CO_2 capture: an overview (II)

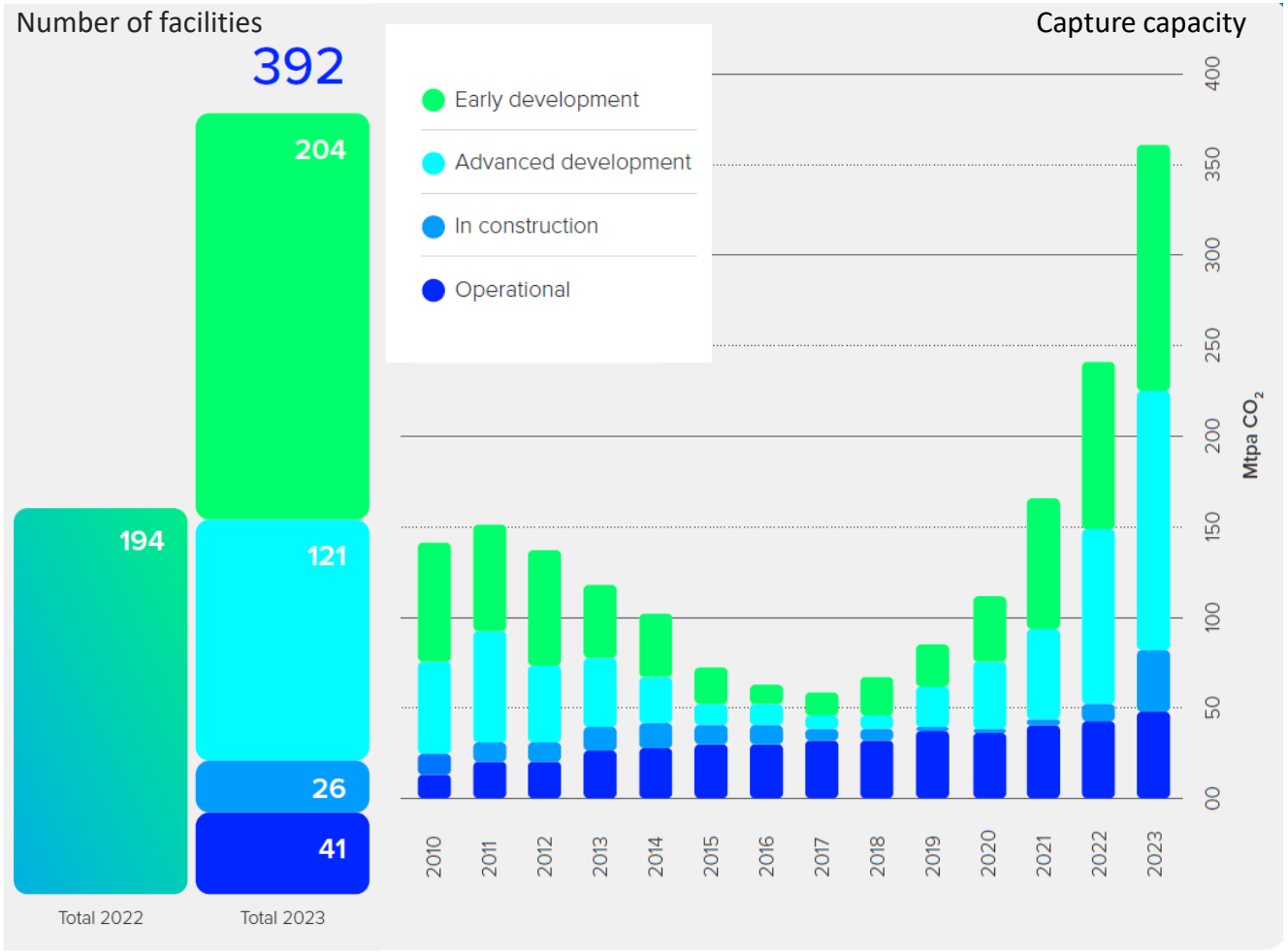
CO_2 capture processes and facilities

E. Lorenceau, LIPhy – CNRS and UGA

A CO_2 capture facility is designed to trap CO_2 molecules to prevent their release into the atmosphere.

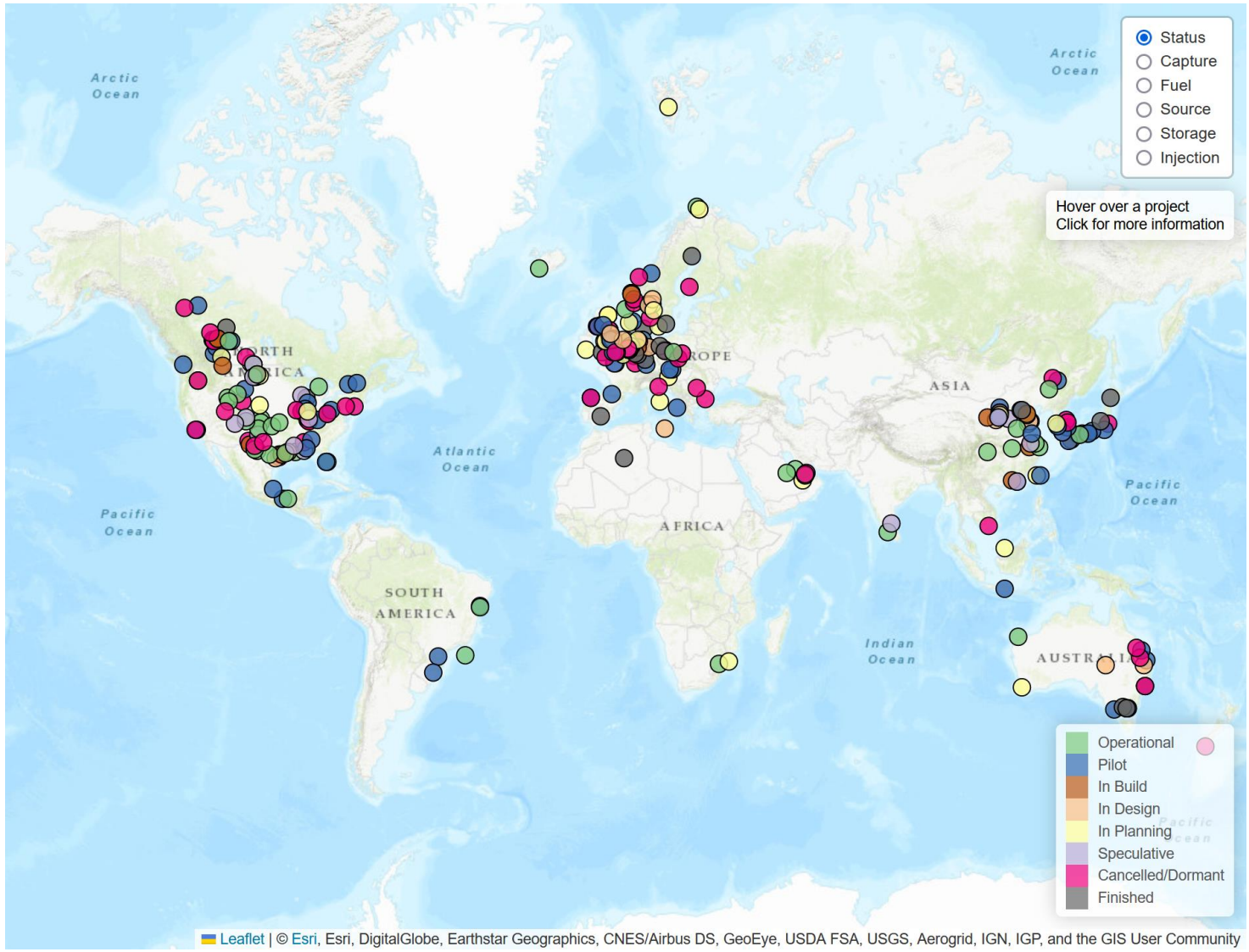
DefiCO2
Université Grenoble Alpes

Overview of the Carbon Capture facilities



The existence of these facilities with their limited potential should not obscure the urgent need to drastically limit the use of fossil fuels...

Overview of the Carbon Capture facilities



https://www.sccs.org.uk/resources/global-ccs-map

Scottish Carbon Capture & Storage

Different types of industrial carbon capture facilities

- **Part of an industrial plant equipped with a unit dedicated to carbon capture, utilization and storage (CCUS).**

CO_2 is separated from other emitted gases, treated and transported
- to a long term storage location (CCS)
- to be used as a carbon source (CCU)

➡ **CO_2 capture from concentrated sources emitted by industry and the energy sector**

Fuel combustion in air

$CH_4 + 2O_2 +$ excess of $O_2 +$ excess of $N_2 \rightarrow CO_2 + 2H_2O +$ excess of $O_2 +$ excess of N_2

CO_2 ~ 8 to 15 (% vol)
O_2 ~ 2 to 8 (% vol)
H_2O ~ 8-10 (% vol)
N_2 ~ 70 to 76 (% vol)
+ other gases

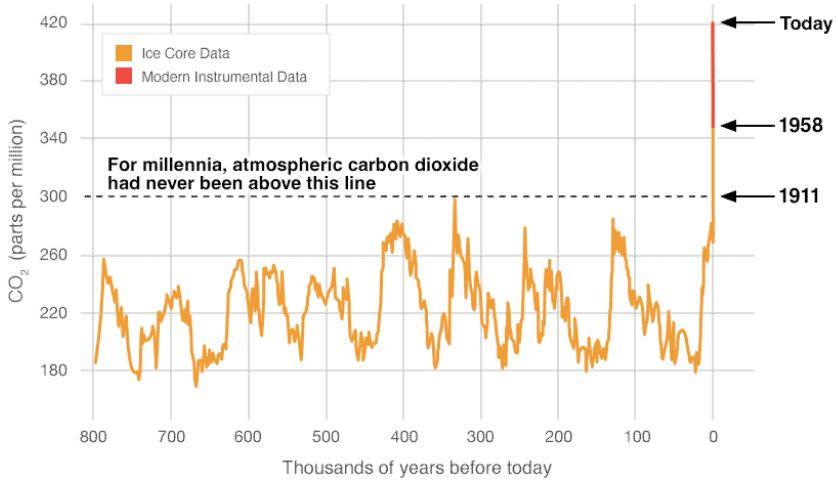
Different types of industrial carbon capture facilities

- **Autonomous unit of direct Air Capture technologies (DAC)**

CO_2 from air is separated from other air gases, treated and transported
- to a long term storage location
- to be used as a carbon source

➡ **CO_2 capture from diluted sources – CO2 present in air**

CO_2 ~ 0,04%
O_2 ~ 21 (% vol)
N_2 ~ 78 (% vol)
H_2O ~ 0-10 (% vol)
+ other gases



Wikipedia flue gas
F. Scala et al. **"Spray-Dry Desulfurization of Flue Gas from Heavy Oil Combustion" (2005)**

Different types of industrial carbon capture facilities

Concentrated sources of CO2

- ***Post-Combustion Capture*** a family of technologies implemented after combustion takes place.

- ***Pre-Combustion Capture***, where carbon is removed prior to combustion, leaving a carbon-free fuel - hydrogen - to burn.

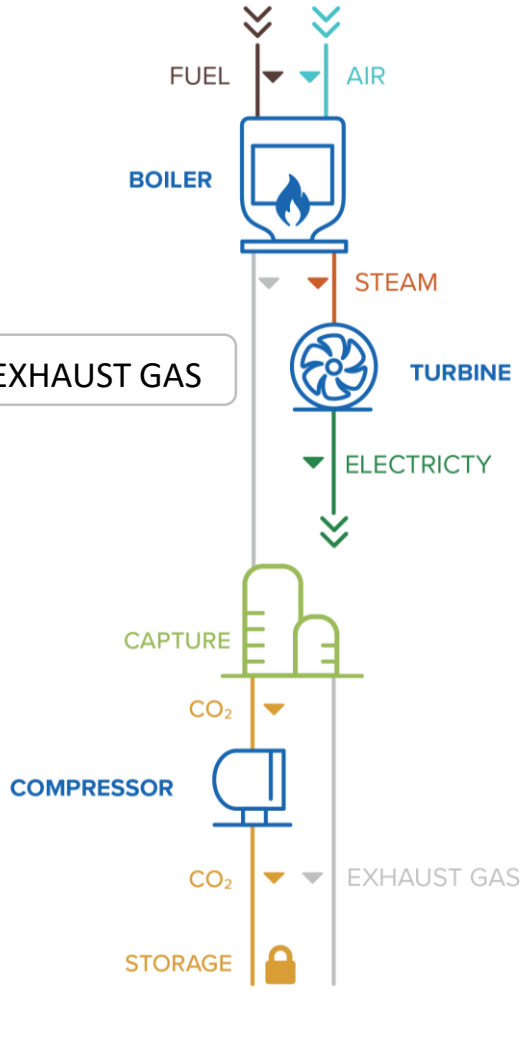
- Capture by ***Oxyfuel Combustion***, where fuel is burned in oxygen, without nitrogen.

Diluted sources of CO2

- ***Direct Air Capture*** a family of technologies capturing CO_2 from ambient air

Post Combustion CO_2 capture

CO_2 ~ 8 to 15 (% vol) – EXHAUST GAS



Conventional power station or other CO_2 emitting industry (cementry)

Carbon Capture unit

- One separation unit
- Possible to retrofit CCS facilities to existing power stations or CO_2 -emitting industries

https://www.globalccsinstitute.com/

Post-combustion capture: Example of Petra Nova

Industry: Carbon capture unit installed in 2017 on one of the boilers of a coal burning power plant in Texas (entered commercial service in 1977) *-> cleaner coal plant*

Carbon Capture Technology : Amine based absorption

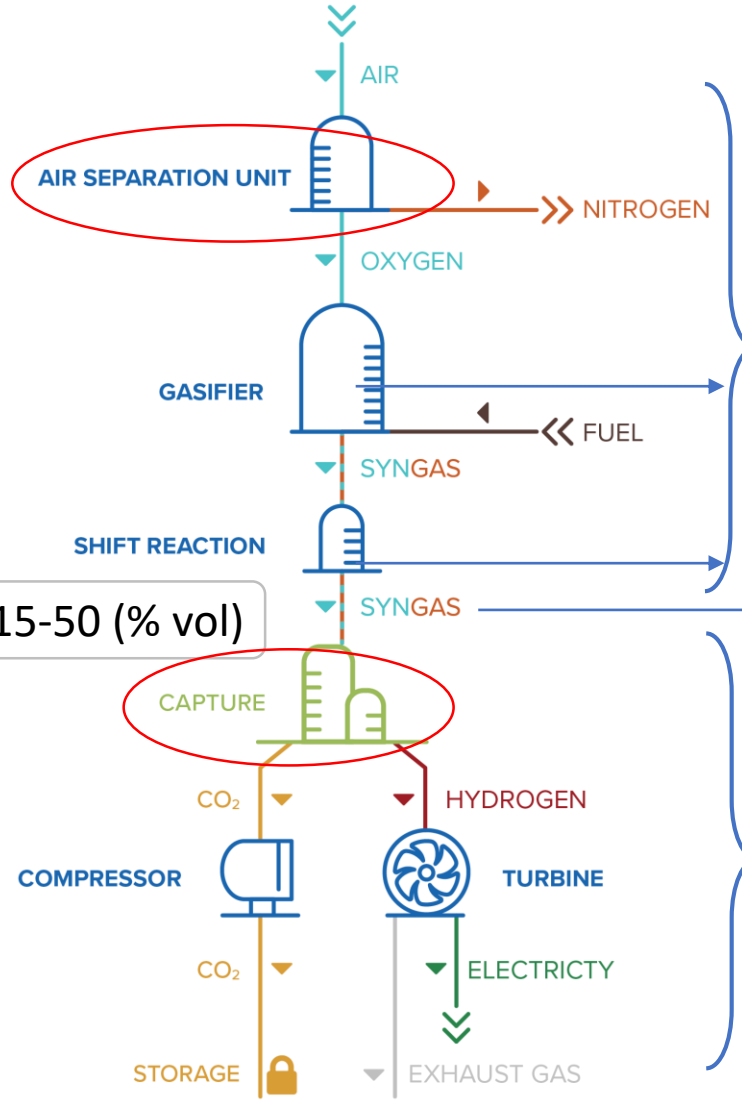
Target: 1.4 10^6 tons of CO_2/yr used for injection in enhance oil recovery – 33% of emitted CO_2

Business plan: $1 billion to install the CCS unit paid by NRG Energy and JX Nippon Oil ($190 million grant from US government, $250 million loan from the Japanese government). Expected profit from enhanced oil recovery rates(X50) … But oil prices drop and Petra Nova shut down in 2020. Sold to Eneos japanese (to gain expertise in CCUS) – dormant project

Carbon capture costs linked to energy prices. Becomes prohibitive when energy prices are too low.

https://www.powermag.com/engineering-the-largest-post-combustion-carbon-capture-plant/ - https://en.wikipedia.org/wiki/Petra_Nova

Precombustion capture



Conventional gasification power station

$3\ CH_4 + O_2 + H_2O \rightarrow 6H_2 + 3CO$

Coal -> Integrated Gasification Combined Cycle (IGCC -decades old !)

Gaseous Fuel -> Auto-thermal reforming (decades old !)

$CO + H_2O \rightarrow CO_2 + H_2$

mixture of high pressure H_2 , CO_2 , H_2O, (CO)

Carbon Capture unit

- Two gas separation units
- Use of large quantities of water

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No large-scale commercial CCS power stations using Pre-Combustion Capture in operation in 2023!

Precombustion capture: Example of Kemper County CCS

Industry: 2010 – Mississippi Power launches the Kemper project combining Coal precombustion (IGCC) and Carbon Capture
-> "clean" coal plant

Carbon Capture Technology: unknown

Target: Capture 65% of the CO_2 produced by the monthly use of 375,000 tonnes of mined coal – 3 10^6 tons CO_2/yr

Business plan and schedule:

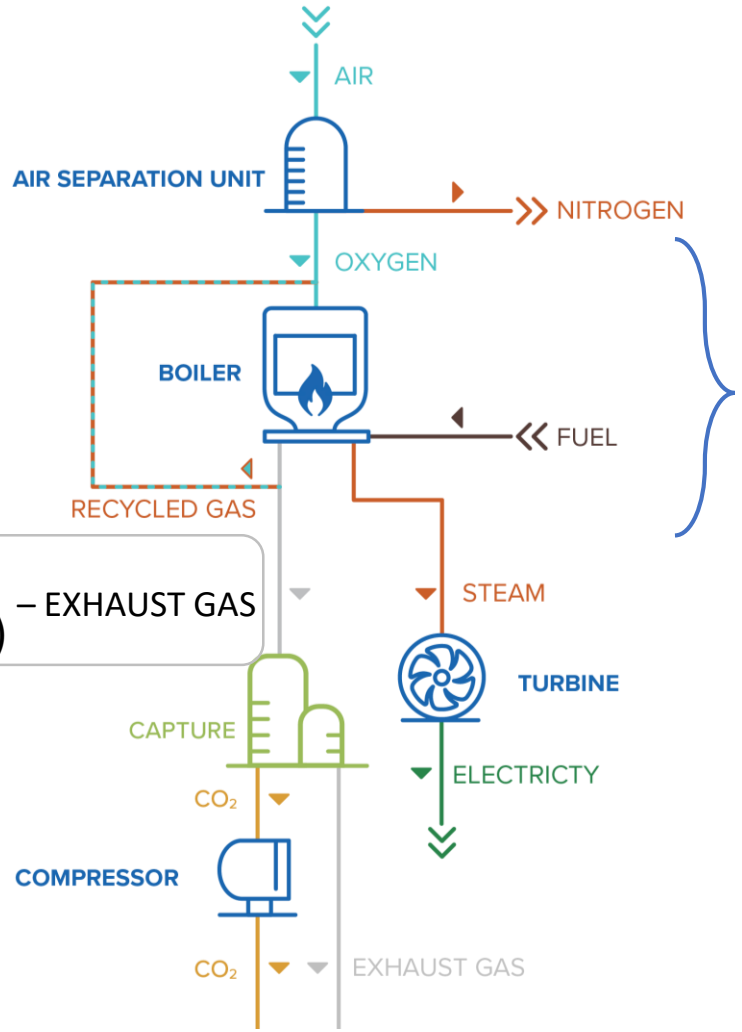
- August 2014: Combined cycle unit in commercial operation - Cost $2.4 billion (Mississippi power -> Electricity cost increases)
- October 2014: Delay of two years + Extra Cost $4 billion
- September 2016: Two over three gasifiers produces syngas (No CCS)
- March 2017: Leakage in syngas machinery (No CCS)
- June 2017: Operation suspended (No CCS)
- October 2021: Gasification structure demolished – now only gas-fired plant.

Failure not related to CCS but rather i) complex technologies ii) Rise of natural gas ressources (gas fracturing) iii) Uncertain financing plan

Vulnerability of technological choices based on energy price forecasts

https://spectrum.ieee.org/the-three-factors-that-doomed-kemper-county-igcc

Capture by Oxyfuel combustion



CO_2 ~ 90(% vol)
H_2O ~ 10(% vol)
– EXHAUST GAS

Combustion in pure oxygen leads to very high temperature
-> Fraction of the combustion gas diverted back to dilute O_2

- Two gas separation units
- Heat can also be used in steel and cement industries

https://www.globalccsinstitute.com/

No large-scale commercial CCS power stations using Oxyfuel in operation in 2023!

Capture by Oxyfuel Lacq Pilot

Industry : One boiler of the gas energy plant has been retrofitted into an oxy-fuel boiler associated to CCS. In operation from 2010 to 2013 – Air Liquide and Total

Carbon Capture Technology : Combination of Membrane and Cryogenics technologies

Target : 60 10^3 tons CO_2/yr – Achieved 17 10^3 tons CO_2/yr injected.

Economics : Cost € 60 millions (Total)

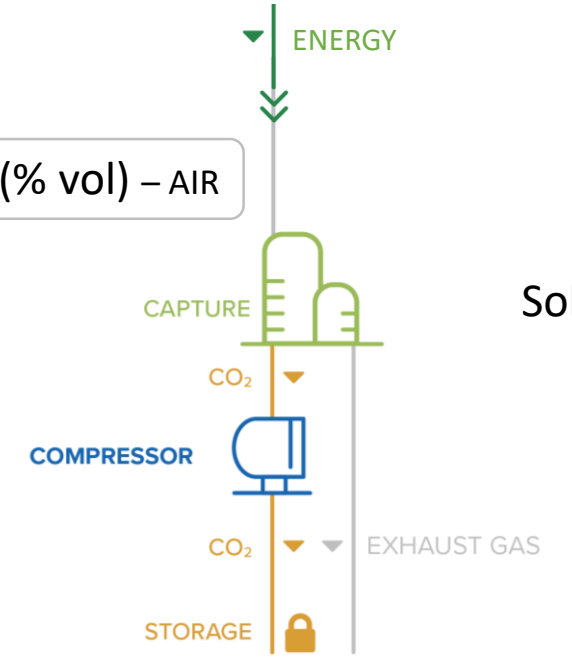
Possible to retrofit an air boiler into an oxycombustion boiler

Air Liquide extensive industrial experience of full oxy-combustion for industries
-> K6 project in 2024 – Technology readiness of the process ?

https://www.globalccsinstitute.com/news-media/insights/total-publishes-lacq-ccs-pilot-report/

Direct air Capture

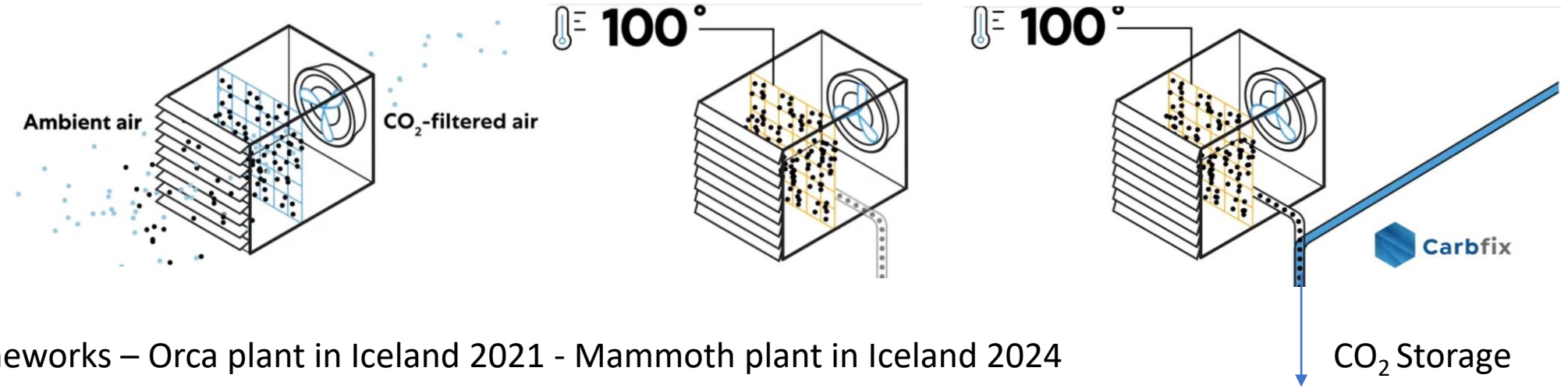
CO_2 ~ 0,04(% vol) – AIR



Solid or liquid sorbent

Adapted from https://www.globalccsinstitute.com/

Direct air Capture



Industry : Climeworks – Orca plant in Iceland 2021 - Mammoth plant in Iceland 2024 CO_2 Storage

Carbon Capture Technology : Temperature swing adsorption on solid sorbents - Carbon capture efficiencies of 85.4% and 93.1%

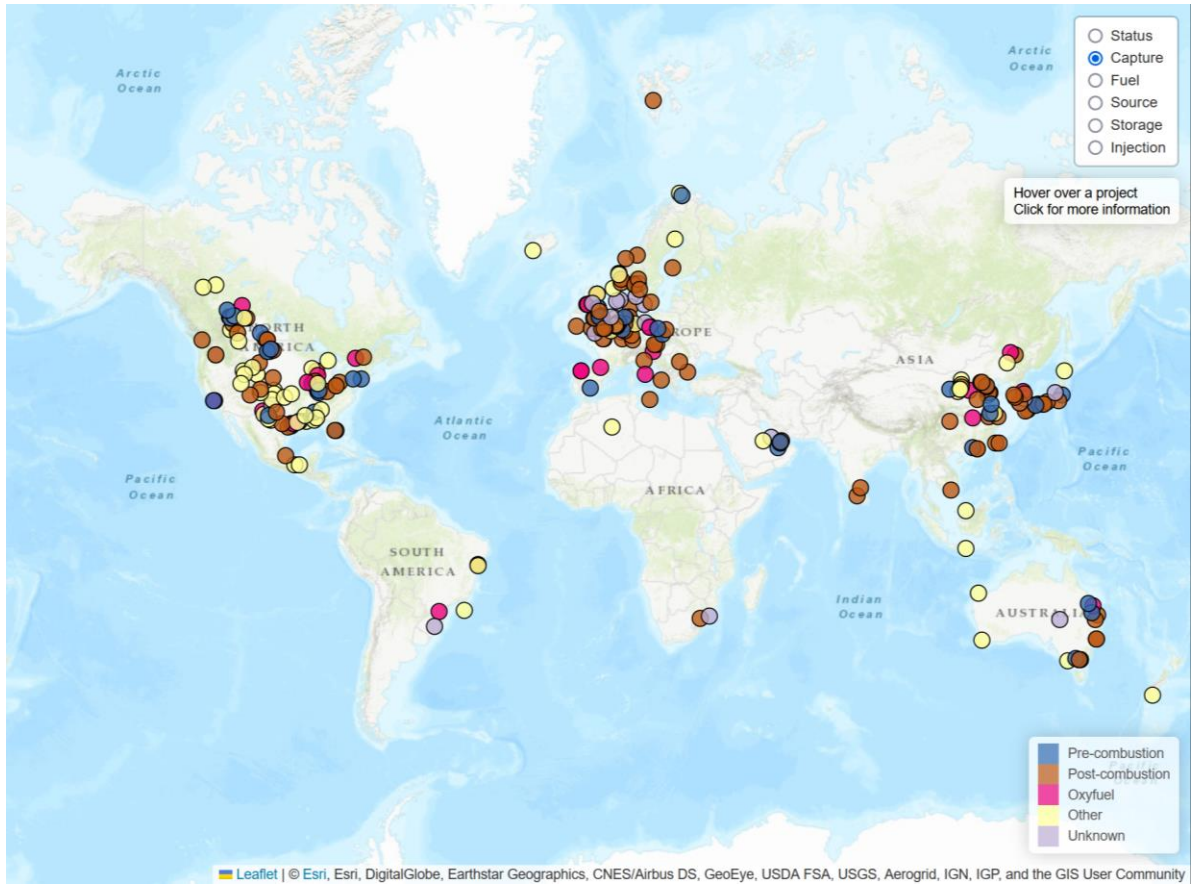
Goal : Orca 4 10^3 tons of CO_2/yr - Mammoth 36 10^3 tons of CO_2/yr

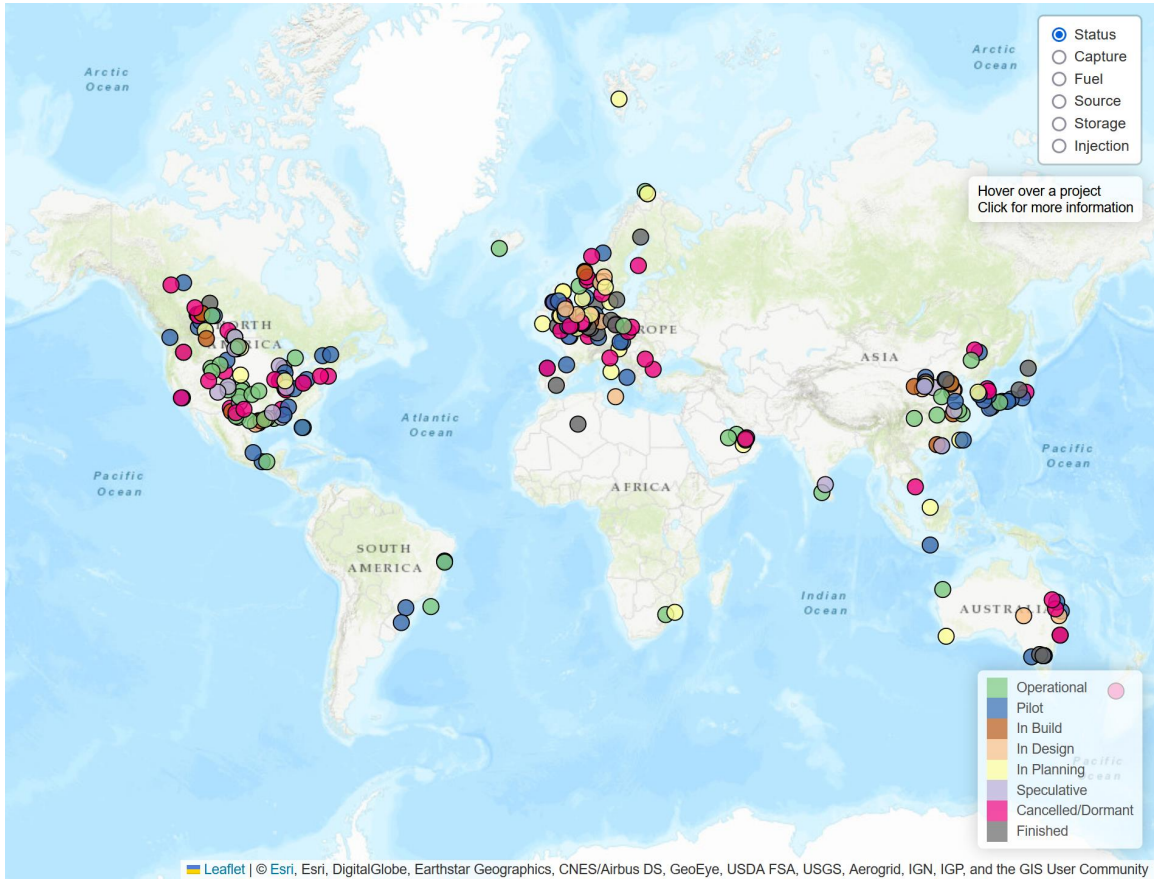
Economics : 1) Fund raising – 2018:$30.8 millions – 2020:$110 millions – 2022:$650 millions 2) Commercialization of CO_2 offesetting

Business model durability? Resources cost?

https://climeworks.com/direct-air-capture

Overview of the type of carbon capture facilities





Credit : Scottish Carbon Capture & Storage, http://sccs.org.uk/resources/global-ccs-map

What is the energy cost of carbon capture?

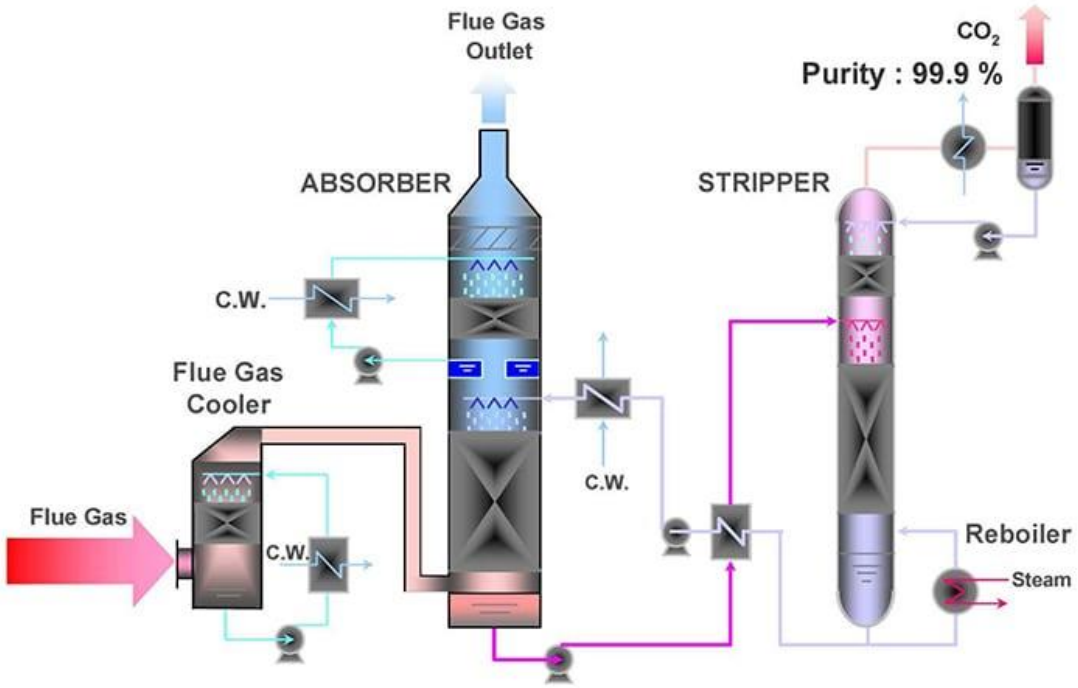


Table 3
Thermal and electric energy consumption for the studied MEA-based CO_2 capture system.

Thermal (MJth/s)	
Reboiler heat duty	484.6
Stripper condenser cooling	188.5
Lean liquid cooling	234.0
Compressor cooling	78.3
Electric energy consumption (MJe/s)	
Gas blower	8.2
Pumps	10.0
CO_2 compression	45.8
Total	64.0

Energy penalty estimates for CO2 capture: Comparison between fuel types and capture-combustion modes, Energy (2016)

What is the energy cost of carbon capture?

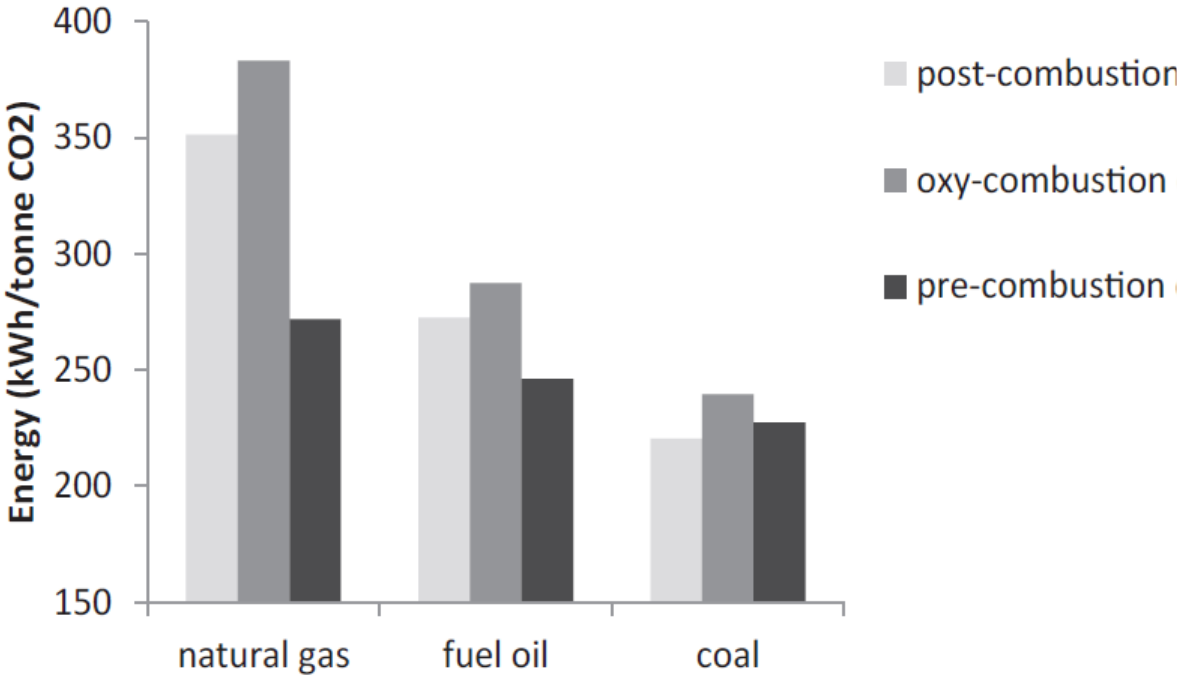


Fig. 2. Energy cost for different methods for CO_2 capture.

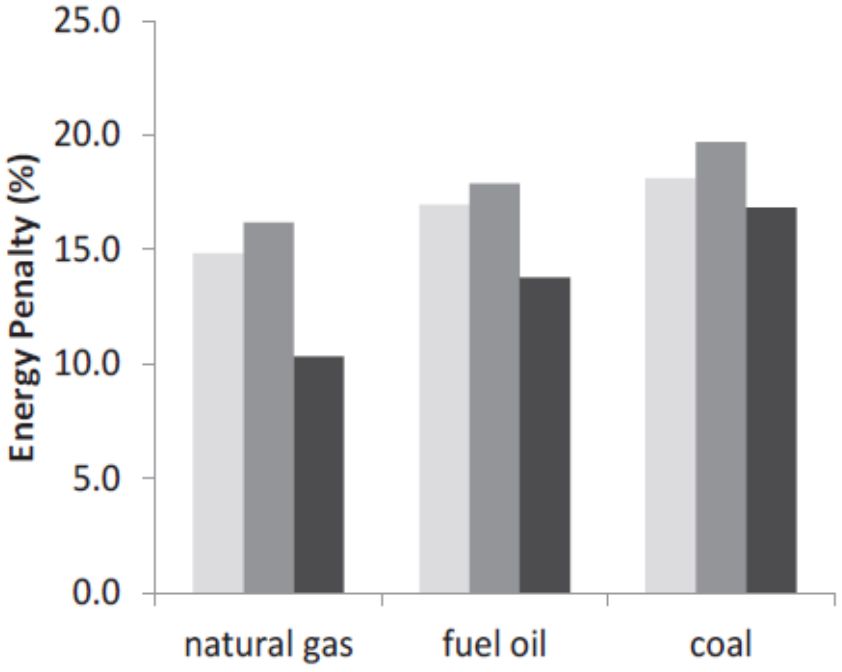


Fig. 3. Target energy penalties for different methods of CO_2 capture.

Lowest E/ton of CO_2 is for coal-based power plants, and for all modes of power generation, followed by fuel oil and natural gas, but … energy density of natural gas is higher than fuel and oil !

Lowest energy penalty for gas in pre-combustion process around 10%

Energy penalty estimates for CO2 capture: Comparison between fuel types and capture-combustion modes, Energy (2016)

What is the energy cost of direct air capture?

Status of the Leading DAC Companies

	Cimeworks	Carbon Engineering	Global Thermostat
Location	Switzerland	Canada	United States
System type	Solid sorbent	Liquid solvent	Solid sorbent
Thermal energy needs	80-120°C / 176-248°F	900°C / 1652°F	105-120°C / 221-248°F
Thermal energy source	Non-fossil energy resources (geothermal, waste heat, etc.)	Natural gas with CCS	Energy resource agnostic
Projects	15 plants around Europe with a collective capacity of just under 6,000 tCO_2/yr	Pilot plant in Canada; developing 1 $MtCO_2$/yr capacity plant in Southwest United States	2 plants in the United States with a collective capacity of 1,500 tCO_2/yr
Investments	Most recent round of funding, in March 2022, reached $650 million	Received $70 million in total investment from governments and corporates	Received investments of $68 million in most recent round of funding in 2019

Resource			Trees
Energy	2 000 kWh/tCO_2	2 400 kWh/tCO_2	0 kWh/tCO_2
Land	66 km^2/tCO_2	1 km^2/tCO_2	862 km^2/tCO_2
Water LOSS	-1 tH_2O/tCO_2	4 tH_2O/tCO_2	

Source: Climeworks 2022, IEA 2022, McQueen et al. 2021, NASEM 2019, Carbon Engineering 2019, Bipartisan Policy Center 2020

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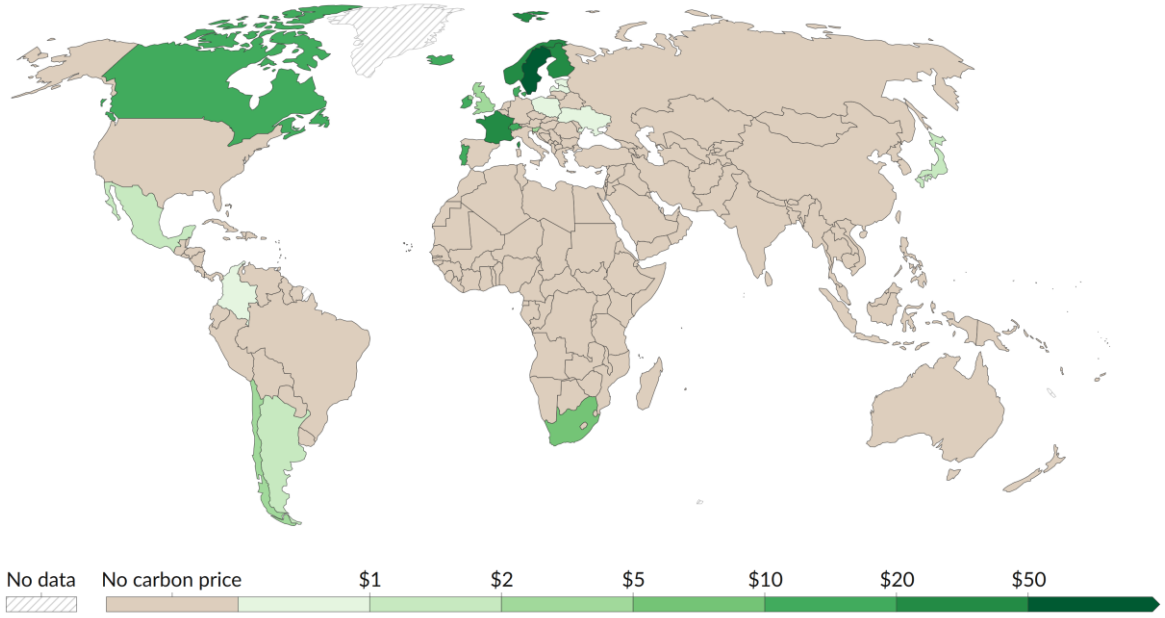
https://www.wri.org/insights/direct-air-capture-resource-considerations-and-costs-carbon-removal

CCS and DAC supporting policies

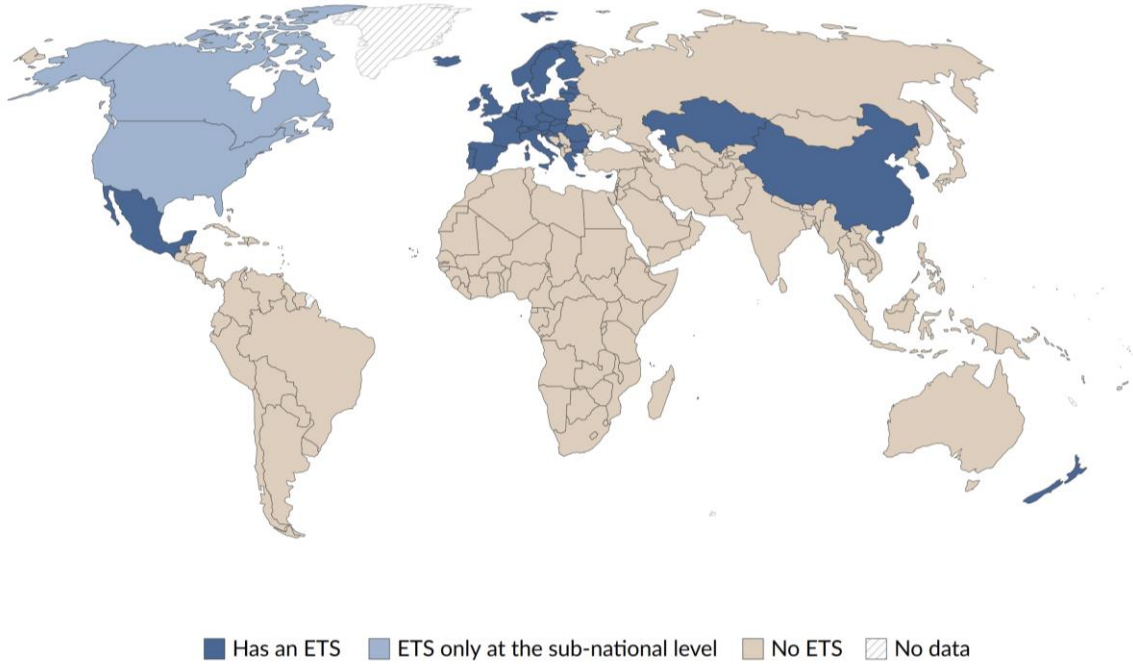
Carbon tax: applied to the production of greenhouse gas emissions directly or fuels that emit these gases when they're burned.

Emission trading system: carbon price changes over time. A maximum level of pollution (a 'cap') is defined and manufacturers need licenses to emit greenhouse gases.

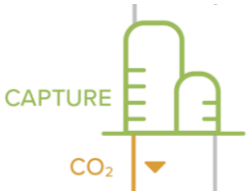
Carbon tax



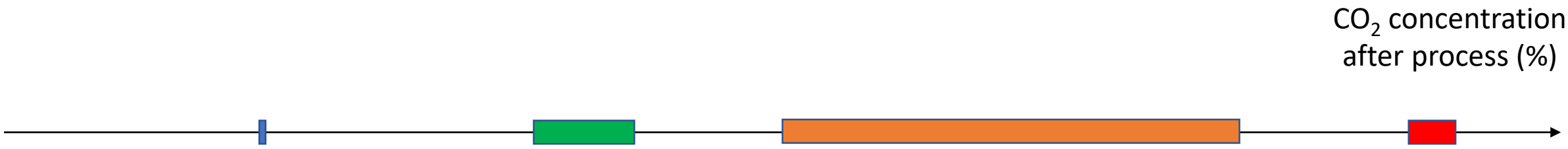
Emission trading system



https://ourworldindata.org/grapher/emissions-weighted-carbon-price?time=2021



Summary



	Direct air capture	Post-combustion capture	Precombustion capture	Oxyfuel capture
E/tCO_2	2000 kWh/tCO_2	225-350 kWh/tCO_2	245-260 kWh/tCO_2	250-375 kWh/tCO_2
\$/tCO_2	250 – 600	~100	~100	~100

MOOC - Climate change: Carbon Capture and Storage – University of Edinburgh

https://www.globalccsinstitute.com/archive/hub/publications/17011/costs-co2-capture-transport-and-storage.pdf