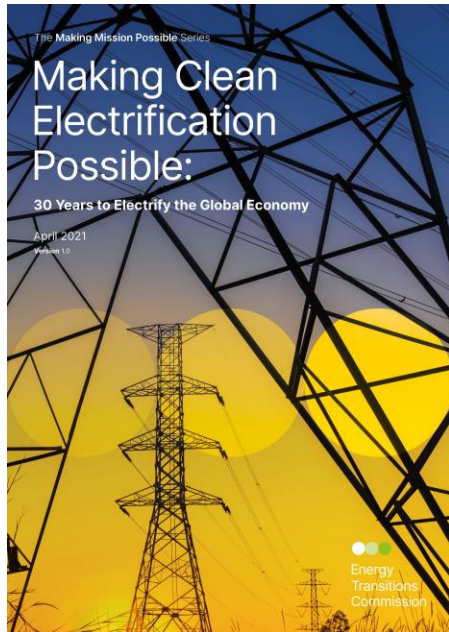
Energy  
Transitions  
Commission

# Carbon Capture, Utilisation and Storage in the Energy Transition: Vital but Limited

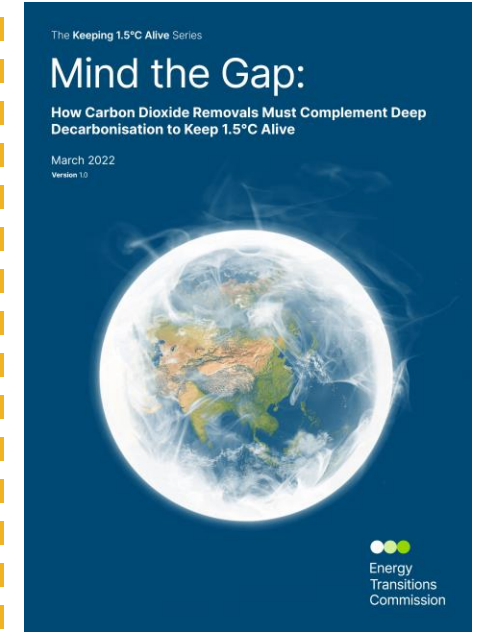
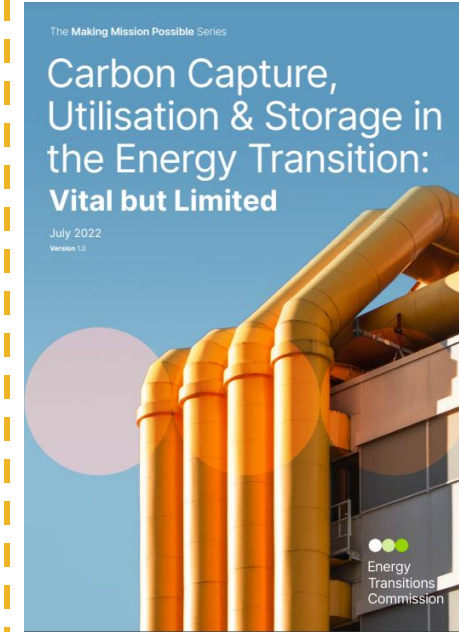
September 2023

# This is the fifth of five reports by the ETC, setting out how to achieve a Net Zero economy by mid-century in energy, buildings, industry & transport

## Decarbonisation



## Negative Emissions



# CCUS plays a critical role in achieving Net Zero by 2050 but reliance on this technology is mitigated by the availability of preferable alternatives

CCUS is critical to decarbonizing process emissions and CO<sub>2</sub> removals, and in some instances offers the cheapest pathway to decarbonization

CCUS in the energy transition: **vital** but **limited**

CCUS accounts for 10-15% of total CO<sub>2</sub> abatement in 2050 and **does not mean a business-as-usual scenario for fossil fuels.**

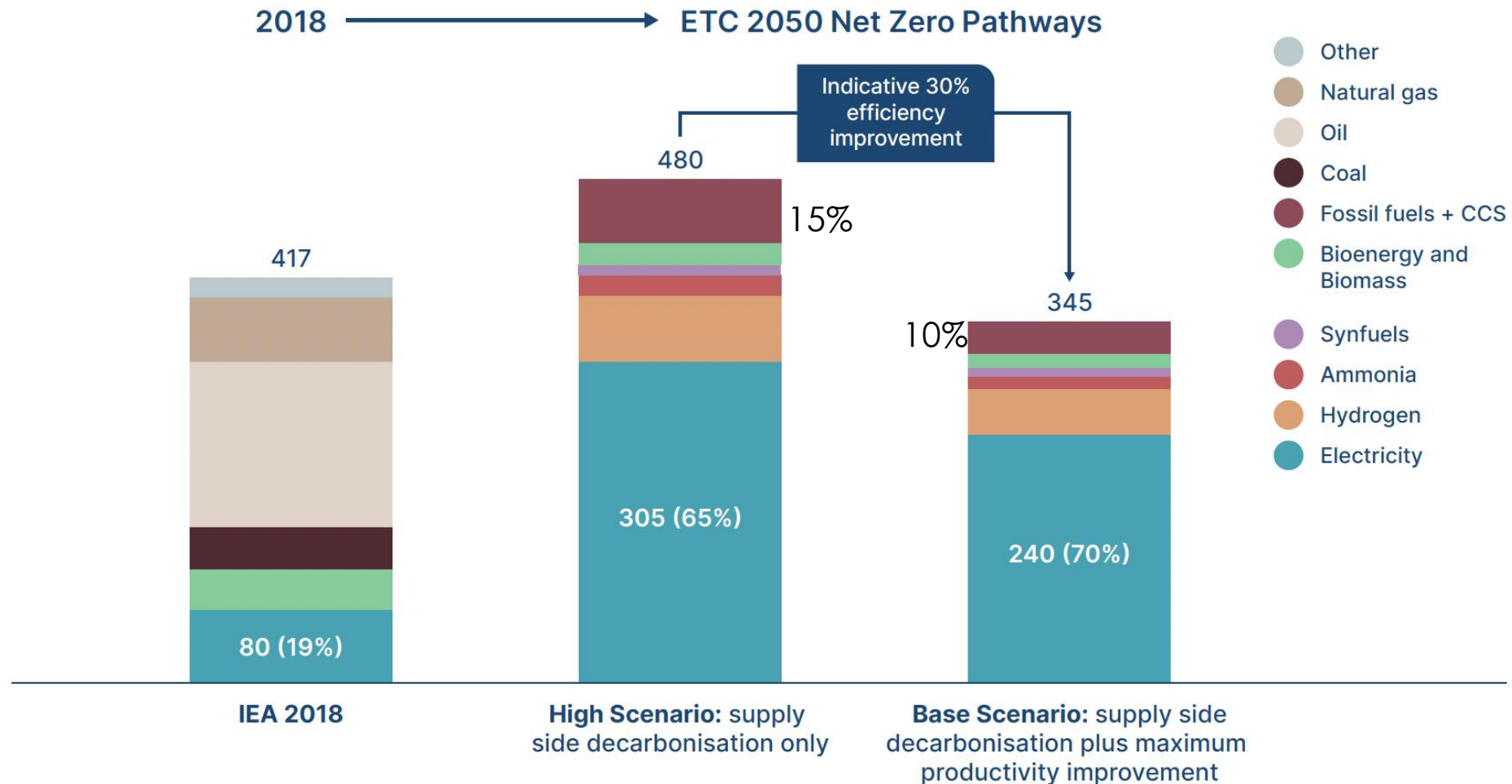
- Clean electrification, hydrogen and bioresources are the main engines of decarbonization
- Oil and coal consumption fall 90% to 2050, gas by >30%



# Clean electricity, hydrogen & bioresources can decarbonize most, but not all of the global economy: CCUS has a role to play in addressing the remainder

Final energy mix in a zero-carbon economy – illustrative scenario

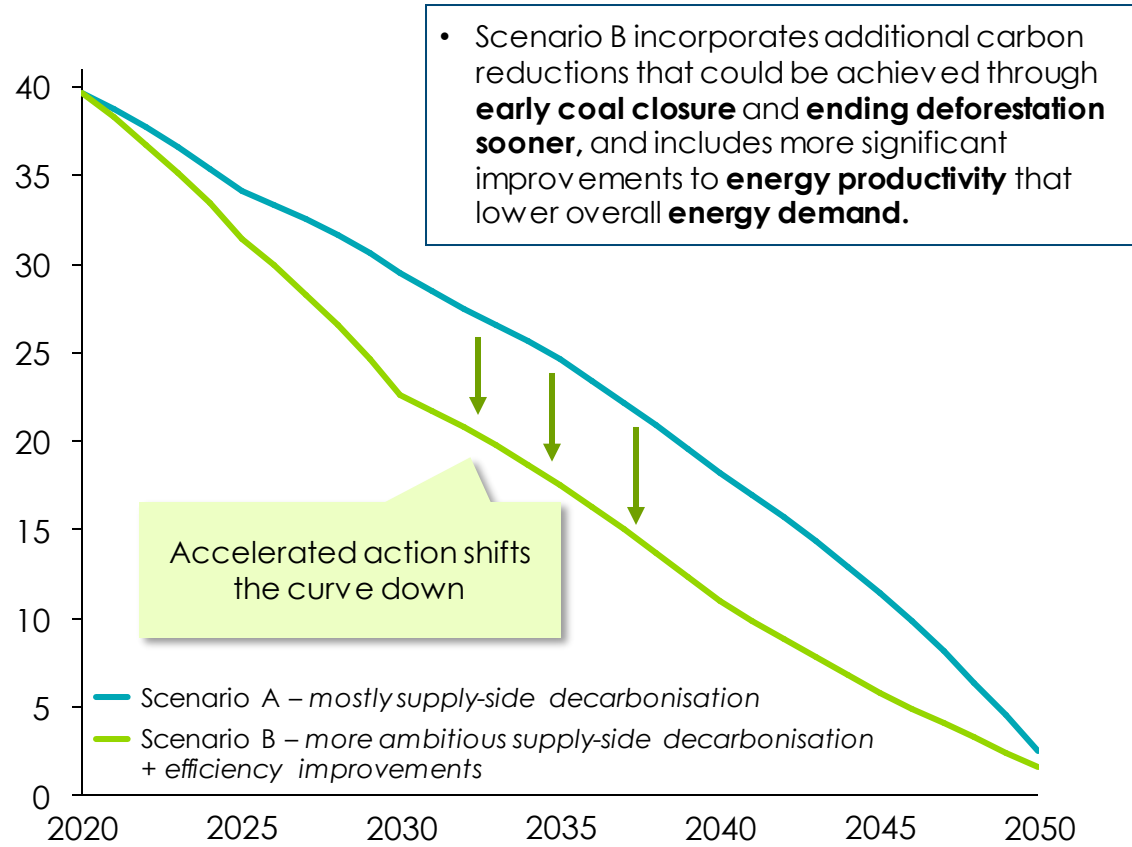
Ej/year



# Even ambitious decarbonisation scenarios overshoot the carbon budget : carbon dioxide removals (incl. CCUS) are needed to address the overshoot

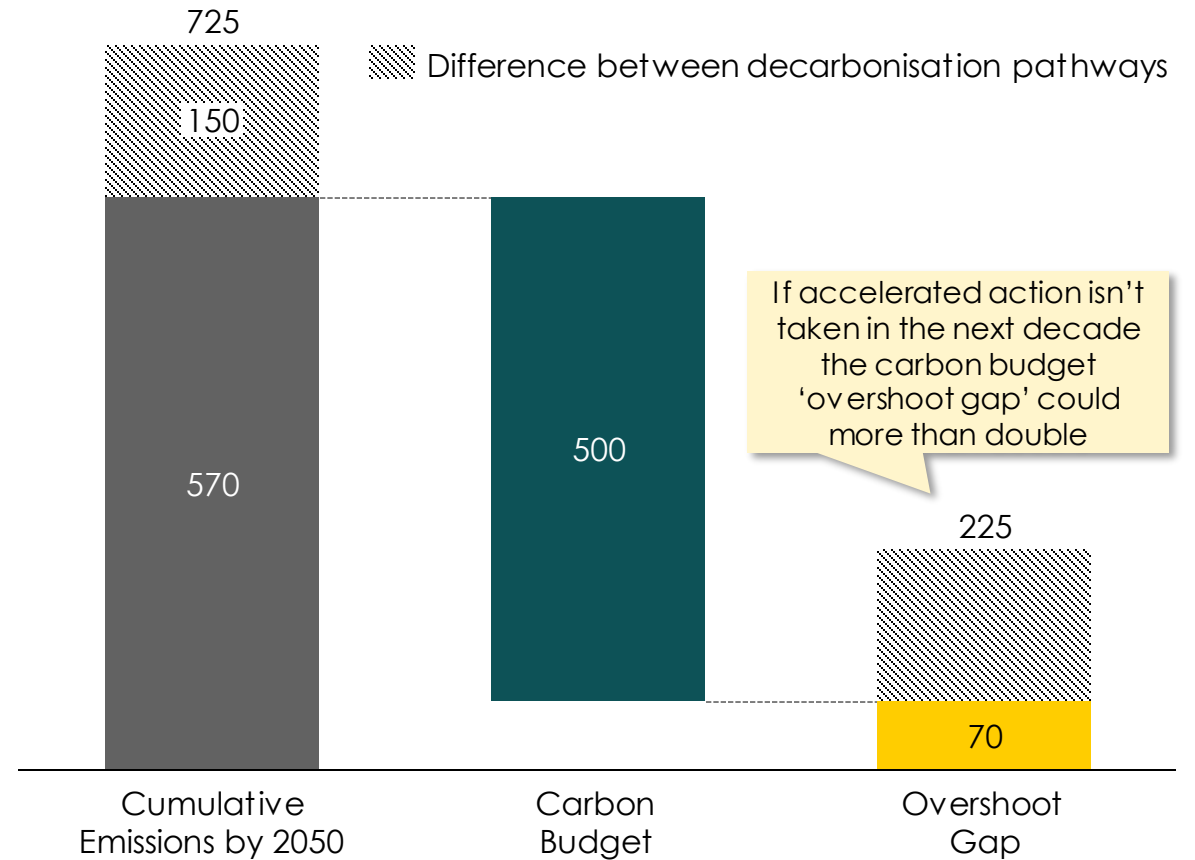
## Annual emissions for two decarbonisation pathways

Gt CO<sub>2</sub>/year, Global



## Overshoot gap under two decarbonisation pathways

Gt CO<sub>2</sub> Cumulative, Global



NOTES: Carbon budget refers to maximum cumulative emissions available in order to keep temperature increases from exceeding 1.5°C by 2050

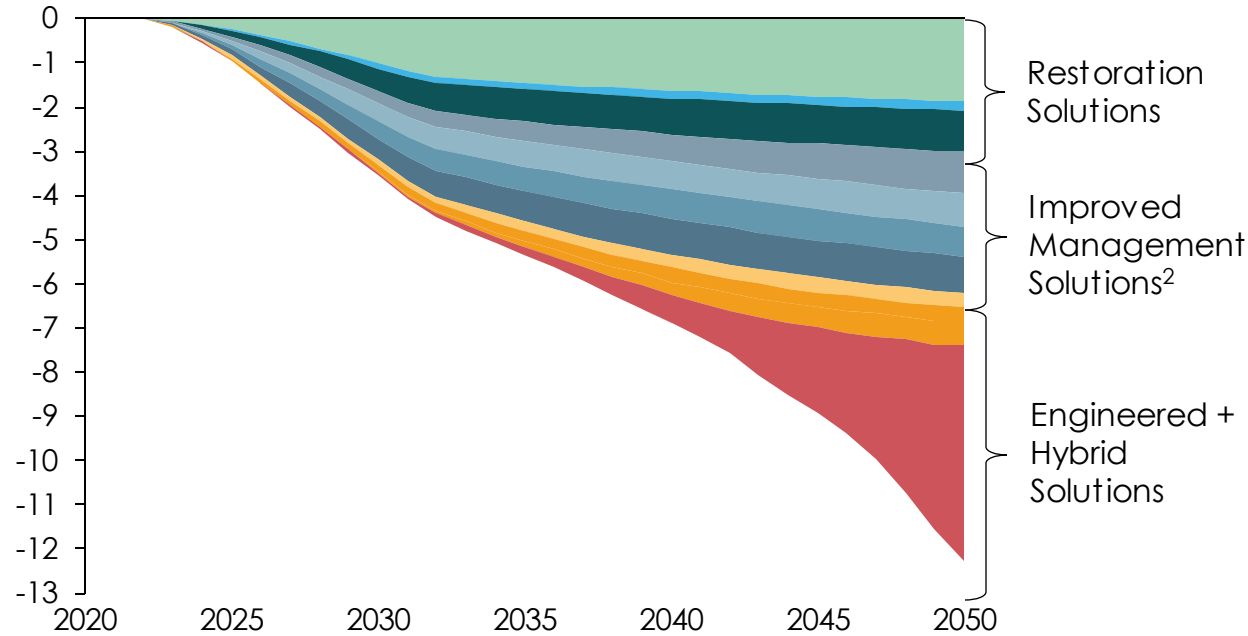
SOURCES: SYSTEMIQ analysis for the ETC based on: IEA (2017), Energy Technology Perspectives; IEA (2020), Energy Technology Perspectives; IPCC (2021) *Climate Change 2021: The Physical Science Basis*



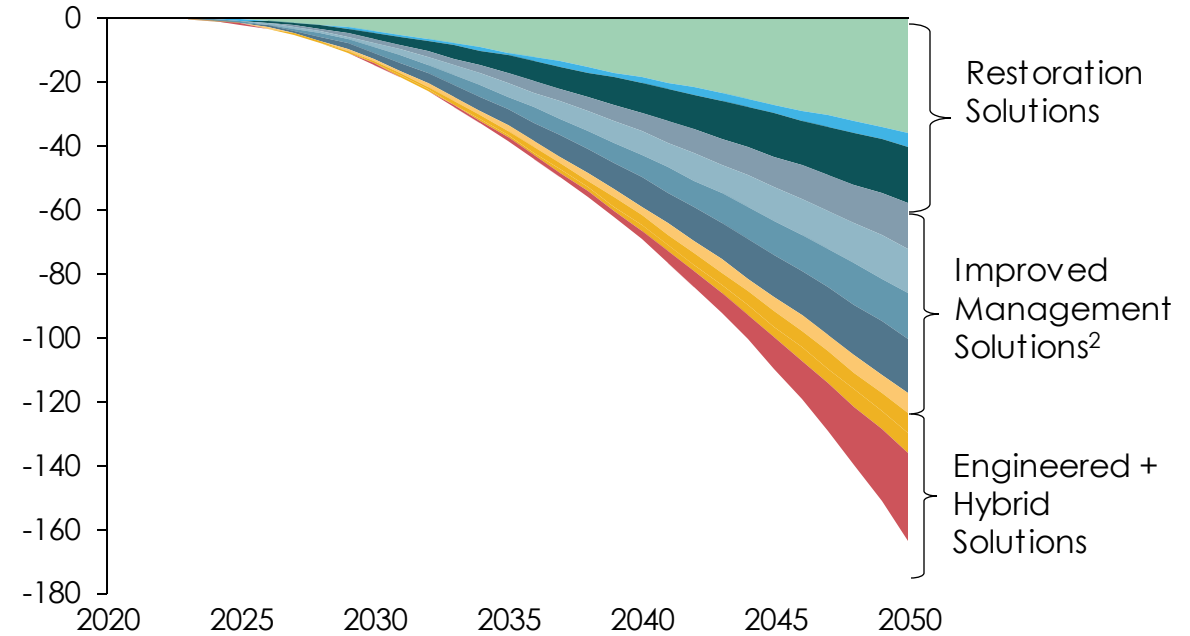
# BECCS and DACCS have a role to play in lowering atmospheric CO<sub>2</sub> concentration through negative emissions

CO<sub>2</sub> ONLY

Potential ramp-up of CDR, GtCO<sub>2</sub>/year, global



Cumulative CDR 2020-2030, GtCO<sub>2</sub>, global



**NCS: Restore**

- Restore forests
- Restore Blue carbon<sup>1</sup>
- Restore drained peatlands

**NCS: Manage**

- Improve forest management
- Agroforestry
- Enhance soil carbon sequestration in croplands
- Enhance soil carbon sequestration in grazing lands

**Hybrid and engineered approaches**

- Apply biochar
- BECCS
- DACCS

Notes: The analysis was designed to avoid potential double-counting of emissions reductions, and is adjusted from annualised average potential estimates for 2020-2050 period. The models reflect land use & management changes, yet in some instances can also reflect demand-side effects from carbon prices, so may not be defined exclusively as 'supply-side'. (1) 'Blue Carbon' is defined as ocean-based biomass sequestration including mangroves, seagrasses, and tidal marshes. (2) Improved management solutions have been adjusted for feasibility on a country-by-country basis. Overall average reduction is ~50%.

Source: SYSTEMIQ analysis for the ETC (2021), based on Roe et al. (2021), Hannah et al. (2021), Griscom (2017), ETC (2021) *Bioresources for a Sustainable Net-Zero Economy*, High Level Panel for Oceans (2020)



# The rationale underpinning CCUS technology deployment varies between sectors



## **POWER**

Dispatchable generation capable of balancing grids or providing low carbon electricity in regions where renewable capacity is constrained



## **CEMENT**

~60% emissions from cement production arise from process and therefore cannot be eliminated through low carbon energy



## **HYDROGEN**

Blue hydrogen is likely to be competitive with green until ~2030 in most regions – possibly later in regions with abundant cheap natural gas



## **IRON & STEEL**

Depending on local resource endowments CCUS may be the cheapest option for decarbonizing iron & steel production



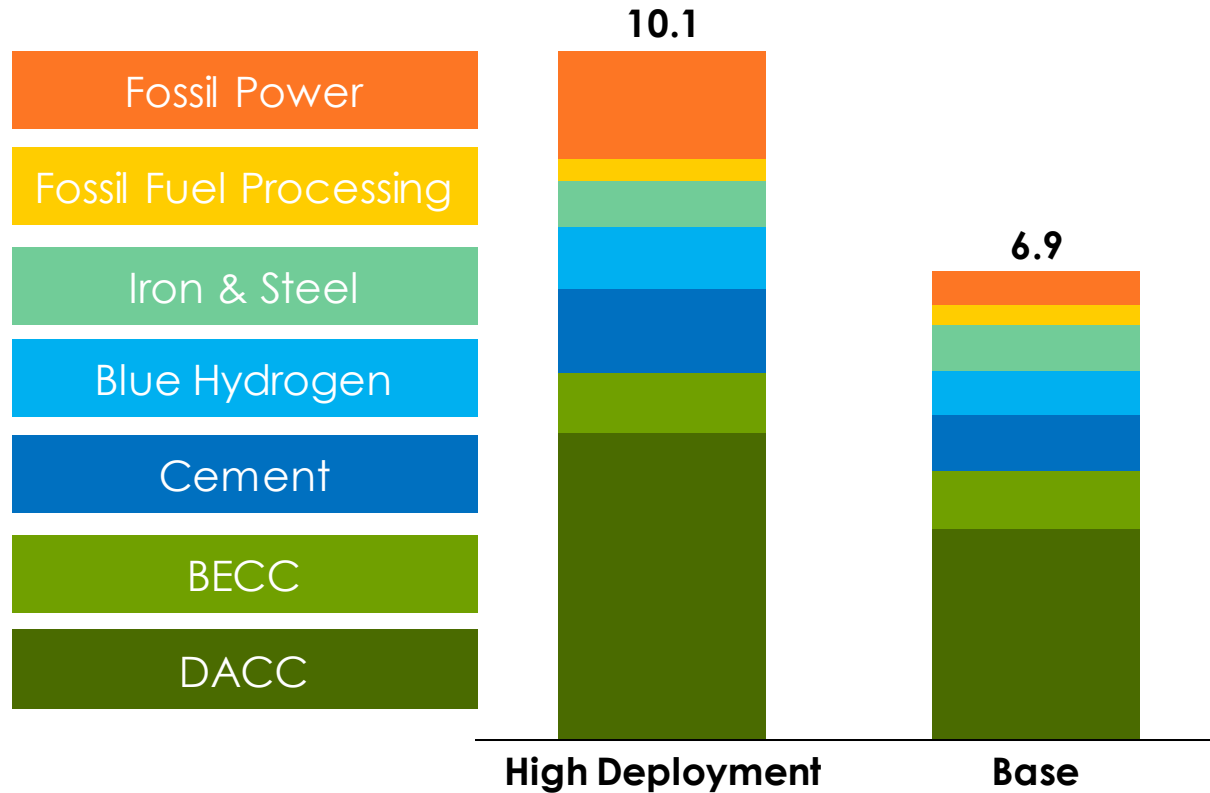
## **FOSSIL FUELS & PETROCHEMICALS**

Decarbonization of process emissions from fossil fuel (LNG & refined oil products) and petrochemical production

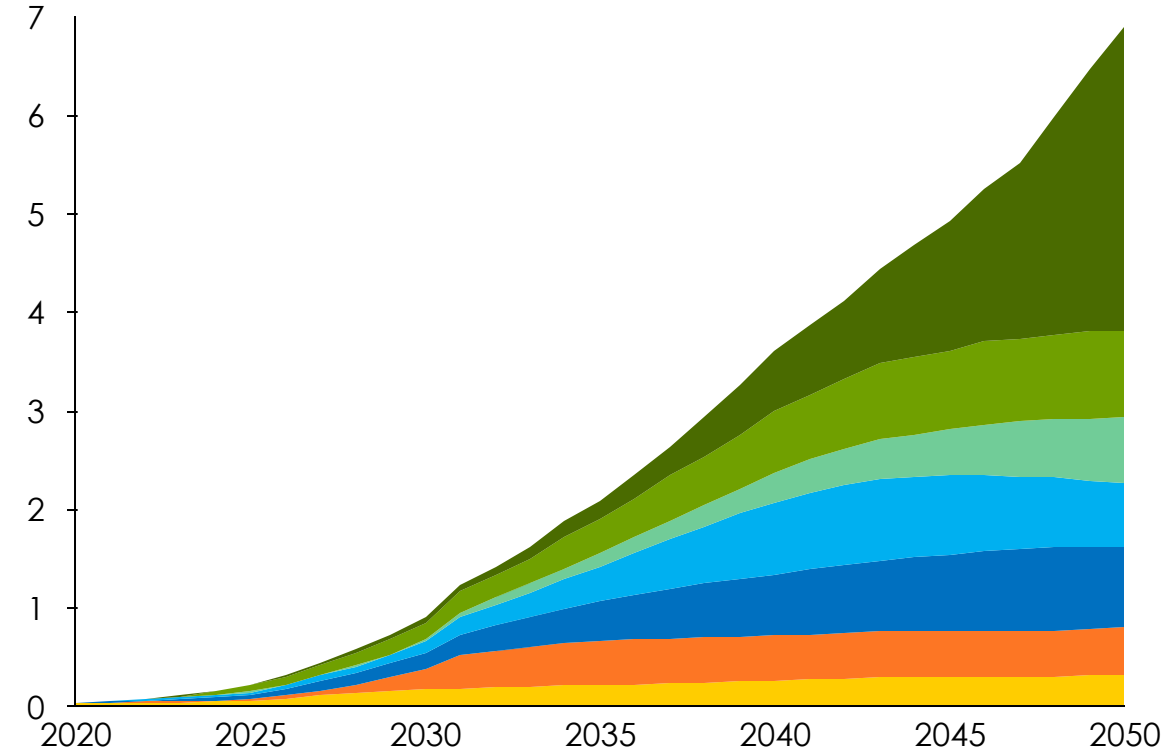


# The ETC Base Scenario sees just under 7 GtCO<sub>2</sub> captured per annum by 2050; slower progress in demand side measures would necessitate c.10GtCO<sub>2</sub>/year

Scenarios for CCUS volumes in 2050 – by source of capture  
GtCO<sub>2</sub>/year



CO<sub>2</sub> captured by sector in Base scenario  
GtCO<sub>2</sub>/year

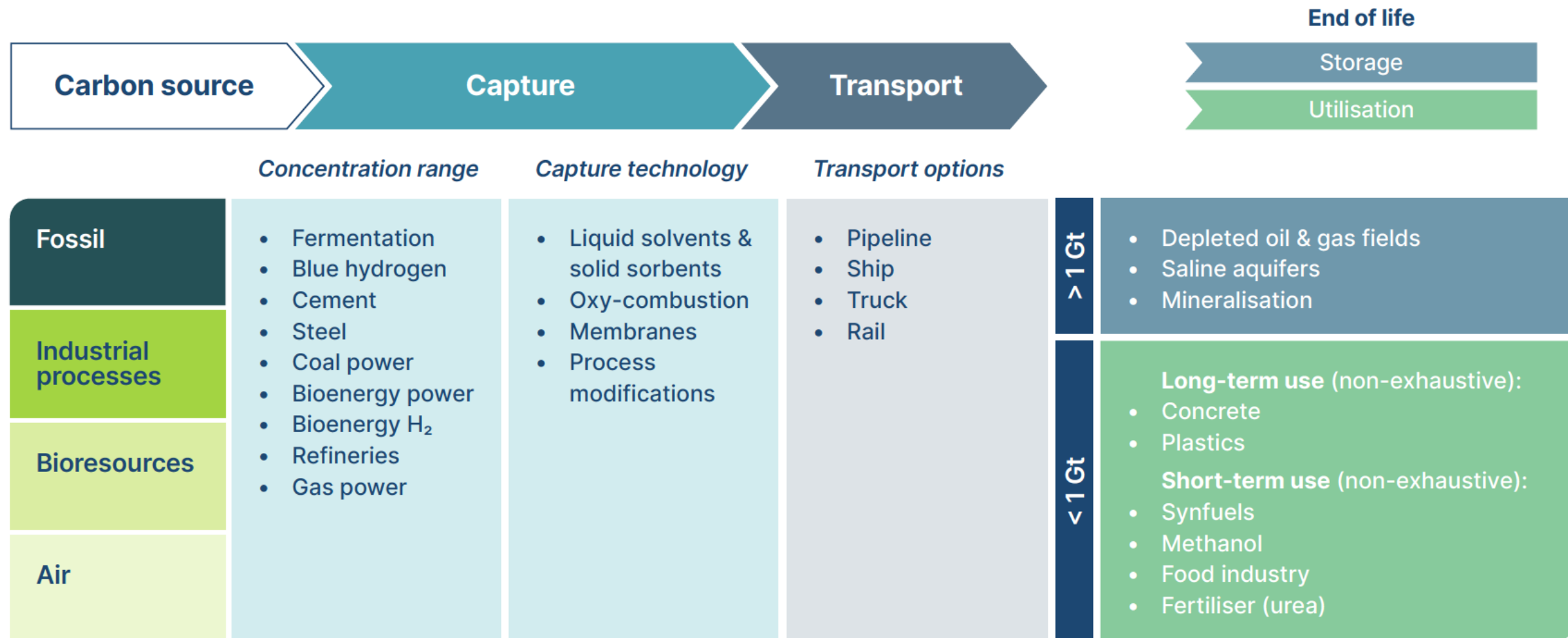


NOTES: Fossil Fuel Processing refers to natural gas processing, refinery operations and high value chemicals production. Blue Hydrogen includes ammonia production.

SOURCE: SYSTEMIQ for the ETC (2022)

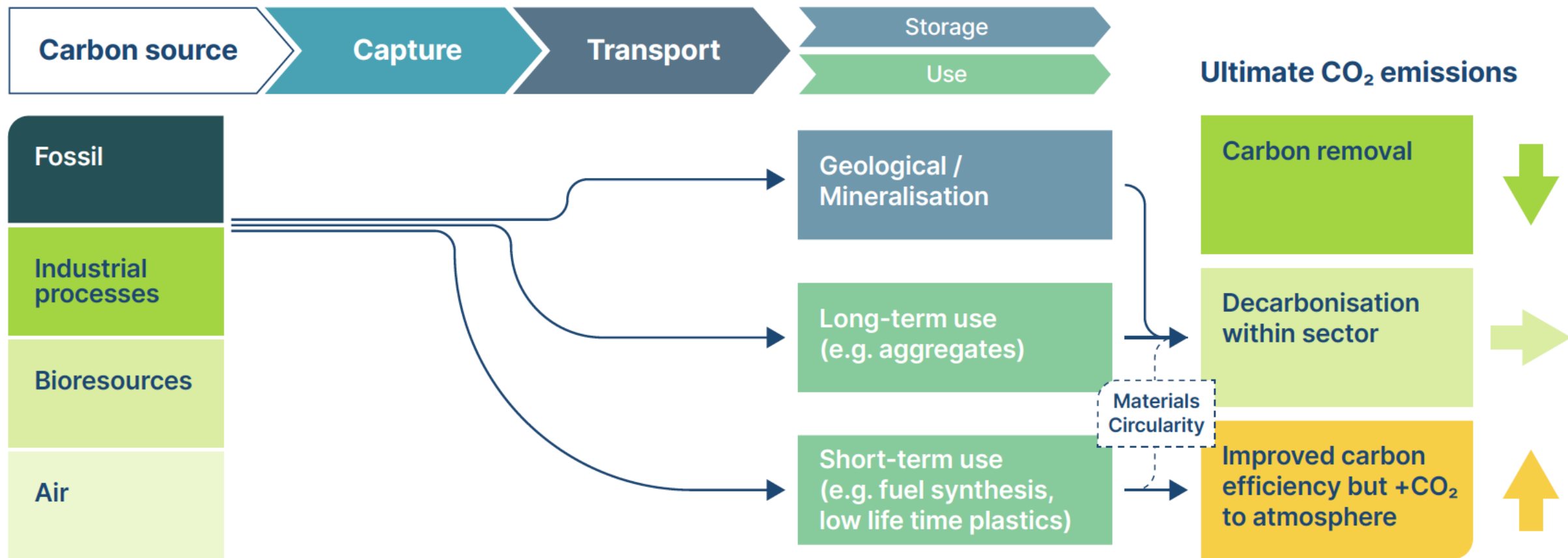
# The CCUS value chain can be broken down into three distinct stages: capture, transport and end-of-life which can entail either storage or utilisation

## The CCUS value chain



# Emissions captured from fossil combustion and industrial processes can deliver carbon neutrality or improved carbon efficiency

Ultimate emissions of CO<sub>2</sub> from point source fossil and industrial processes



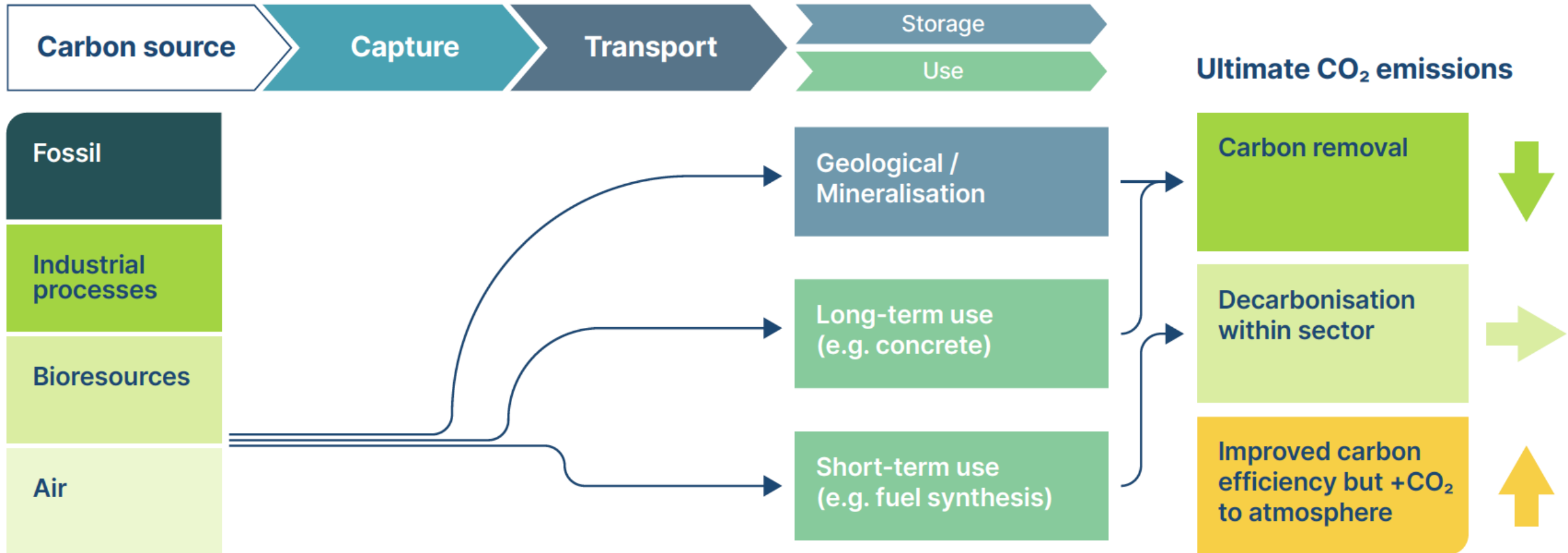
NOTES: Materials Circularity requires that the carbon molecules be recovered and reused. This can be achieved up to a point through mechanical recycling although this often limits future application options. Alternatively, chemical recycling or pyrolysis in conjunction with CCU can theoretically provide virgin quality feedstock with low emissions. However, these processes are highly energy intensive and can result in declines in feedstock volumes. See SYSTEMIQ (2020) Breaking the Plastic Wave.

SOURCE: SYSTEMIQ analysis for the ETC (2022)



# Emissions captured via DACCC & BECC can yield negative emissions

Ultimate emissions of CO<sub>2</sub> from bioresources and DACC

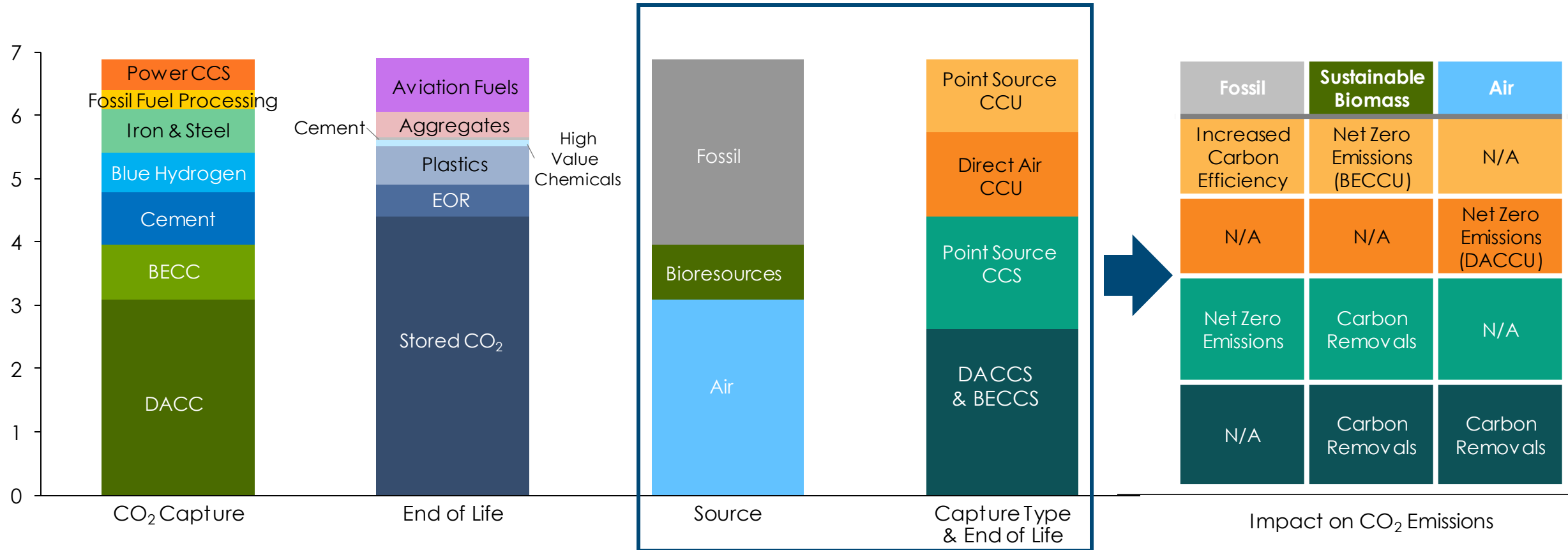


SOURCE: SYSTEMIQ analysis for the ETC (2022)

# The impact CCUS has on atmospheric carbon dioxide concentration levels is a function of the source of the CO<sub>2</sub> and its end of life treatment

CCUS volumes in 2050 under Base scenario

GtCO<sub>2</sub>/year



NOTES: Volume shown refer to Base Scenario in which demand side measures are fully implemented. Fossil Fuel Processing includes natural gas processing, oil products refining and production of high value petrochemicals (methanol, ethylene, propylene, butadiene, benzene, toluene, xylene and BTX). EOR = enhanced oil recovery. CCU = carbon capture and utilization. CCS = carbon capture and storage. DACCS = direct air carbon capture and storage. DACCU = direct air carbon capture and utilization. BECCS = bioenergy with carbon capture and storage. Note that the majority of point source CCS emissions will come from fossil processes and combustion. Fossil in the source bar includes process emissions.

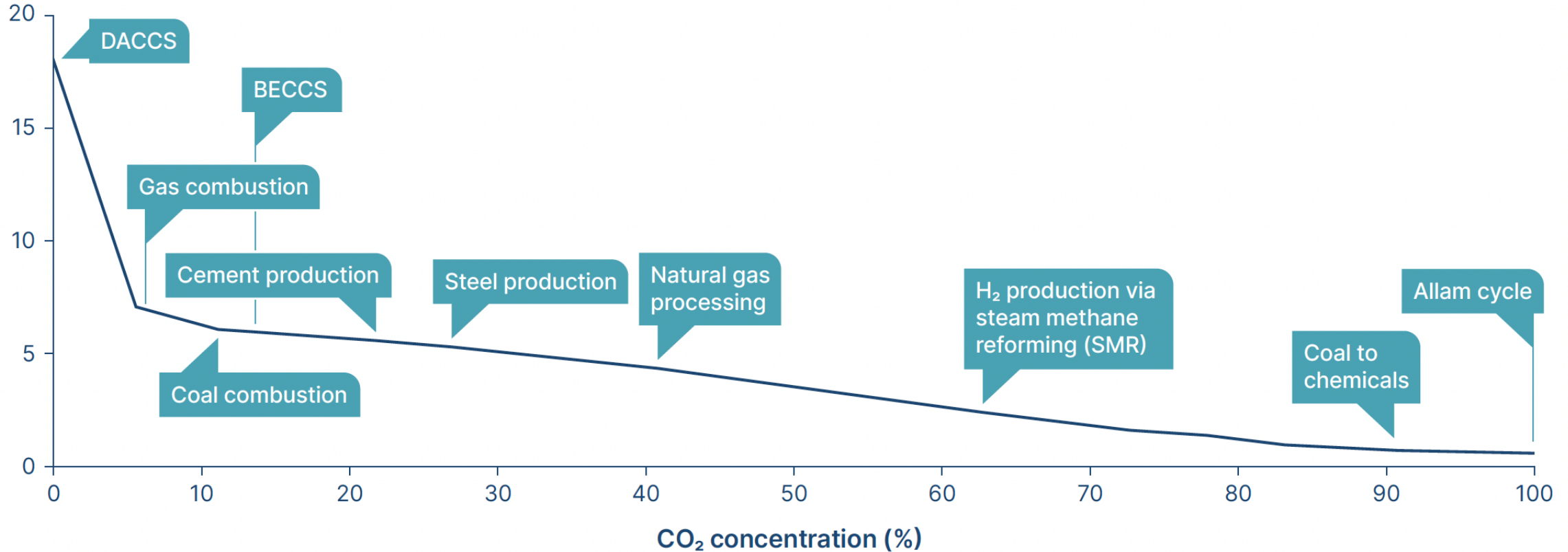
SOURCE: SYSTEMIQ for the ETC (2022)



# Energy required is the key determinant of cost of capture and declines with CO<sub>2</sub> concentration

Minimum work required for CO<sub>2</sub> capture

**kJ/mol CO<sub>2</sub>**

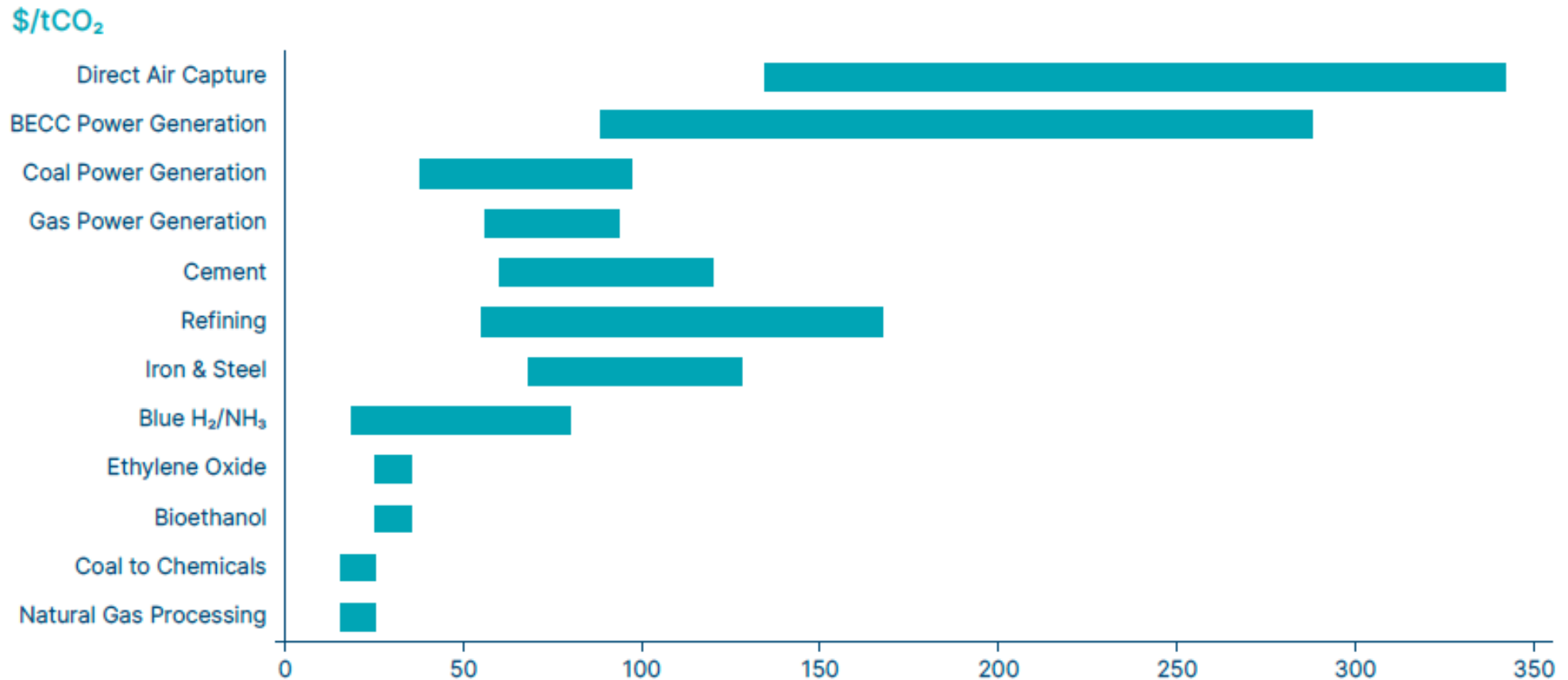


**NOTES:** SMR = Steam Methane Reforming. The Allam Cycle (see Allam et al. (2017) *Demonstration of the Allam Cycle: An Update on the Development Status of a High Efficiency Supercritical Carbon Dioxide Power Process Employing Full Carbon Capture*).

**SOURCE:** Bui et al. (2018) *Carbon capture and storage: the way forward*

# Estimates of cost of CO<sub>2</sub> capture vary widely

Range of levelised cost of capture estimates by sector today



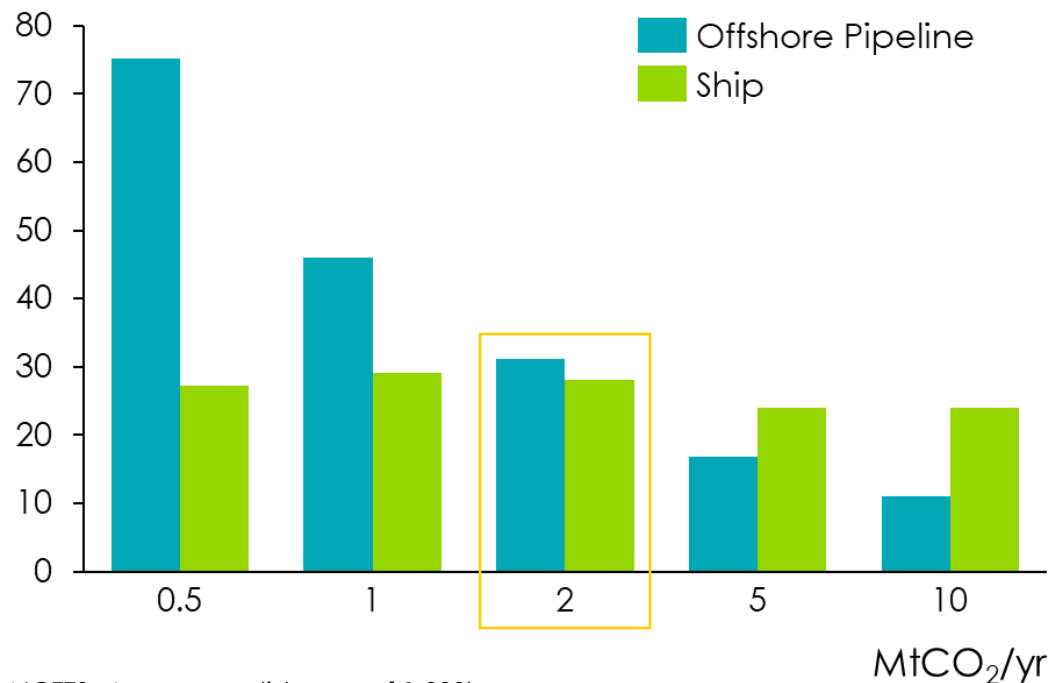
NOTES: Coal to chemicals refers to methanol and ammonia.

SOURCES: IEA (2017) *CCUS in Clean Energy Transitions (2021)*, GCCSI (2017), *Global costs of carbon capture and storage*, IEAGHG (2014), *CO<sub>2</sub> capture at coal-based power and hydrogen plants*, Keith et al. (2018), *A Process for Capturing CO<sub>2</sub> from the Atmosphere*, NETL (2014), *Cost of capturing CO<sub>2</sub> from Industrial sources*, Rubin et al (2015), *The cost of CO<sub>2</sub> capture and storage*; Bloomberg NEF *CCUS Costs and Opportunities for Long Term CO<sub>2</sub> Disposal (2021)*; Fuss et al (2018) *Negative emissions—Part 2: Costs, potentials and side effects*; IEA (2021) *Is carbon capture too expensive?*



# Pipelines are the cheapest option for large volumes over short distances; ships are more competitive over long distances and with smaller volumes

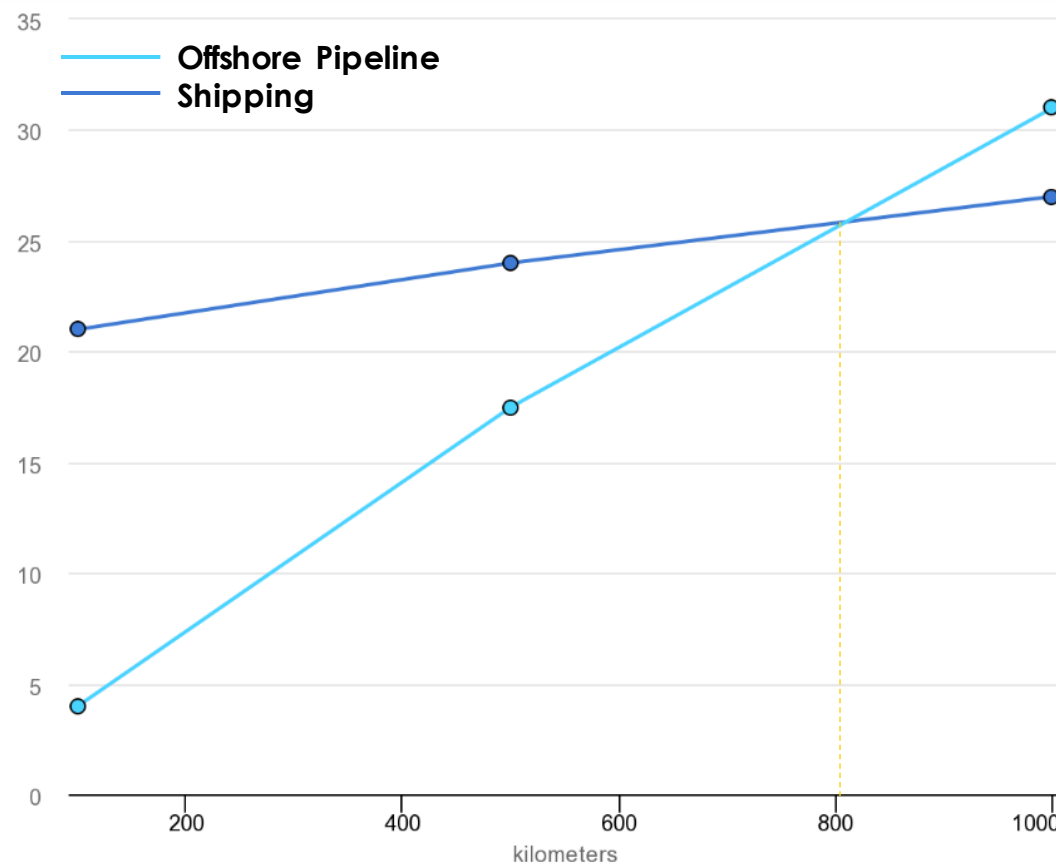
Offshore CO<sub>2</sub> shipping & pipeline costs by volume  
\$/tCO<sub>2</sub>



NOTES: Assumes a distance of 1,000km

SOURCE: IEA (2020) *CCUS in clean energy transition*.

Comparison of CO<sub>2</sub> shipping vs. offshore pipeline  
\$/tCO<sub>2</sub>



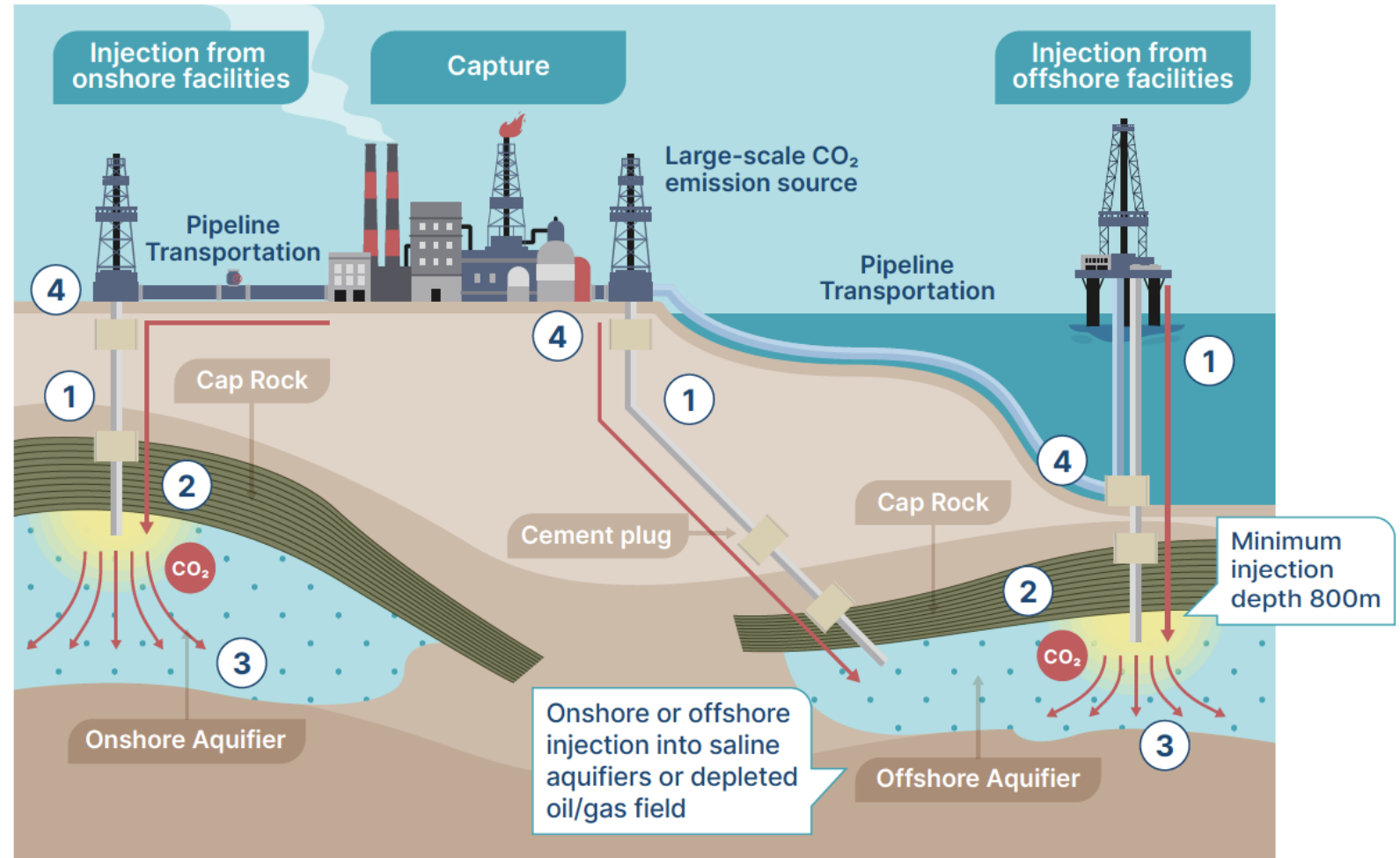
NOTES: Assumes a capacity of 2 MtCO<sub>2</sub>/year.

SOURCE: IEAGHG (2020) *The Status and challenges of CO<sub>2</sub> Shipping Infrastructure*.



# The process of storing CO<sub>2</sub> is broken into injection, containment, trapping and plugging

- 1 Injecting**  
Compressed CO<sub>2</sub> pumped underground via well
- 2 Containment**  
CO<sub>2</sub> impermeable cap rock layer on top of the reservoir or aquifer prevents diffusion to the ground
- 3 Trapping**  
CO<sub>2</sub> moves within store and becomes trapped by dissolving in brine or being physically absorbed in small rock pores
- 4 Plugging**  
At the end of operation, a cement plug is used to seal the injection well permanently

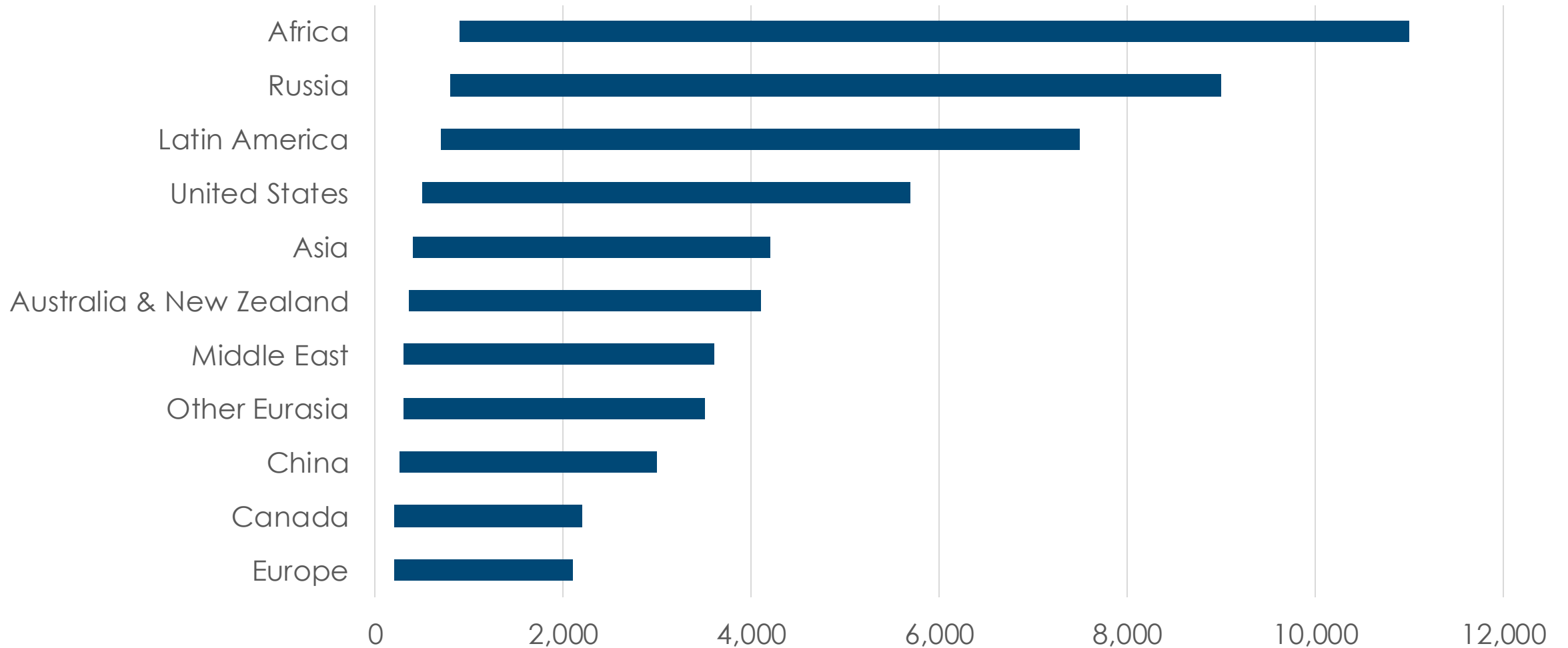


# Median estimates of global storage capacity exceed 25,000 GtCO<sub>2</sub>: enough to store over a century's worth emissions at today's levels

Storage

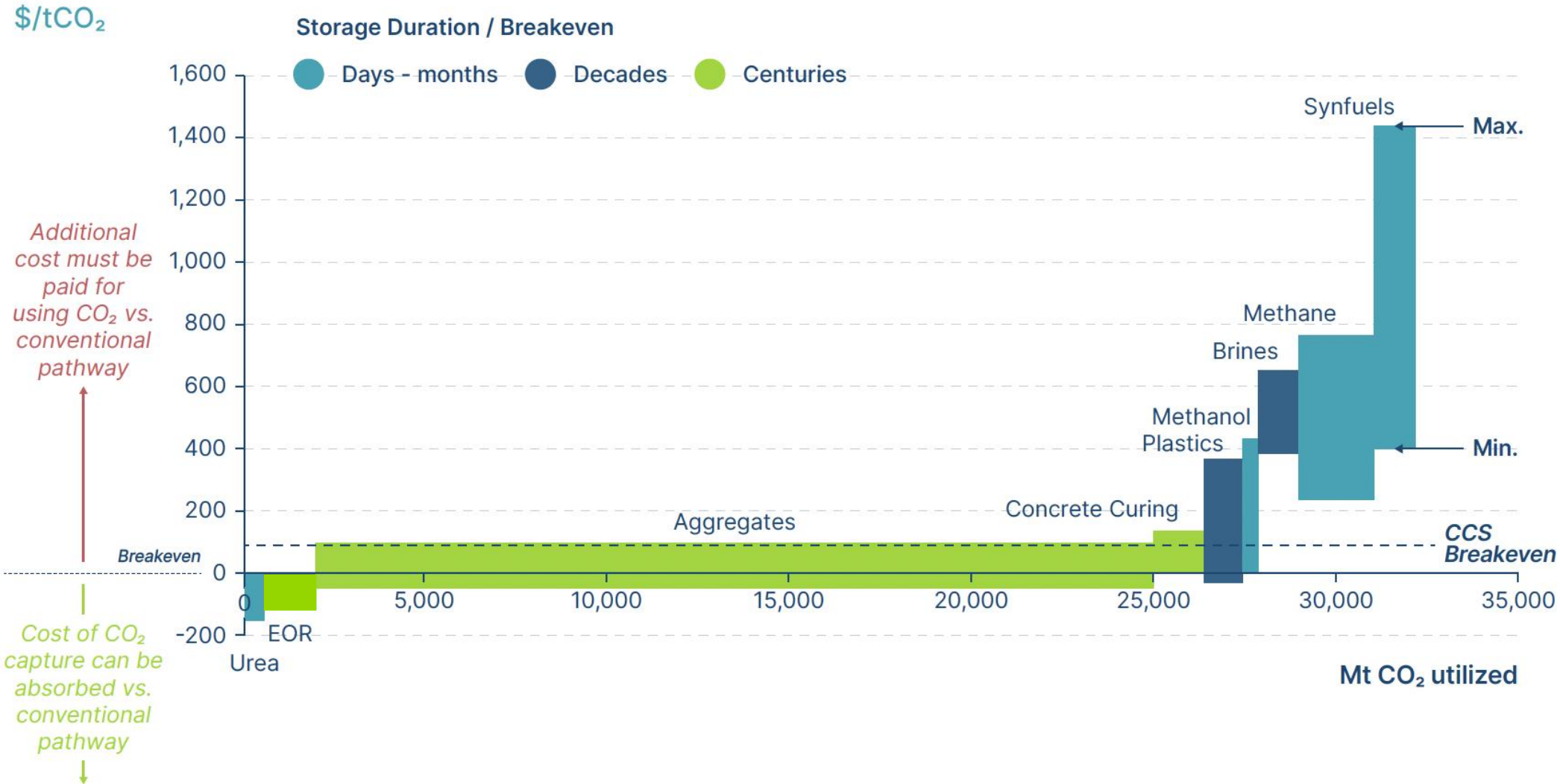
Range of estimated practical onshore and offshore geological storage capacity

GtCO<sub>2</sub>



# Most carbon capture and utilization applications cost more than CO<sub>2</sub> storage

## CCU supply cost curve



Utilisation

SOURCES: SYSTEMIQ analysis for the ETC (2022); Hepburn, C. et al. (2019) *The technological and economic prospects for CO<sub>2</sub> utilization and removal*; J.-L. Gálvez-Martos et al. (2020) *Techno-economic assessment of a carbon capture and utilization process for the production of plaster-like construction materials*

# The majority of CO<sub>2</sub> utilised in EOR comes from naturally occurring subsurface reservoirs

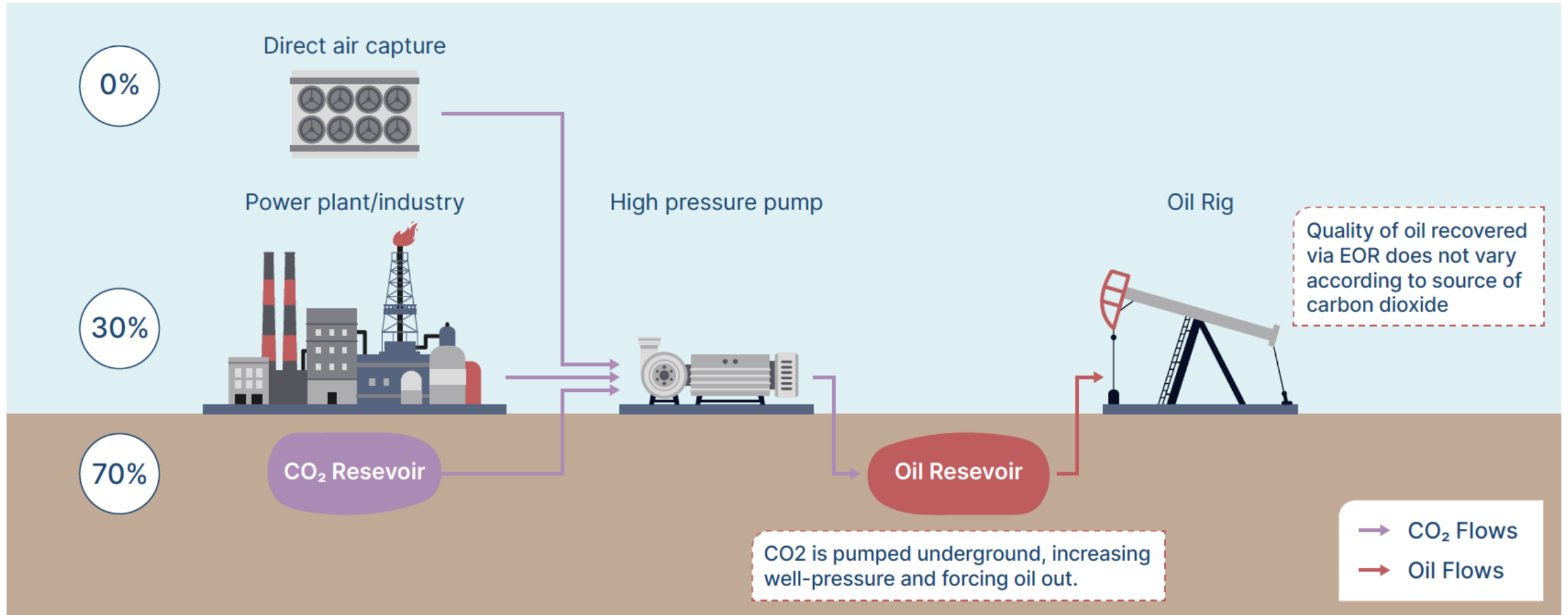
Utilisation

Share of CO<sub>2</sub> used  
in EOR today

CO<sub>2</sub> Source

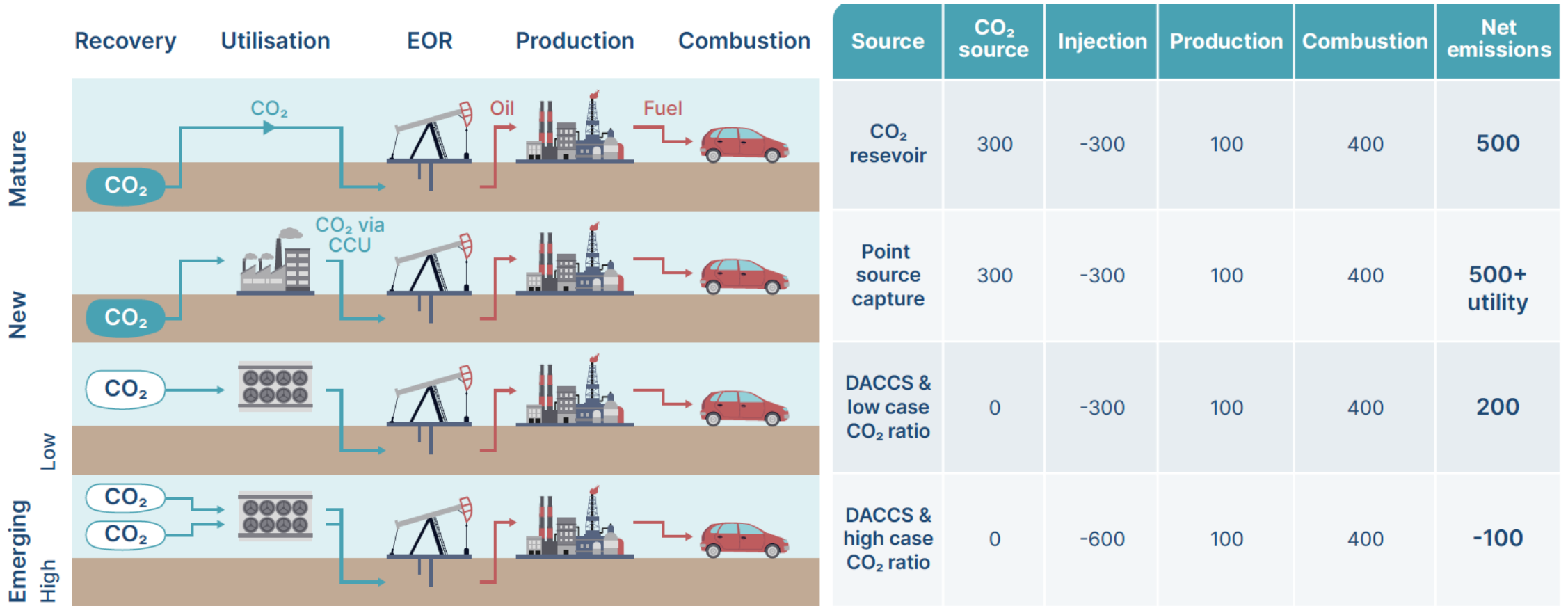
CO<sub>2</sub> injected underground

Oil Recovery



# Net CO<sub>2</sub> emissions from oil produced via EOR vary according to where the CO<sub>2</sub> is sourced from and the ratio of CO<sub>2</sub> injected to oil recovered

CO<sub>2</sub> emissions from EOR by recovery source and intensity  
kgCO<sub>2</sub>/bbl

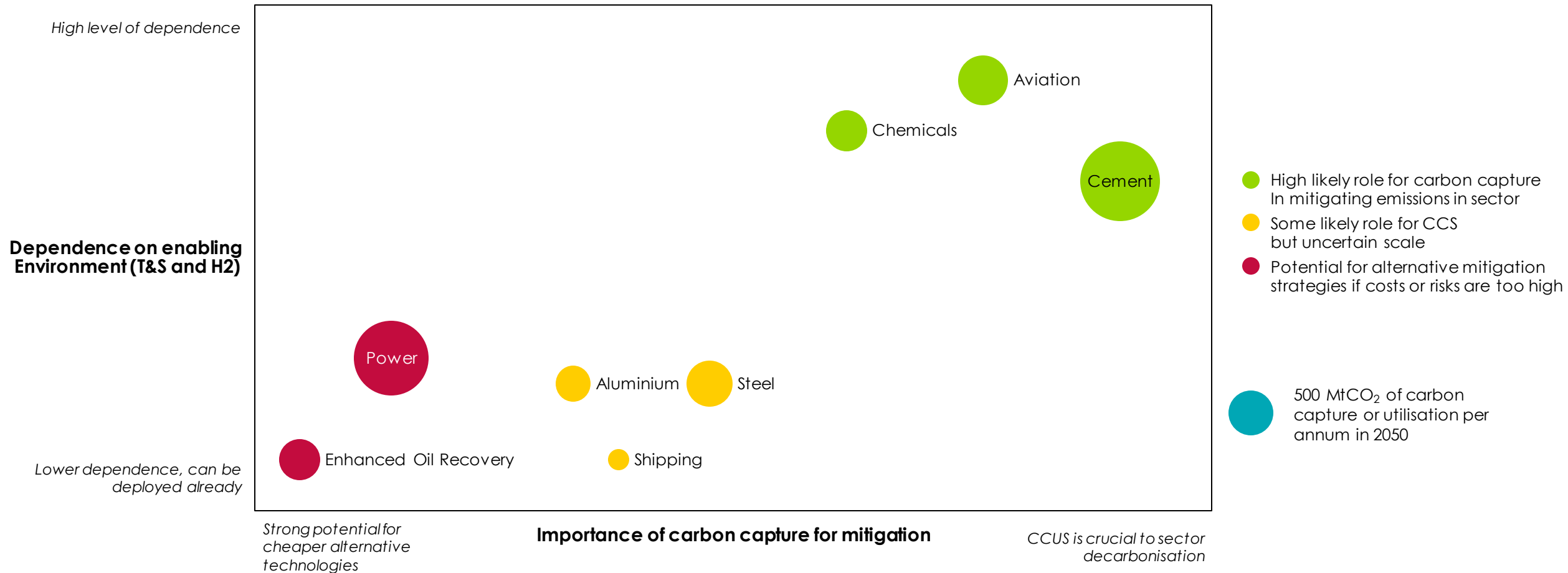


NOTE: Production includes processing, refining, transmission, distribution and retail.

SOURCE: Adapted from IEA (2019) *Can CO<sub>2</sub>-EOR really provide carbon-negative oil?*

# Carbon capture is necessary to decarbonise cement, aviation chemicals, and is likely to play a role in several other hard-to-abate sectors; role in power and EOR is less vital

## Mapping of likelihood of carbon capture, utilization and storage for sectoral decarbonisation



Note: Shipping and chemicals would require carbon capture in the process of making blue hydrogen for inputs. Both chemicals and aviation would make use of CO<sub>2</sub> as an input to make chemical products or sustainable aviation fuels. Cement would make use of carbon capture for process emissions, and would make use of CO<sub>2</sub> in mineralisation or recarbonation processes. Steel would make use of carbon capture for process emissions. Aluminium and the power sector would make use of carbon capture for emissions from power generation. Enhanced oil recovery would make use of CO<sub>2</sub> to increase rates of extraction. We do not show sectors where the ETC does not see any feasible role for CCUS, for example in trucking.

Source: Systemiq analysis for the ETC

# What is required between now and 2030 in order to deliver 7GtCO<sub>2</sub> CCUS capacity by 2050?



## Capture

- 0.8 GtCO<sub>2</sub>/year of capture across a suite of technologies by 2030
- Active carbon capture at around 340 sites
- 90%+ capture rates



## Transport & Storage

- 5 GtCO<sub>2</sub> storage capacity by 2035,
- 0.5 GtCO<sub>2</sub>/year being injected in 2030,
- At least 100 CCS hubs in operation around the world



## Innovation

- Focus on efficiency and capture rates for high TRL
- Proof of concept and demonstration for low TRL



## Finance

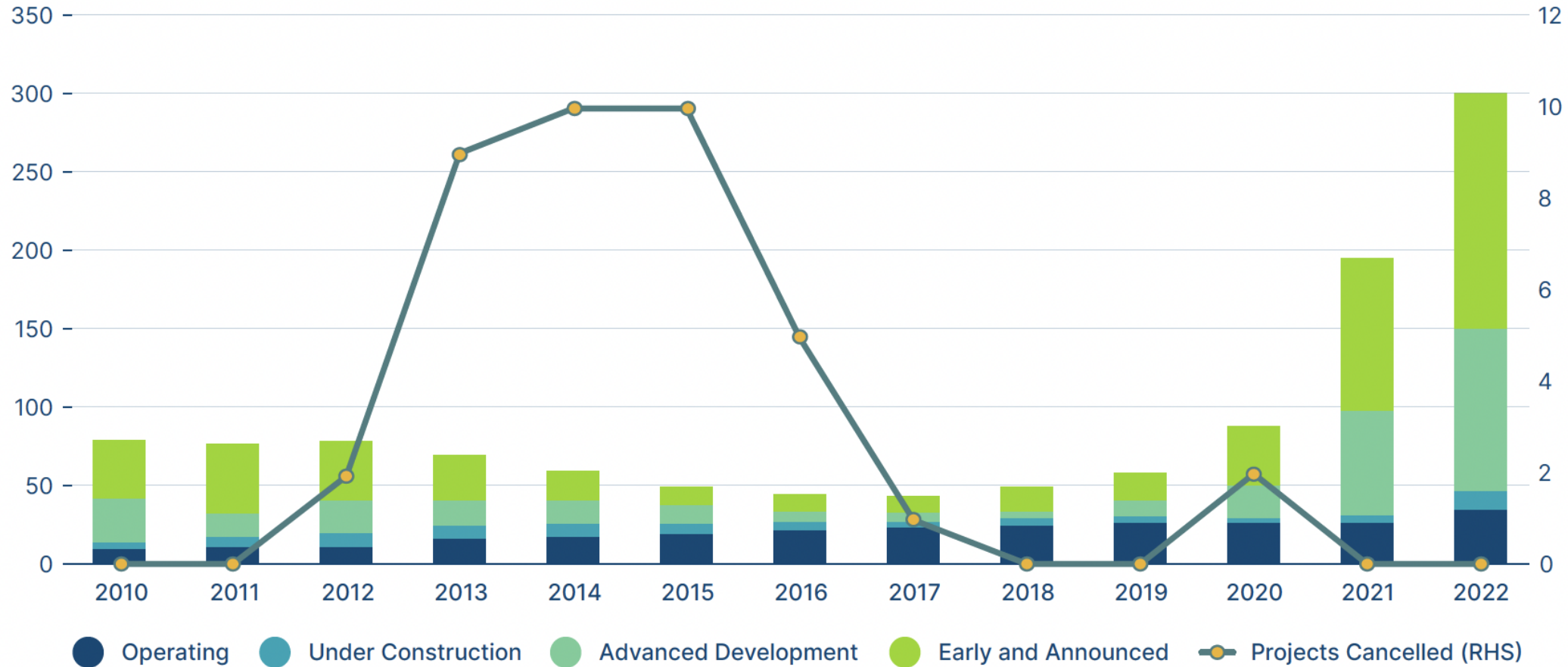
- Investment increases from \$3bn p.a. today to ~\$70bn p.a. by 2030



# Global CCUS project cancellations peaked in the mid-2010s but the pipeline is recovering sharply in the early 2020s

## Global CCUS project pipeline and cancellations

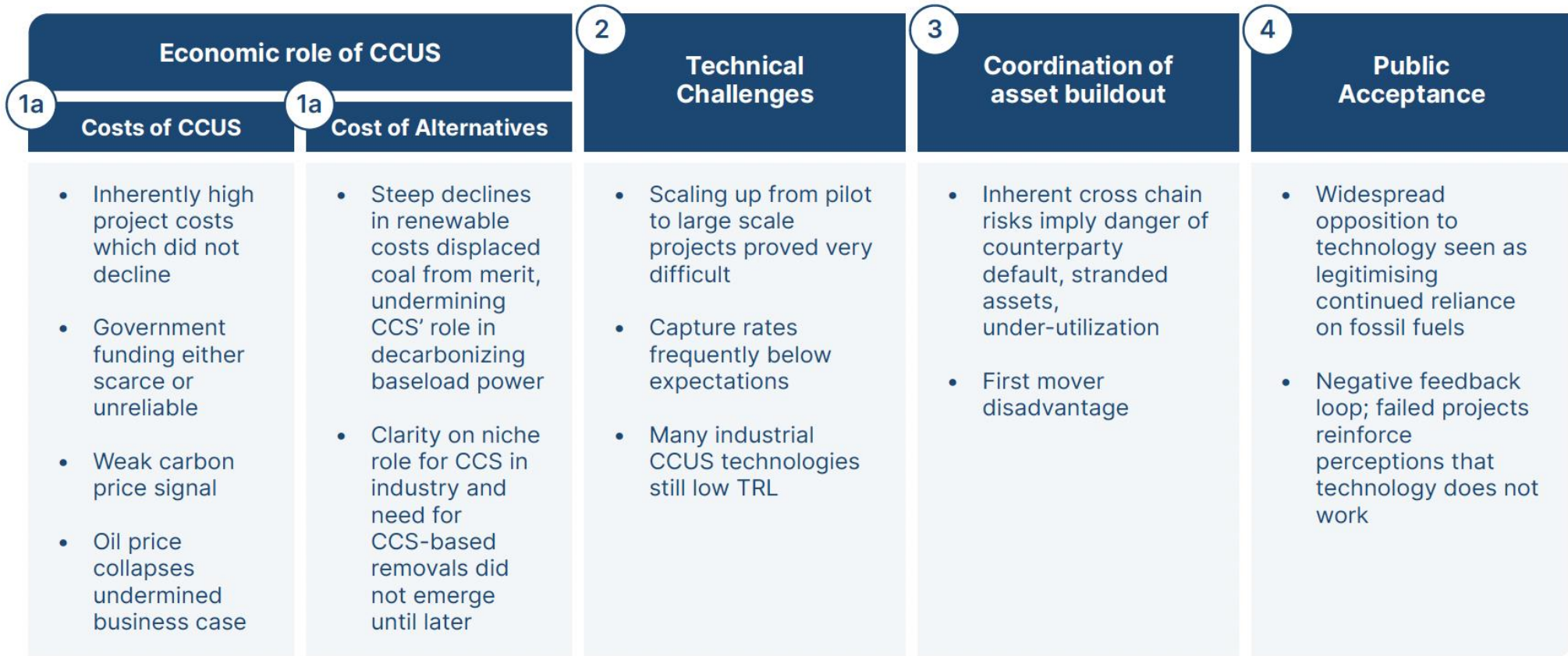
Number of projects



SOURCES: IEA (2021) *Carbon capture in 2021: off and running or another false start?* (2021)

# Challenging economics, technical problems, a lack of coordination and public opposition held back CCUS deployment in the previous decade

## Causes of CCUS project cancelations



SOURCES: SYSTEMIQ analysis for the ETC (2022)



# Policy makers' understanding of the role CCUS can and should play in the energy transition has evolved since the start of the 21<sup>st</sup> century

## Changes in policy-makers' understanding of CCUS' role in the energy transition

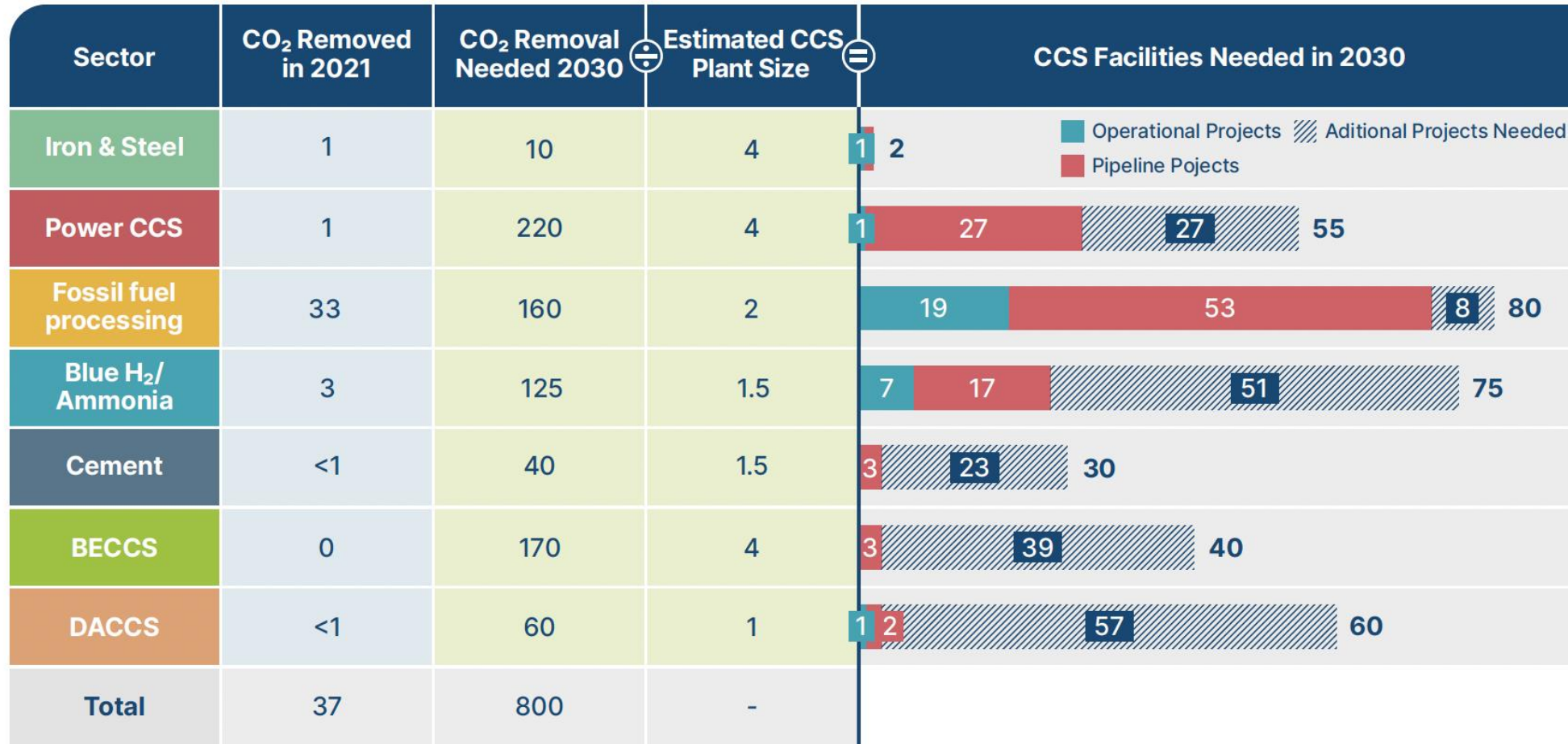
	2000 - 2015	2020s
<b>Underlying climate ambitions</b>	Emerging consensus on climate change science but no agreement on targets	Net Zero by 2050 widely accepted as critical to limiting global warming to 1.5°C
<b>Electricity</b>	Assumed renewables would remain uncompetitive: CCS essential to decarbonizing baseload	Wind and Solar already outcompete thermal in most geographies
<b>Industry</b>	Widespread uncertainty on how to decarbonize industry	Clarity on options to deliver; CCS competes with other routes – clear cement dependent on CCS for decarbonization
<b>Carbon dioxide removals</b>	Limited focus on emissions removals	Recognition of need for removals to reach 1.5°C
<b>Role of CCUS in the Energy Transition</b>	Limited principally to coal & gas baseload; industry as a secondary priority	Complementary role for CCS along side clean electrification; <ul style="list-style-type: none"> <li>• Essential role in non-fossil decarb (cement and CDR);</li> <li>• Small role in other industry and grid balancing</li> </ul>



# Over 300 new capture projects are likely required by 2030

## CCS facilities needed by 2030

Million tonnes CO<sub>2</sub> per annum

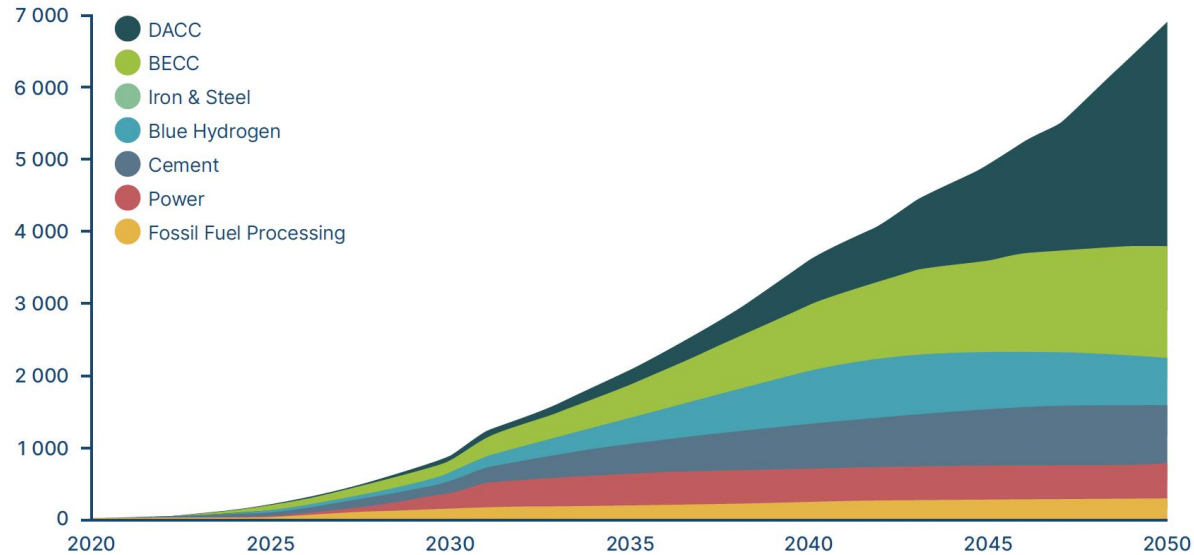


**NOTES:** Average size of new plants is based on the average plant size of the largest 20% plants in the US and EU. This applies to all sectors except BECCS where we assume the majority of early plants will be conversions from coal and thus draw upon Drax in the UK as a typical plant size. For DACCS, based on Carbon Engineering and 1point5's plans to build 70 DACC plants by 2035, each with a CO<sub>2</sub> capture capacity of 1Mtpa.

**SOURCE:** SYSTEMIQ Analysis; EEA; EPA; Global Cement and Concrete Association; MPP; IEA (2020) *CCUS in the transition to net zero emissions*; Global CCS Institute (2021) *Global Status of CCS 2021*

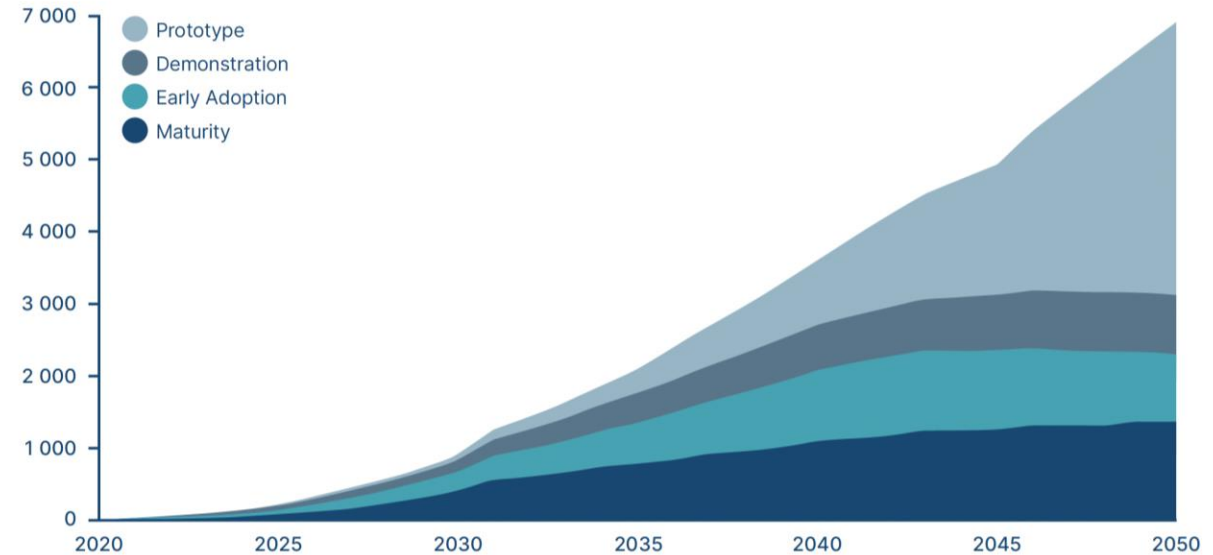
# High TRL sectors such as power, fossil processing and blue hydrogen drive capacity installations in the 2020s and 30s.

CO<sub>2</sub> captured by sector  
GtCO<sub>2</sub>/yr



SOURCE: SYSTEMIQ analysis for the ETC (2022)

CO<sub>2</sub> captured by TRL  
GtCO<sub>2</sub>/yr



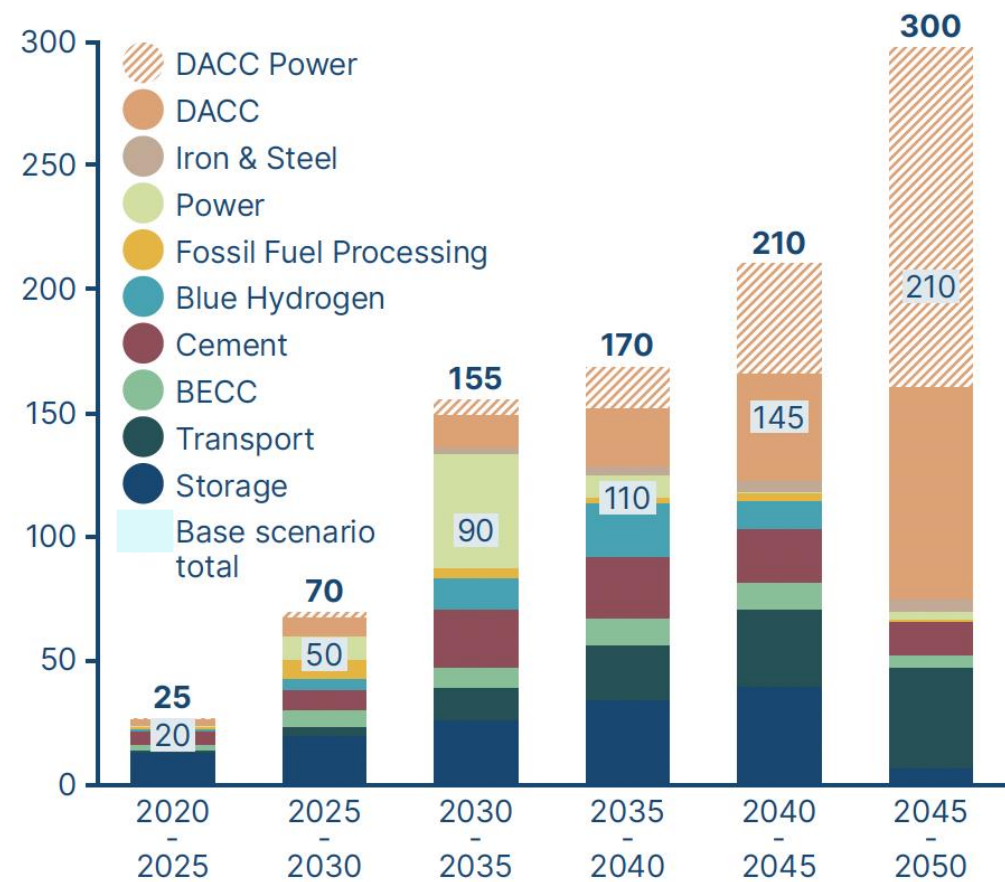
SOURCE: SYSTEMIQ analysis for the ETC (2022)



# Average annual CAPEX reaches \$300bn per annum in the late 2040s. Cumulative CAPEX is projected between \$3tn - \$5tn

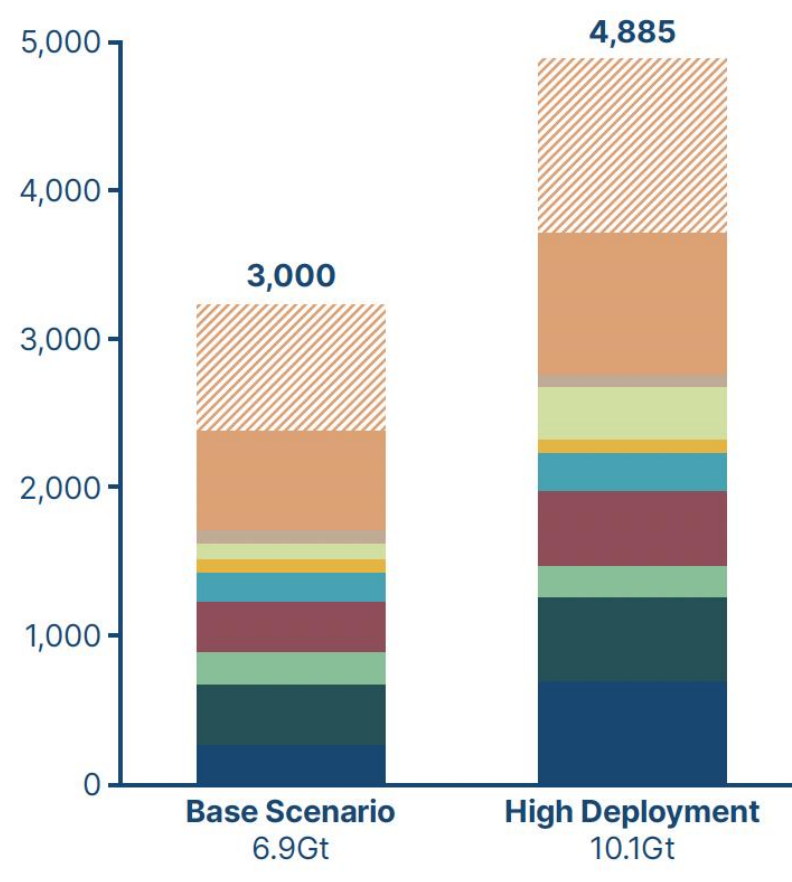
Average annual CAPEX by sector 2020-50

\$bn/year (High deployment scenario)



Cumulative CAPEX by sector and scenario 2020-50

\$bn/year

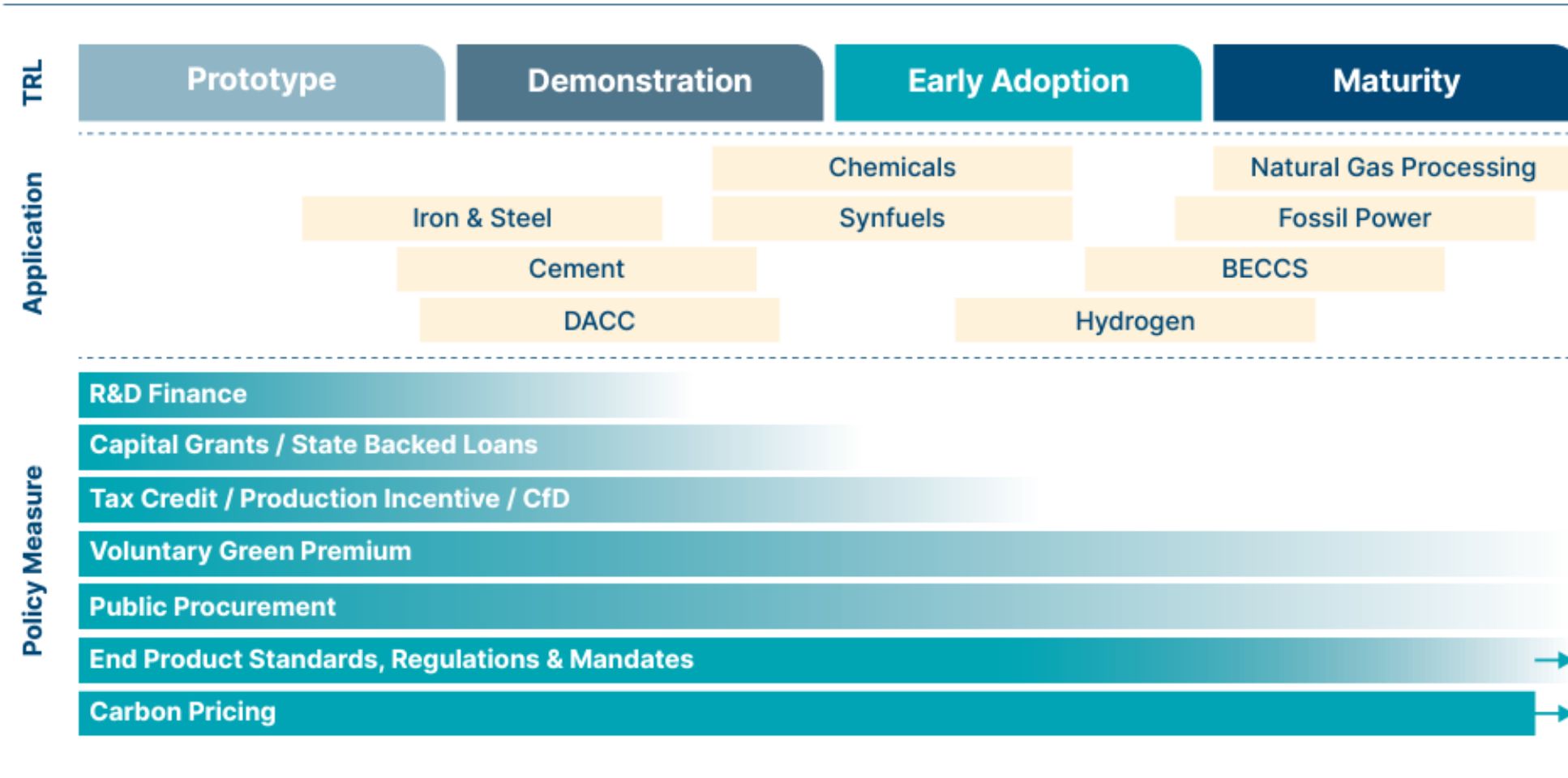


**NOTES:** DACC power is modelled owing to the especially high energy costs associated with collecting CO<sub>2</sub> from low concentration levels. For point source capture methods, energy consumption relatively trivial and is treated as an operational expenditure, therefore not shown here. High deployment scenario refers to 10.1GtCO<sub>2</sub> CCUS capacity by 2050 in which supply side decarbonisation measures only are deployed. Base Scenario sees 6.9GtCO<sub>2</sub> CCS capacity by 2050 as supply side decarbonization supported by energy productivity improvements as well.

**SOURCE:** SYSTEMIQ analysis for the ETC

# Technology specific support should gradually decline as technologies mature; carbon pricing, standards and mandates can remain indefinitely

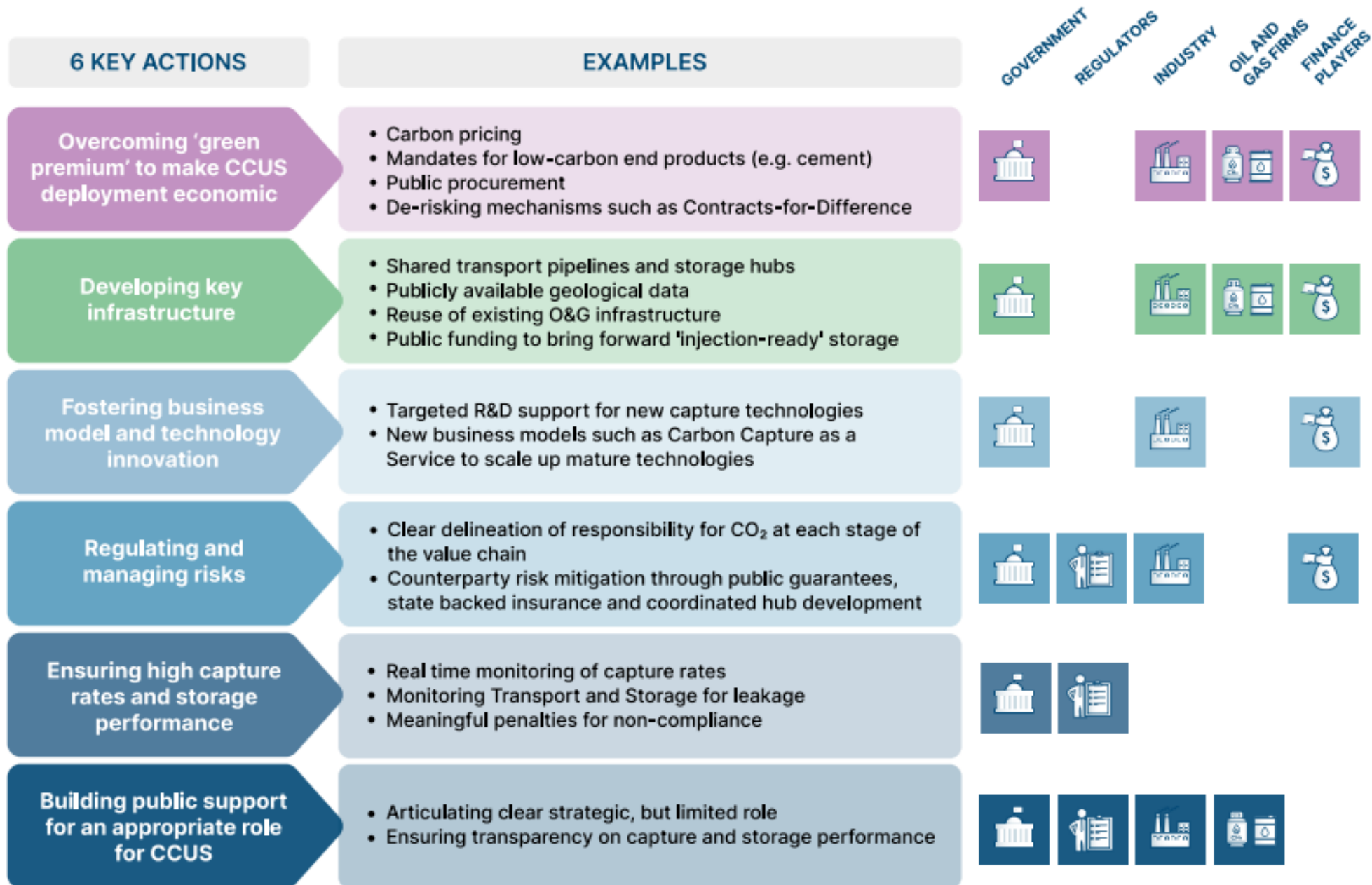
## Evolution of support for carbon capture



**NOTES:** These support measures pertain to carbon capture projects only. Regulated revenue streams are required in order to deliver – and share the costs of - the supporting T&S infrastructure (see Section 3.4.3).

**SOURCE:** adapted from IEA (2020) *Energy Technology Perspectives 2020: Special report on CCUS*

# Government, industry and finance have a role to play



# CCUS: Our scenarios require approximately 7-9 Gt of CCS by mid-century, in the same range as previous estimates

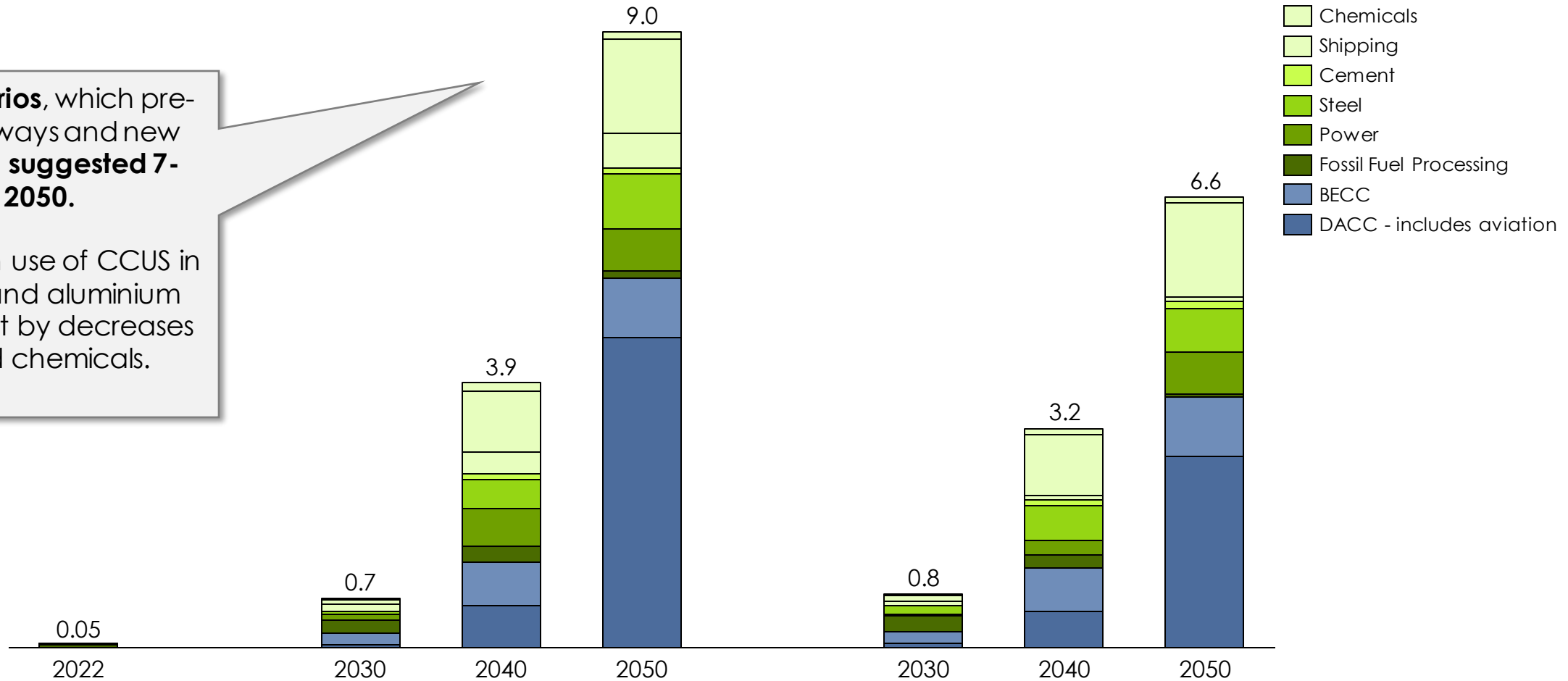
CCUS demand by sector, GtCO<sub>2</sub>

AMBITIOUS BUT CLEARLY FEASIBLE

PLAUSIBLE BUT STRETCH

**ETC (2022) scenarios**, which predated MPP pathways and new power modelling, suggested **7-10 GtCO<sub>2</sub>/year in 2050**.

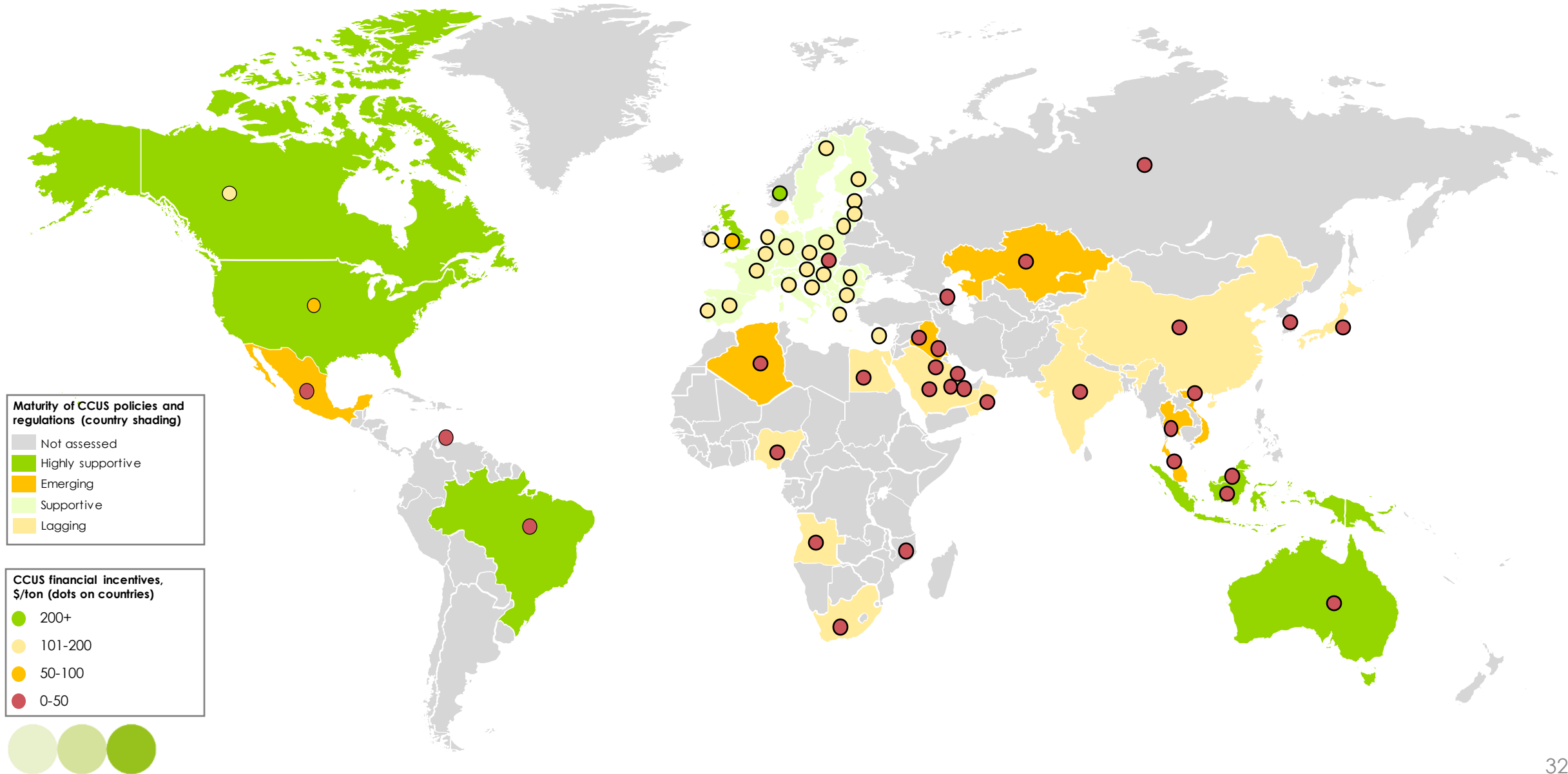
Small increases in use of CCUS in cement, steel and aluminium have been offset by decreases in power and chemicals.



Source: ETC analysis for Systemiq (2023).

Note: total captured emissions include both utilized carbon and carbon that is permanently stored.

# Significant incentives in the US, UK, and Norway are increasing the commercial viability of many CCUS projects



# CCUS policy and projects are advancing

**Biden-Harris Administration Announces Up To \$1.2 Billion For Nation's First Direct Air Capture Demonstrations in Texas and Louisiana**

 ENERGY.GOV

AUGUST 11, 2023

 GOV.UK

Notice

**Cluster sequencing Phase-2: Track-1 project negotiation list, March 2023**

Updated 30 March 2023

**German funding for climate protection contracts could unlock its CCUS market**

 REUTERS®

**China's Sinopec starts first carbon capture, storage facility, plans another two by 2025**



Following the selection of HyNet and East Coast Cluster as Track-1 CCUS clusters in November 2021, and the publication of the shortlist of power CCUS, industrial carbon capture (ICC), waste and CCUS-enabled hydrogen projects in August 2022, the Department for Energy Security and Net Zero has selected 8 projects to proceed to negotiations for support through the relevant Business Models.

**The US government is a new gold mine for carbon capture companies**

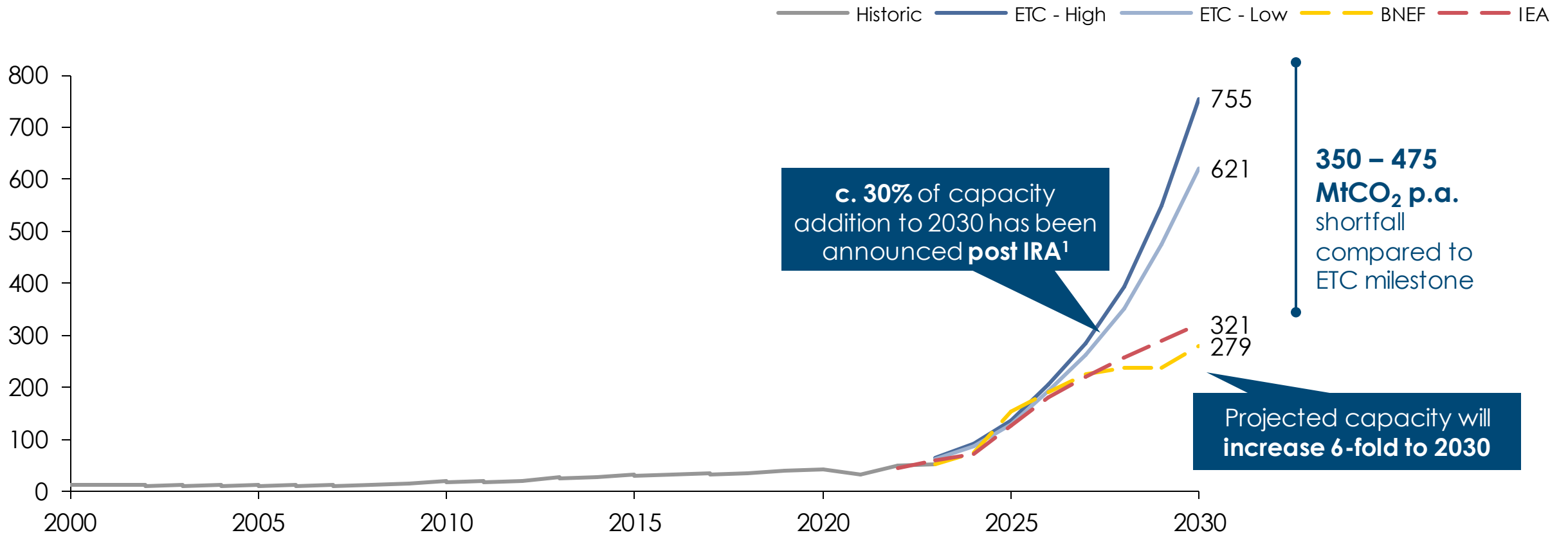
A major expansion of tax credits for carbon capture in the Inflation Reduction Act puts previously unaffordable projects within reach.

**Canadian firm Carbon Engineering being bought by Occidental for \$1.1B US**  CBC

# The CCUS project pipeline growing fast; but despite impact of the IRA, projected 2030 capacity just a third of what's required in the ETC's scenarios

## Total Carbon Capture Utilisation and Storage (CCUS) capacity to 2030

MtCO<sub>2</sub>p.a.



Note: 1. IRA = Inflation Reduction Act, Source: ETC (2022) *Mind the Gap* report, BNEF (2022) *CCUS Market Outlook*; IEA (2023), *Operational and planned capture capacity*, BCG (2023), *Impact of IRA, IJJA, CHIPS, and Energy Act of 2020 on Clean Technologies*





# Energy Transitions Commission

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