Direct Air Capture of carbon dioxide

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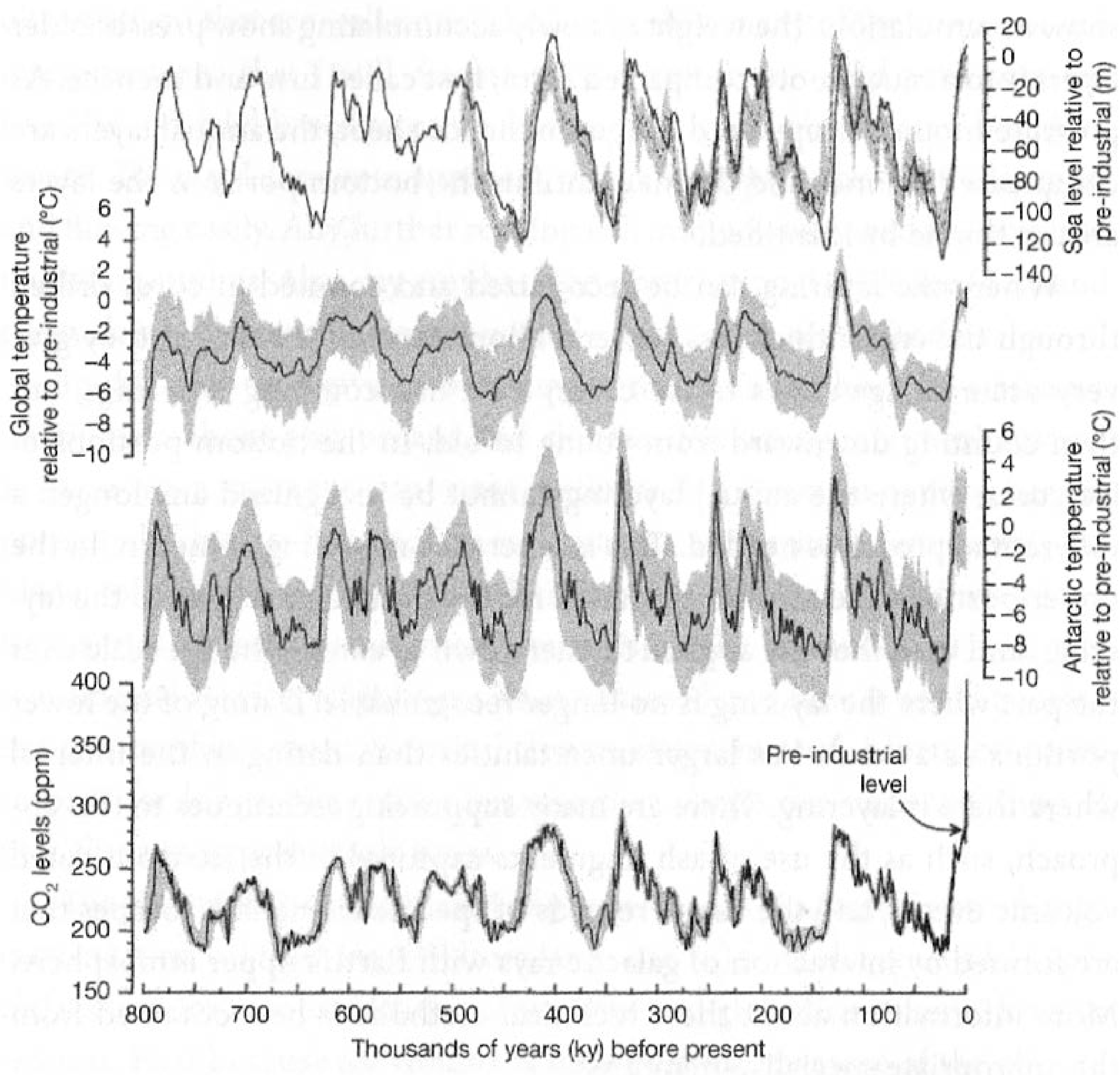
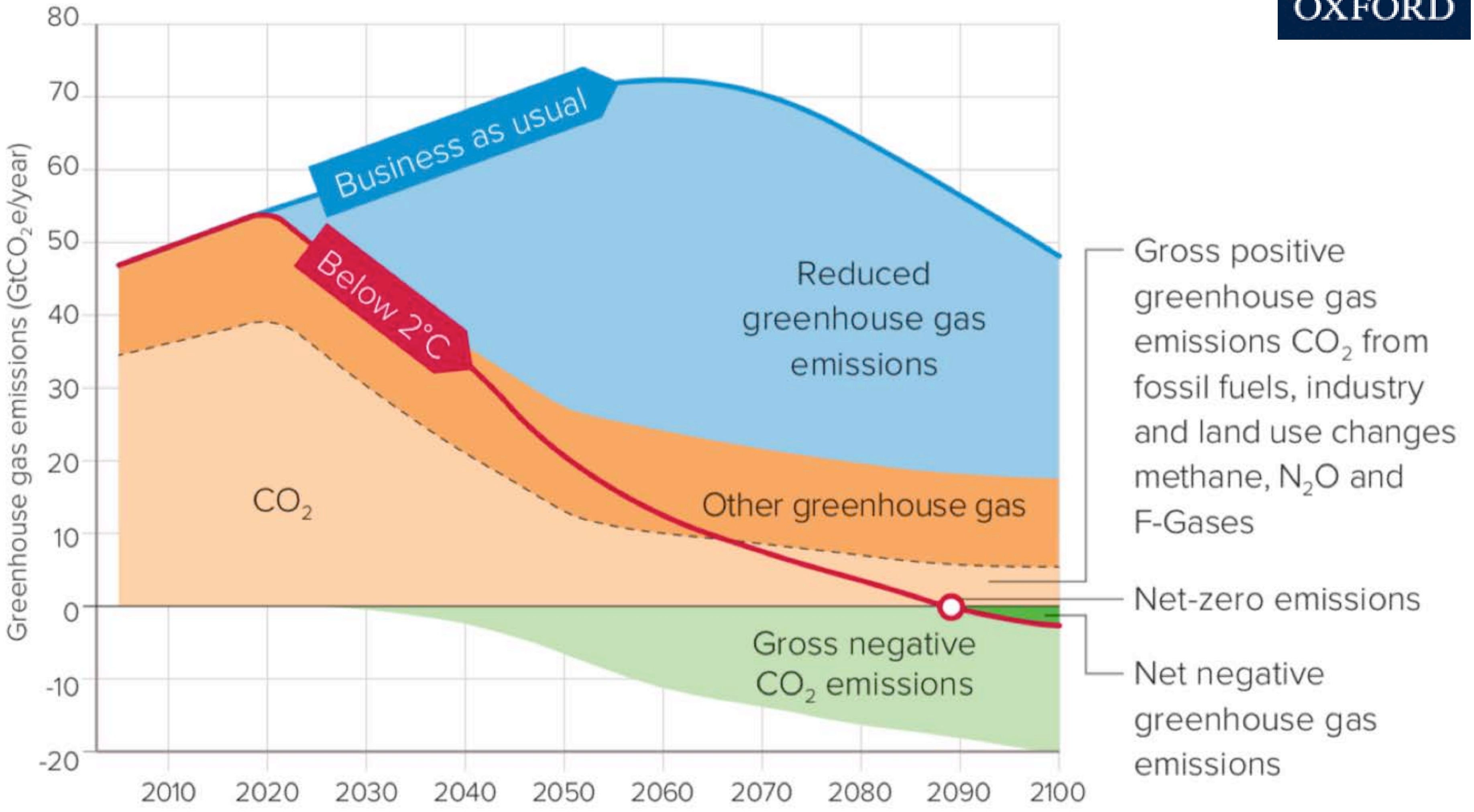
Direct Air Capture of carbon dioxide

- Motivation and options
- Energy needs
- Innovation leads
- Conclusions



3 From: Eelco J Rohling 2019, *The Climate Question*, Oxford University Press Fig 2.1

CO_2 in the air: the 2ºC scenario



Source: UNEP 2017. The Emissions Gap Report 2017. United Nations Environment Programme (UNEP), Nairobi

Removing carbon dioxide from air

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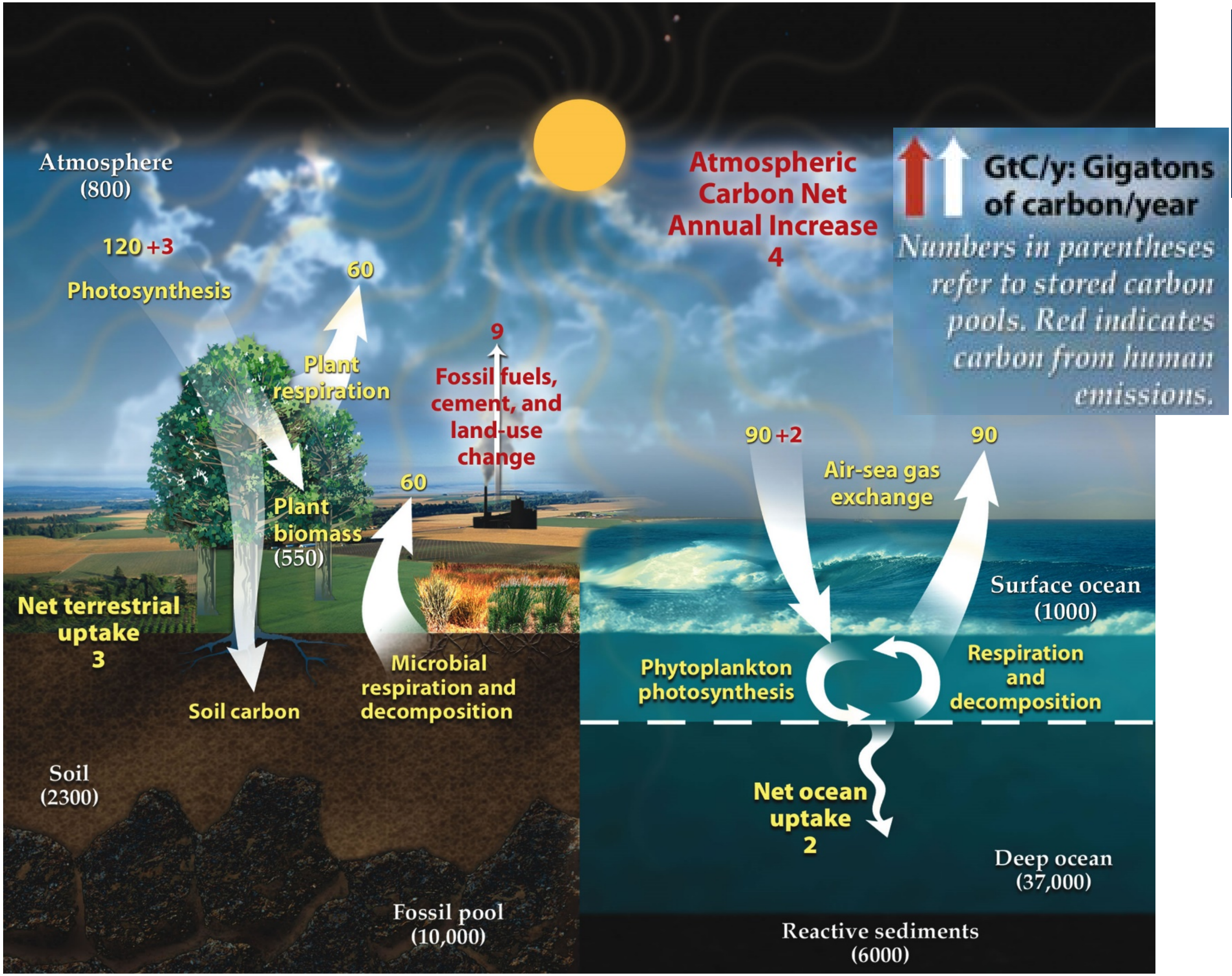
- Target amount by the year 2100: 810* Gt (range 440-1020). UNEP
- How do we capture it?
- Where do we store it?

* 220 Gt carbon (=810*12/44)



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+ Sedimentary rocks 100 000 000 Gt C (estimated)

Diagram adapted from U.S. DOE, Biological and Environmental Research Information System

C-storage location		CO_2 captured from air by photosynthesis	CO_2 captured from air by abiotic sorbent
	Plants on land	(1a) Afforestation and forest management (1b) Wetlands, peatlands and coastal ecosystem restoration and management	(2) DAC, using regenerable solid or liquid sorbent to produce CO_2-enriched air for improving agricultural yield – e.g. tomatoes
	Soil	(3) Increasing soil carbon by land management: Soil carbon sequestration (4) Biochar (from biomass pyrolysis)	(5) Enhanced Weathering (EW) of rock particles scattered on soil
	Above ground as mineral	(6) Biomass combustion to release energy with CO_2 captured from flue gas and reacted with mined mineral or suitable waste (BECCS)	(7) Mineral Carbonation reacting either air, or CO_2-enriched air (flue gas or DAC) with mined (processed) mineral or suitable waste
	Below ground as mineral	(8) Following biomass combustion to release energy, with flue gas treating and injecting CO_2 to react in rock such as silicate or basalt (BECCS)	(9) Following DAC, injecting CO_2 to react in rock such as silicate or basalt (DACCS)
	Below ground, as compressed CO_2	(10) Biomass combustion to release energy, with flue gas treating to produce high purity CO_2 for underground storage (BECCS)	(11) DAC to produce high purity CO_2 for underground storage (DACCS)
	Ocean	(12) As (10), with CO_2 dispersed into the ocean, or injected at a depth where it is not buoyant (13) Ocean Fertilization (OF) to stimulate growth of marine biota	(14) As (11), with ocean storage of CO_2 (15) Ocean Liming. Calcination of carbonate rock with CCS. Lime distributed at sea
	Human environment	(16) Buildings made with wood and similar biomaterials (17) Chemicals and products from biomass	(18) DAC, then utilizing produced CO_2 as feedstock for chemical products (CCU)

Energy needs of Direct Air Capture

$$\frac{w_{rev}}{RT_0} = \ln\frac{\alpha}{\beta + (\alpha - \beta)y_c} + \frac{\beta(1 - y_c)}{\alpha y_c}\ln\frac{\beta}{\beta + (\alpha - \beta)y_c} + \frac{(1 - \alpha)}{\alpha}\ln\frac{1 - \alpha}{1 - \beta - (\alpha - \beta)y_c} +$$

$$\frac{(1 - \beta)}{\alpha}\cdot\frac{1 - y_c}{y_c}\ln\frac{1 - \beta}{(1 - \beta) - (\alpha - \beta)y_c}$$

w_{rev} = reversible work of separation per unit CO_2

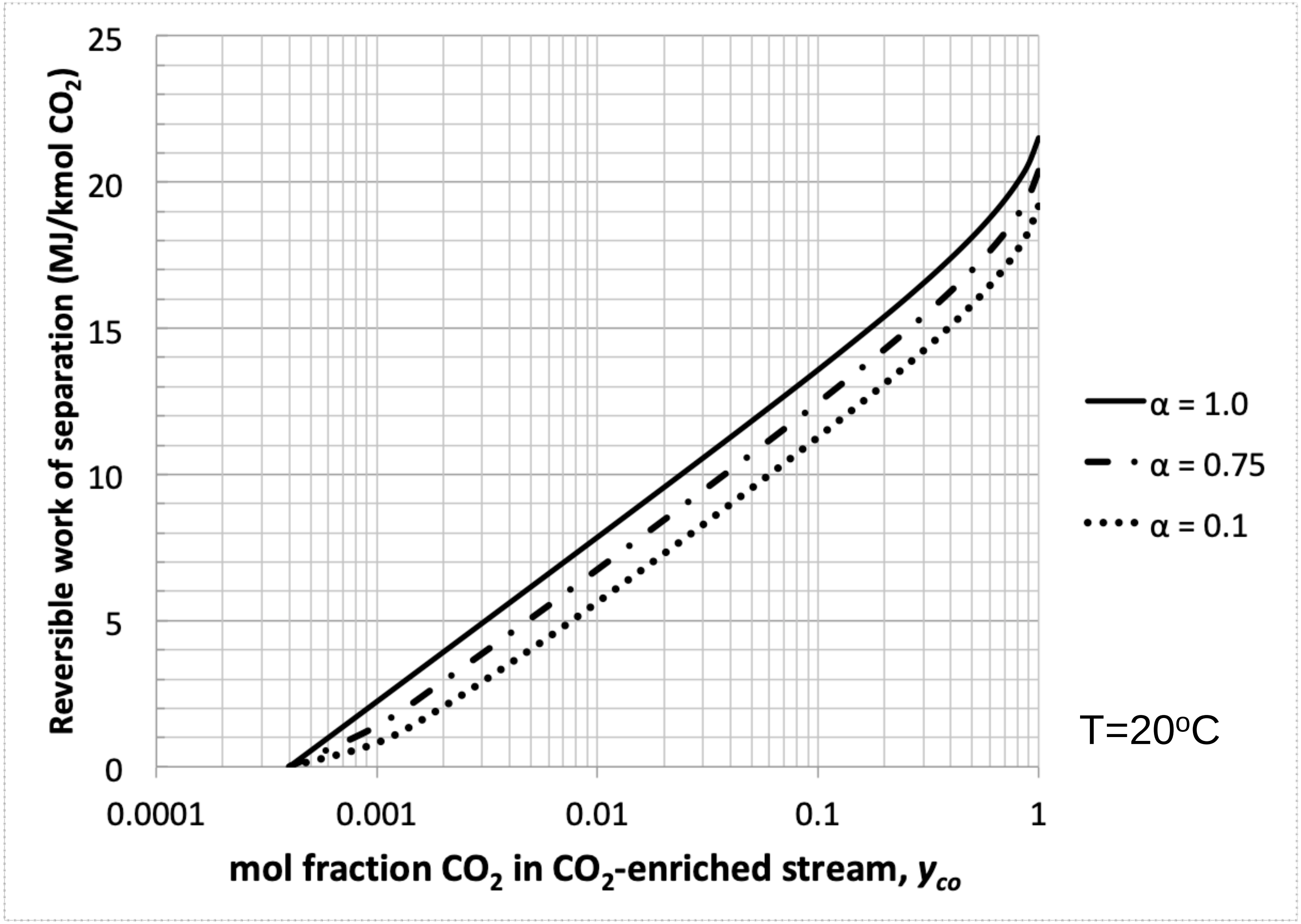
x_c= mol fraction CO_2 in feed

α = fraction CO_2 recovered as product

β = fraction inert slipping into product

R is the gas constant, and T_0 the temperature

Reversible work of separation of CO_2 from air



Actual heat requirement

Air capture ~ 21 MJ/kmol *reversible work*

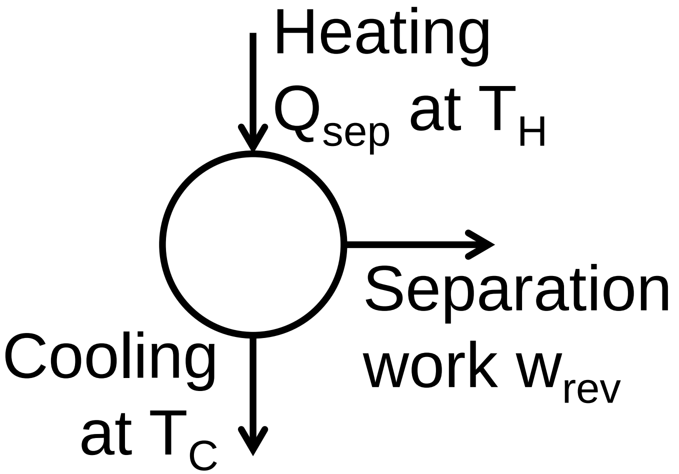
Effncy η = Separation work/Heating

$\eta_{Carnot} = (T_H - T_C)/T_H = w_{rev}/Q_{sep}$

Say ~ 1/6 for amine treating or similar process, and

Actual efficiency ~1/12 ⟶ 1/18

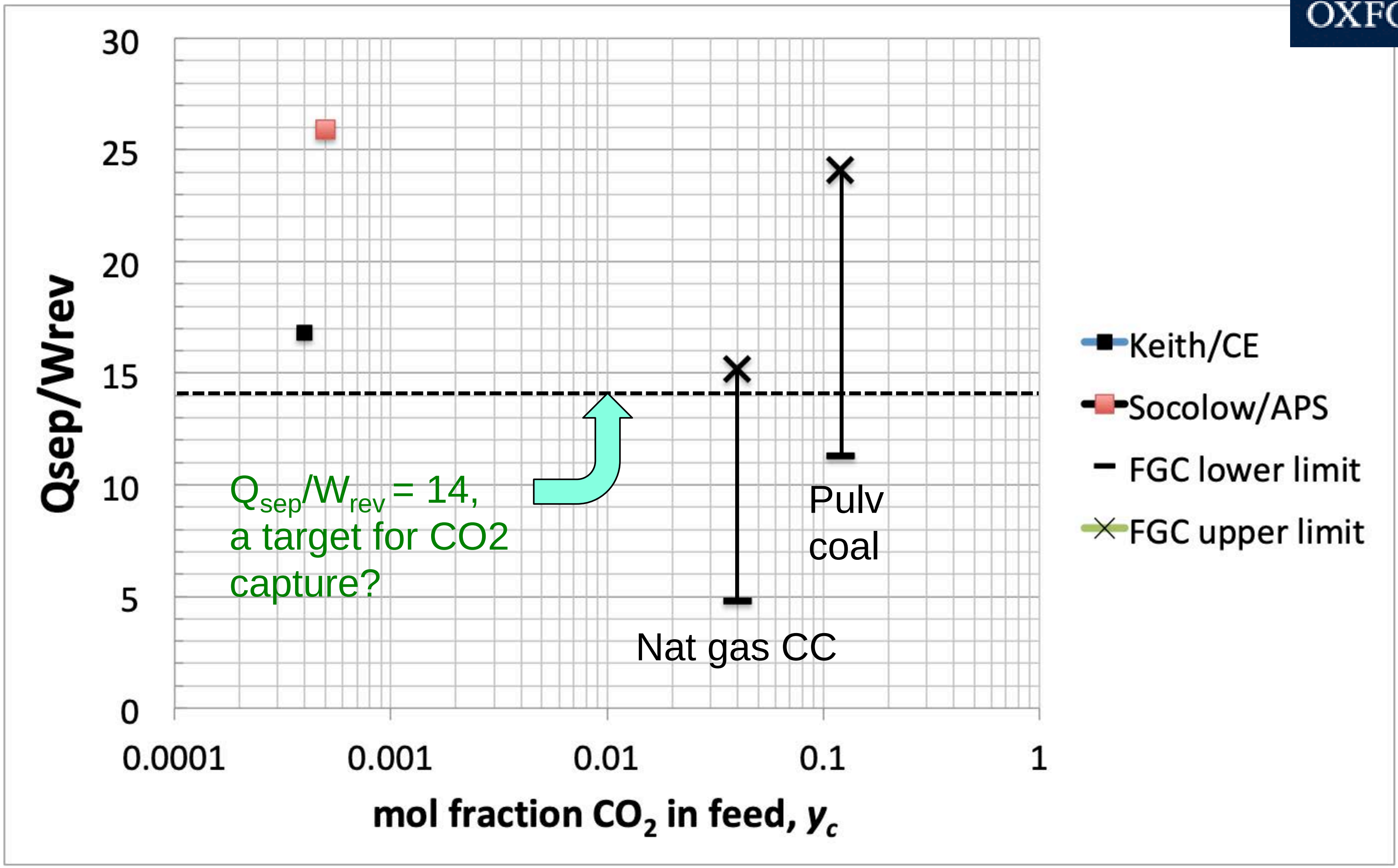
This seems to be quite usual for separation processes



DAC might take ~ 250 to 380 MJ/kmol *heat*

Note: enthalpy of formation of CO_2 = (-)393.5 MJ/kmol

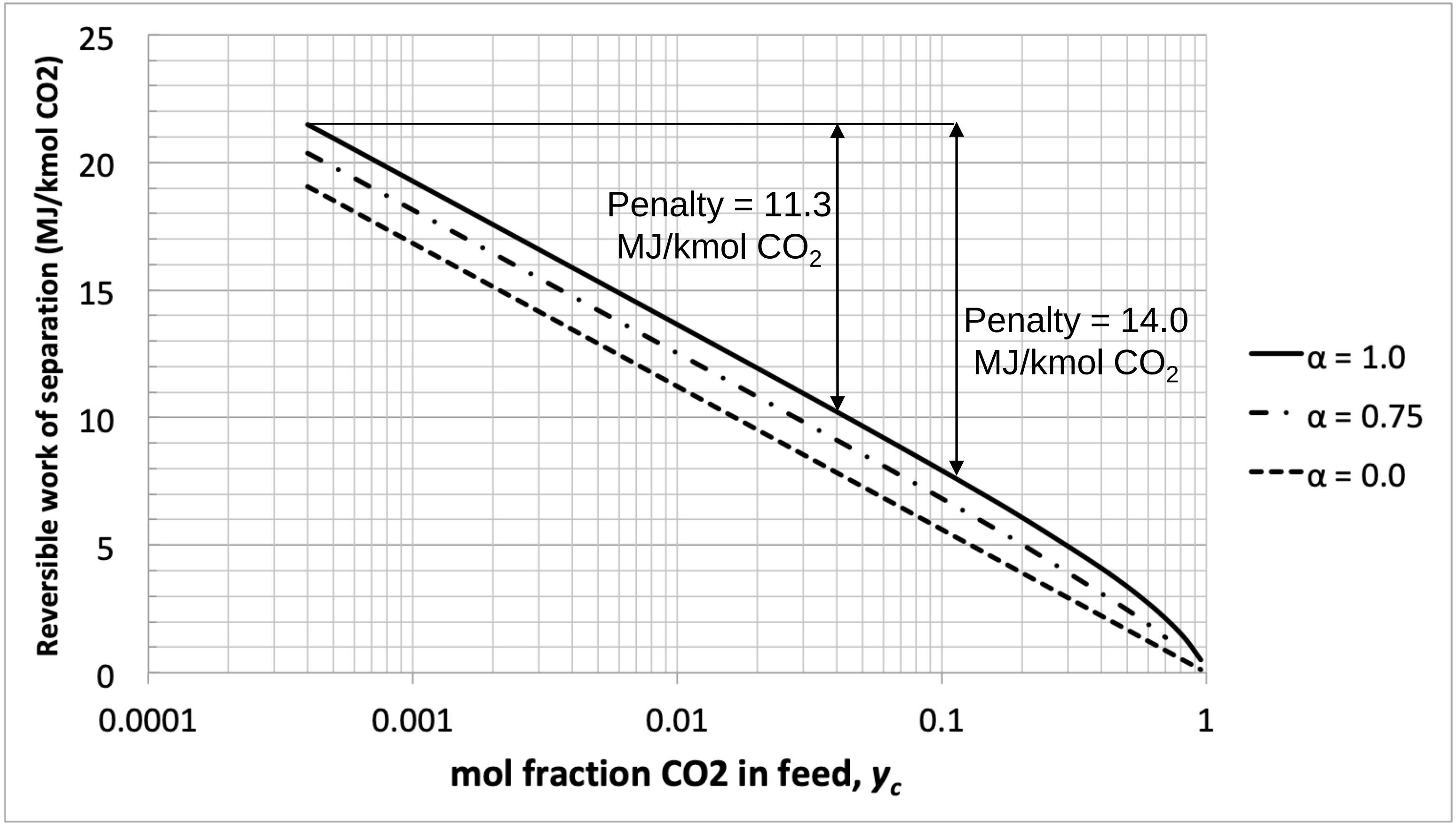
Actual heat requirement



Heat/reversible work for CO2 capture from air and flue gas

Flue Gas Capture data from B Metz et al, 2005 IPCC Special report on CCS. CUP

Chimney stack exit penalty – the cost of delay



Reversible work of separating pure CO_2 (β = 0) from gas at T_0 = 293K. Parameter *α* is the fraction of inlet CO_2 recovered in the product. Penalties shown are the additional reversible work needed to capture CO_2 from air rather than flue gas, for natural gas firing (y_c = 0.04) and coal firing (y_c = 0.12), for *α* = 1.0.

This penalty is payable as soon as the flue gas exits the chimney stack!

Innovation leads

- Novel solvents, adsorbents, process line-ups, tailored to CO_2 capture from air – use waste heat?
- React CO_2 with alkaline minerals → no sorbent & no underground storage of liquid CO_2
- Use sunshine – grow crops: eg BECCS – needs CO_2 storage
- Electrochemistry
- Novel power plant: eg OrigenPower integrates fuel cell with calciner → Electricity + CO_2 to storage.
- Reafforestation and better agricultural practices to draw down and store carbon in soil

Above all – decarbonise as quickly as possible

Conclusions

The "2^{o}C scenario" implies at least THREE huge new industries this century:

- **Renewable energy**
- **Flue Gas Capture of CO_2**
- **CO_2 removal from air**

CO_2 capture needs to be explored now, to

- Develop new technology and business options
- Inform policy. New policy and response options, evidence-based.