

Burying carbon – how we can lock CO₂ underground to combat climate change

Why we need to, how to do it and how we know that it works



Professor Stuart Gilfillan
University of Edinburgh



THE UNIVERSITY of EDINBURGH
School of GeoSciences



Natural Environment
Research Council

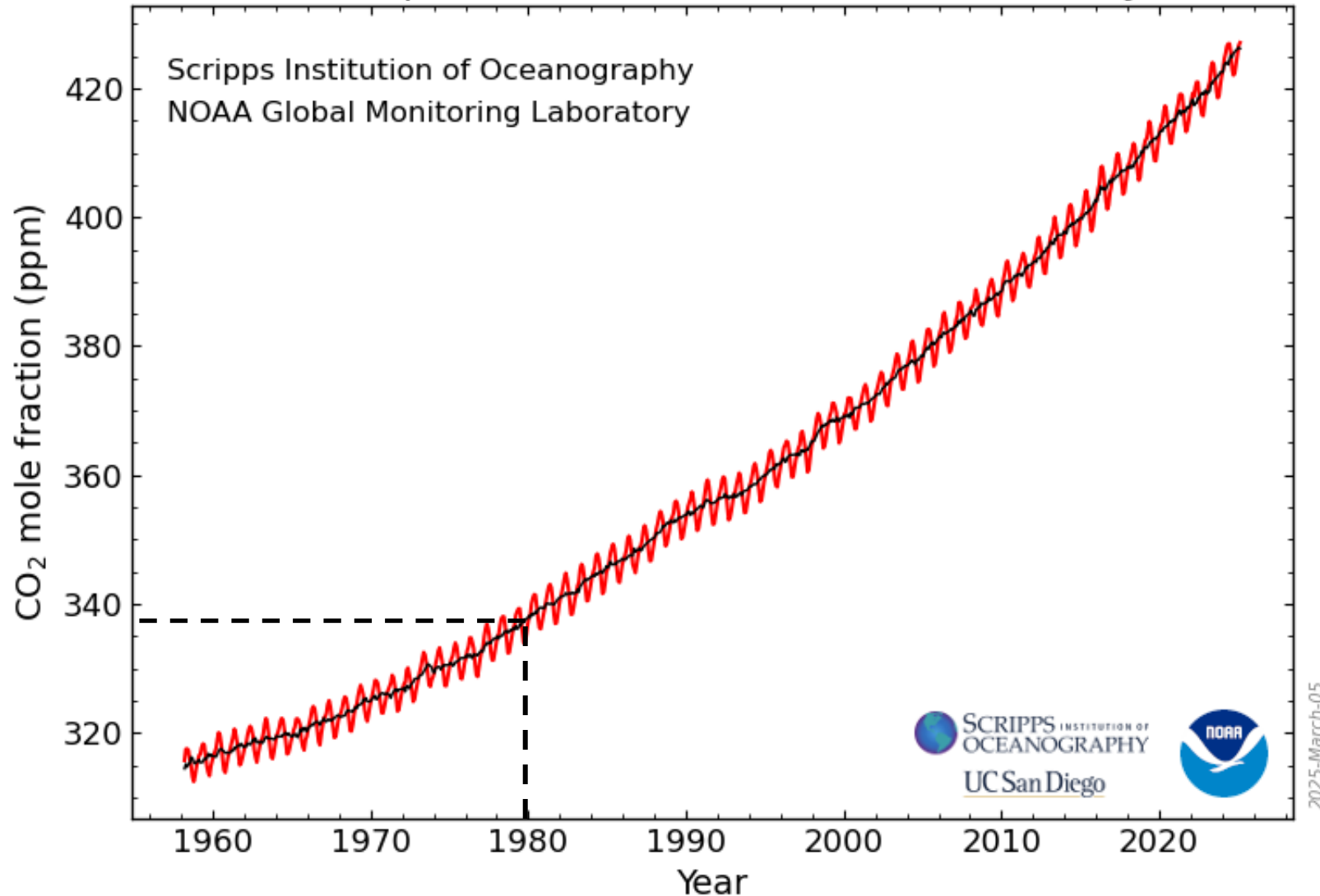


Orkuveita
Reykjavíkur



Atmospheric CO₂ at Mauna Loa Observatory, Hawaii

Atmospheric CO₂ at Mauna Loa Observatory



1980: 339 ppm

2026: ~431 ppm

**24% increase over my
lifetime**



Fossil fuels aren't going away

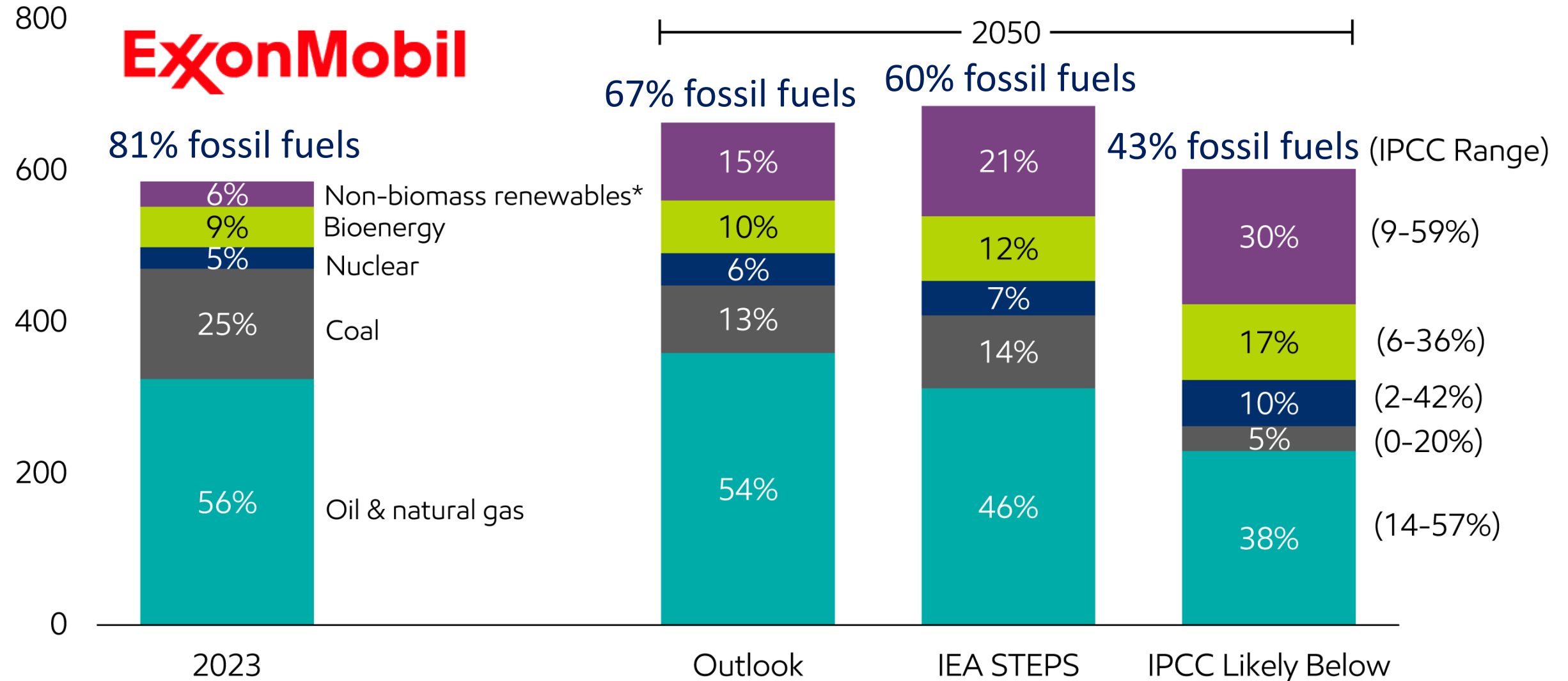
ExxonMobil

2050

67% fossil fuels 60% fossil fuels

81% fossil fuels

43% fossil fuels (IPCC Range)



ExxonMobil

iea
International Energy Agency

ipcc
INTERGOVERNMENTAL PANEL ON climate change



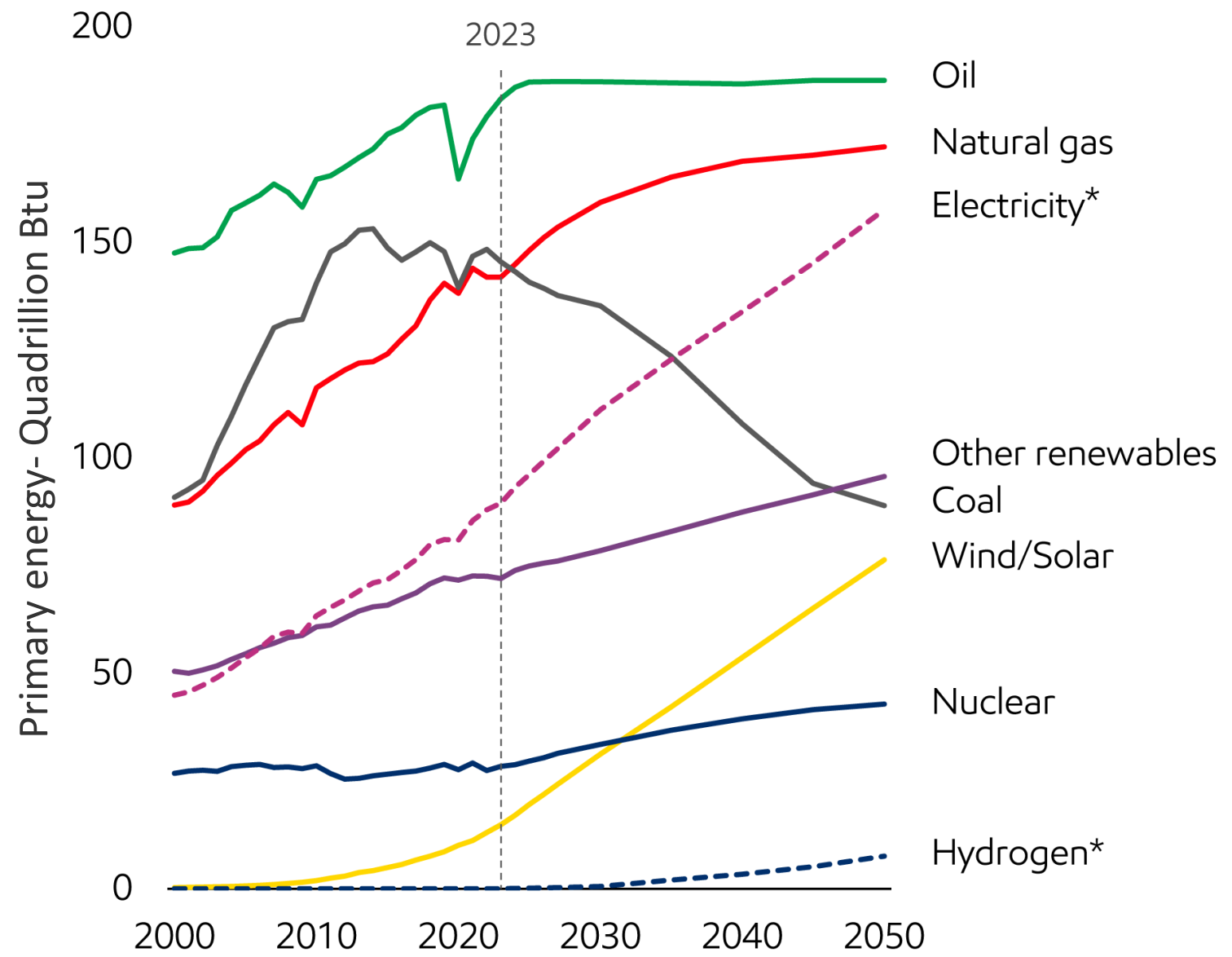
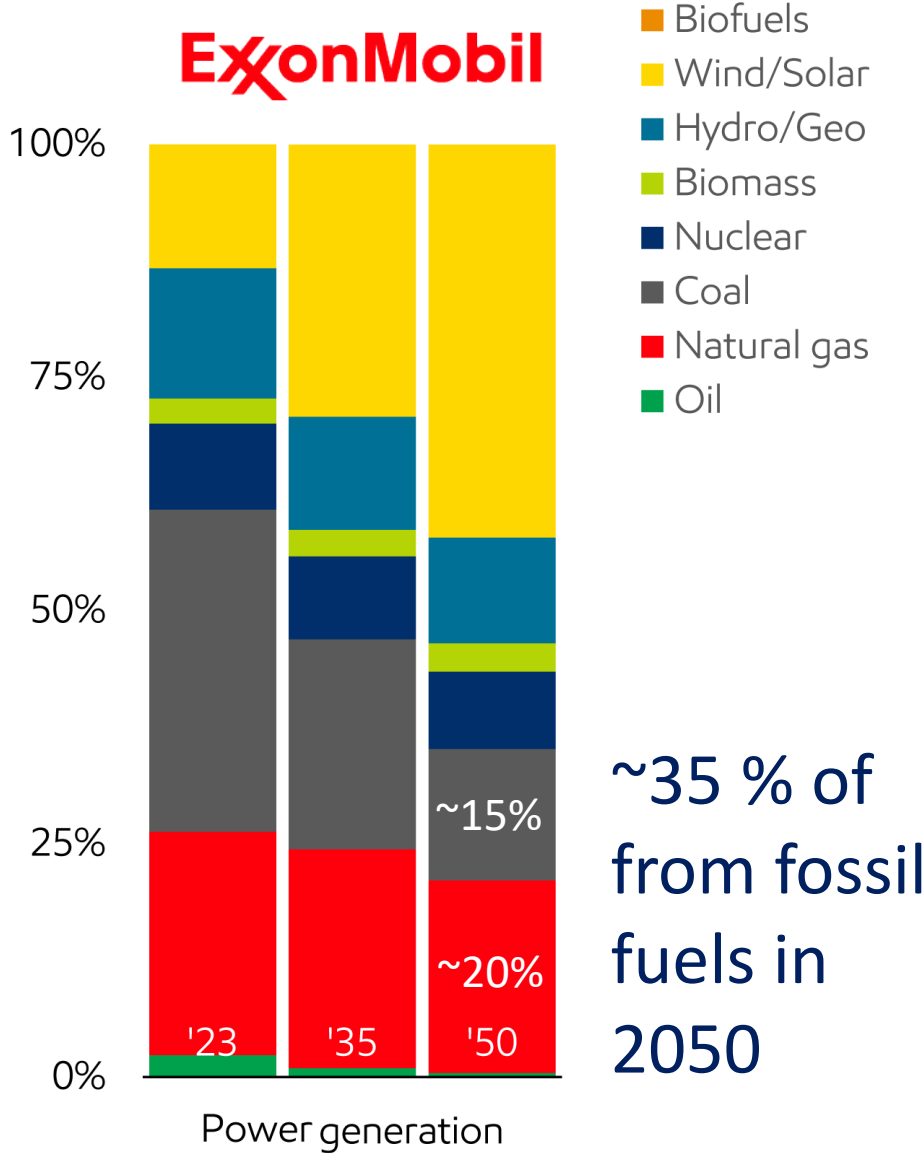
Stuart.Gilfillan@ed.ac.uk



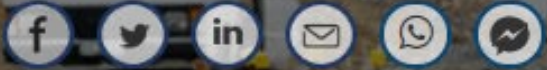
THE UNIVERSITY of EDINBURGH
School of GeoSciences

<https://corporate.exxonmobil.com/sustainability-and-reports/global-outlook/energy-mix-projections>

Energy is NOT just electricity: also transport, heat and industry



Q&A: Why cement emissions matter for climate change



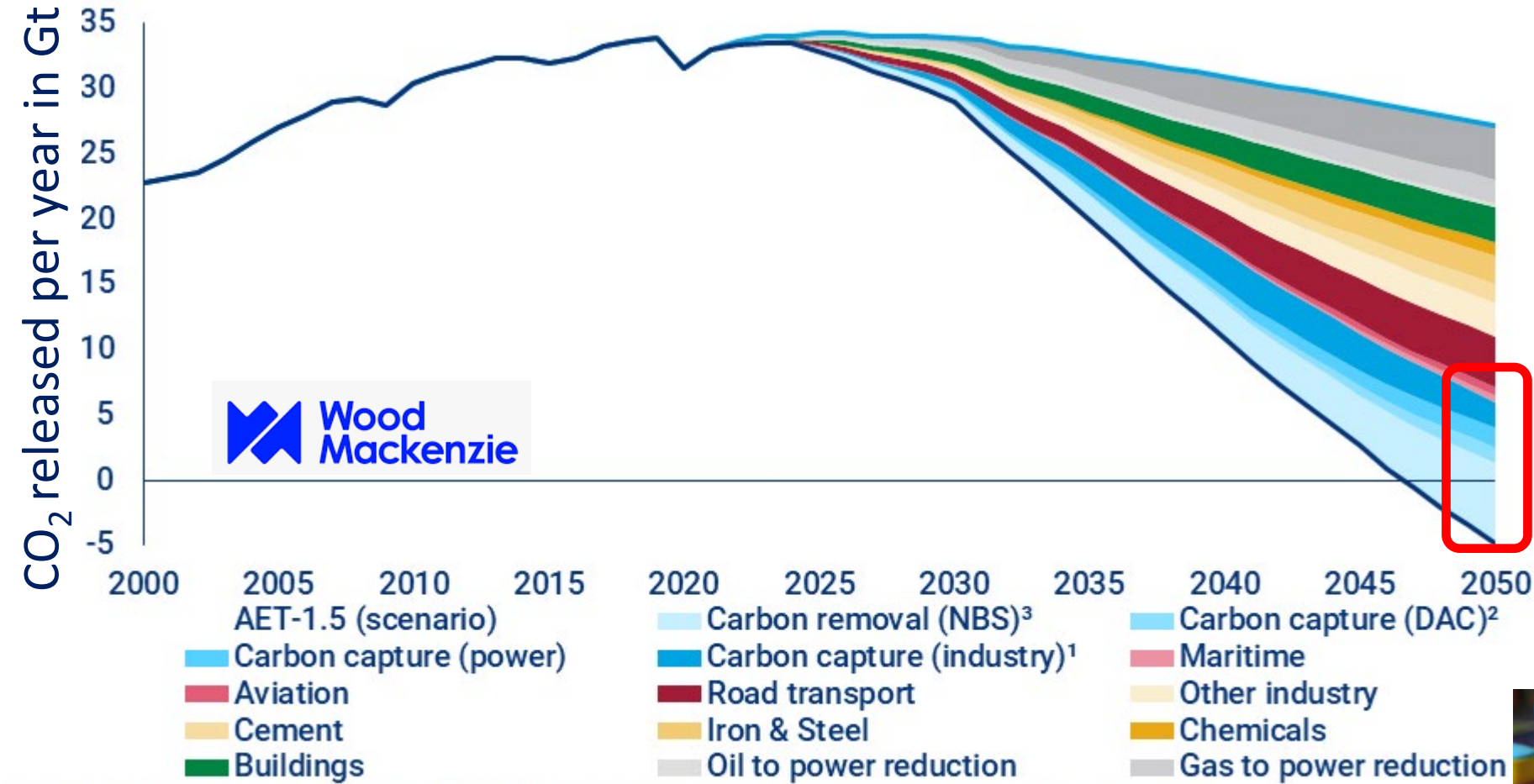
<https://www.carbonbrief.org/qa-why-cement-emissions-matter-for-climate-change>

Cement Industry emissions in 2024: ~2.8bn tonnes of CO₂, 8% of the global total

(Friedlingstein et al. 2024 - <https://essd.copernicus.org/articles/17/965/2025/>)

If the cement industry were a country, it would be the world's third largest emitter

The net-zero energy challenge



Need ALL technologies available

Carbon Capture & Storage (CCS)

- On Power
 - On Industry
 - From atmosphere
- ## Direct air Capture (DAC)



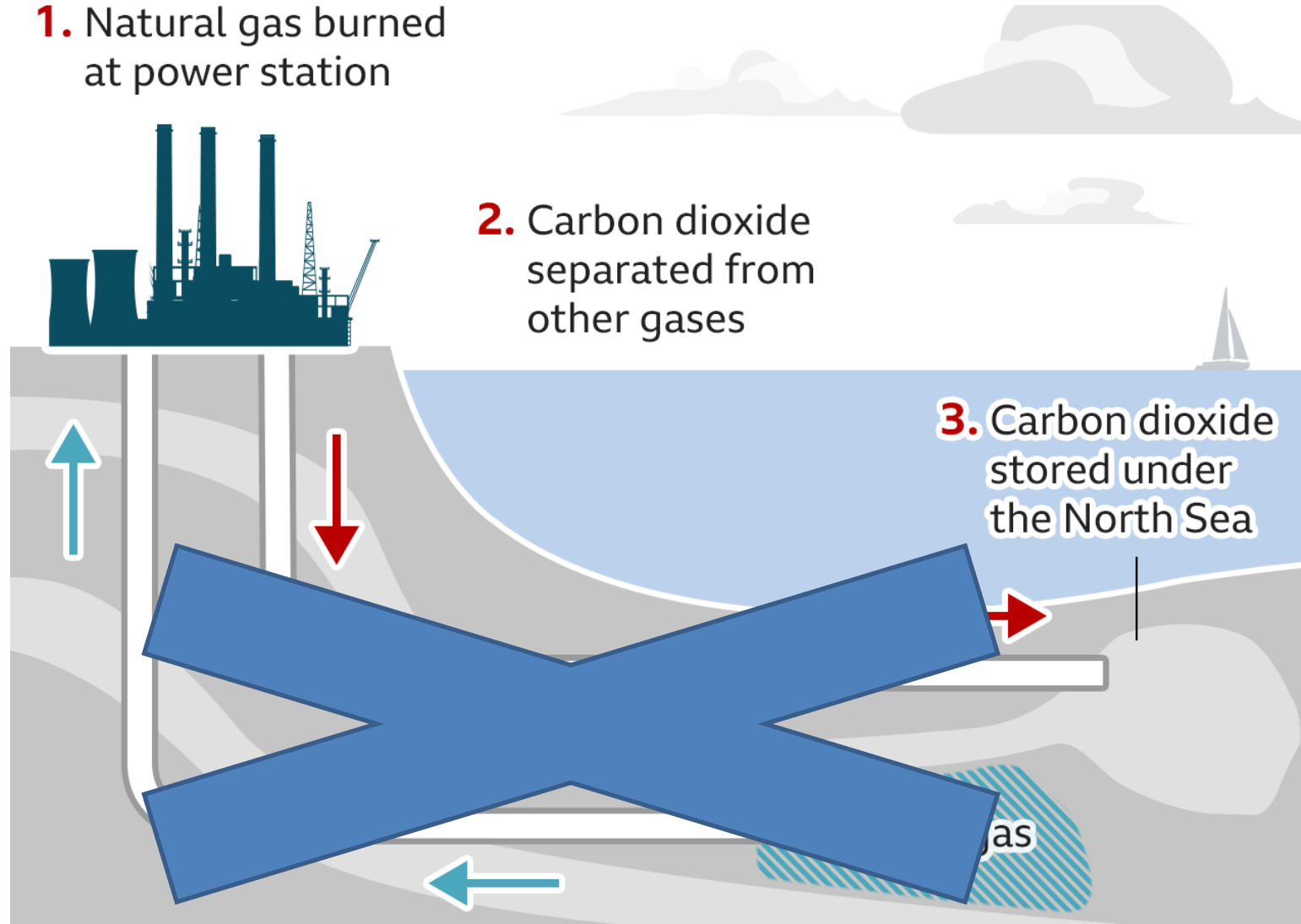
CCS predicted to deliver 25% of reduction required (IEAGHG)

What is Carbon Capture and Storage?

1. Natural gas burned at power station

2. Carbon dioxide separated from other gases

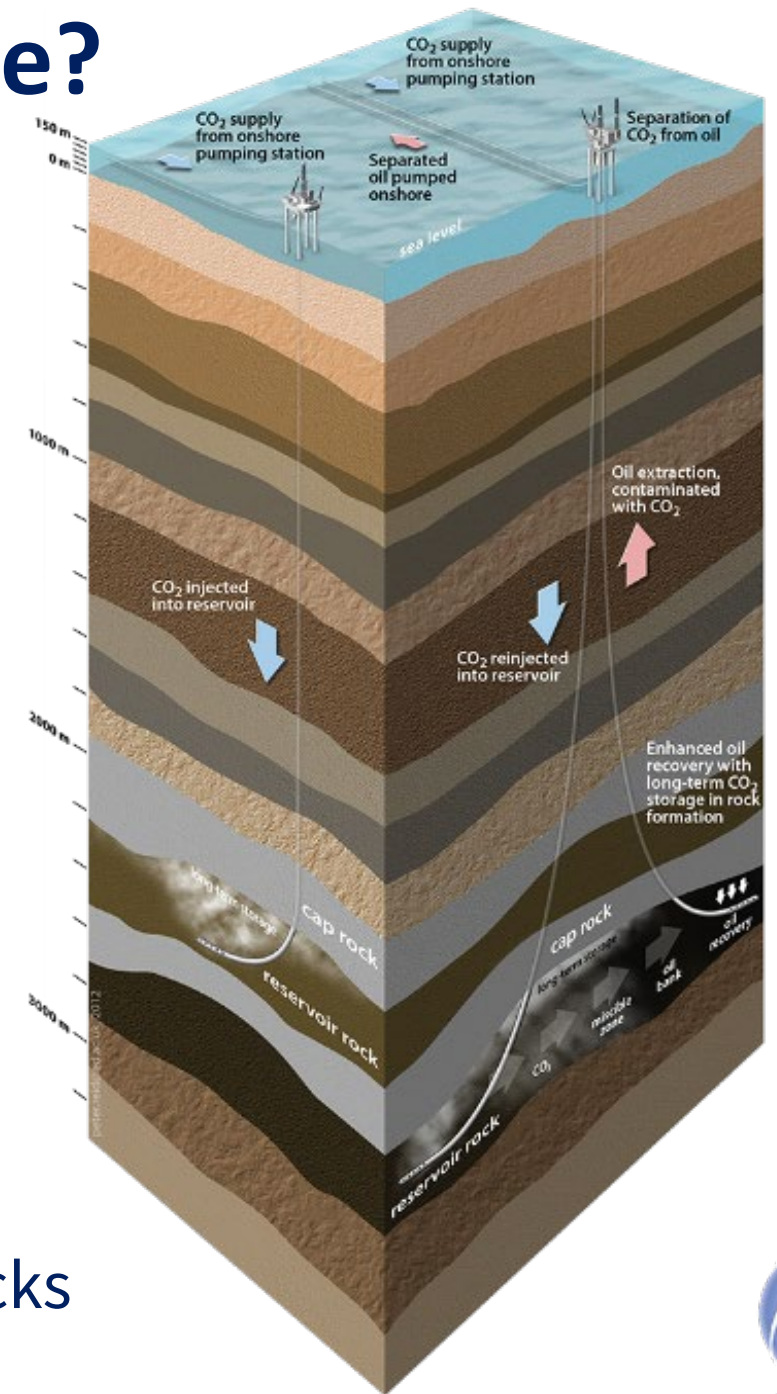
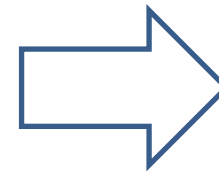
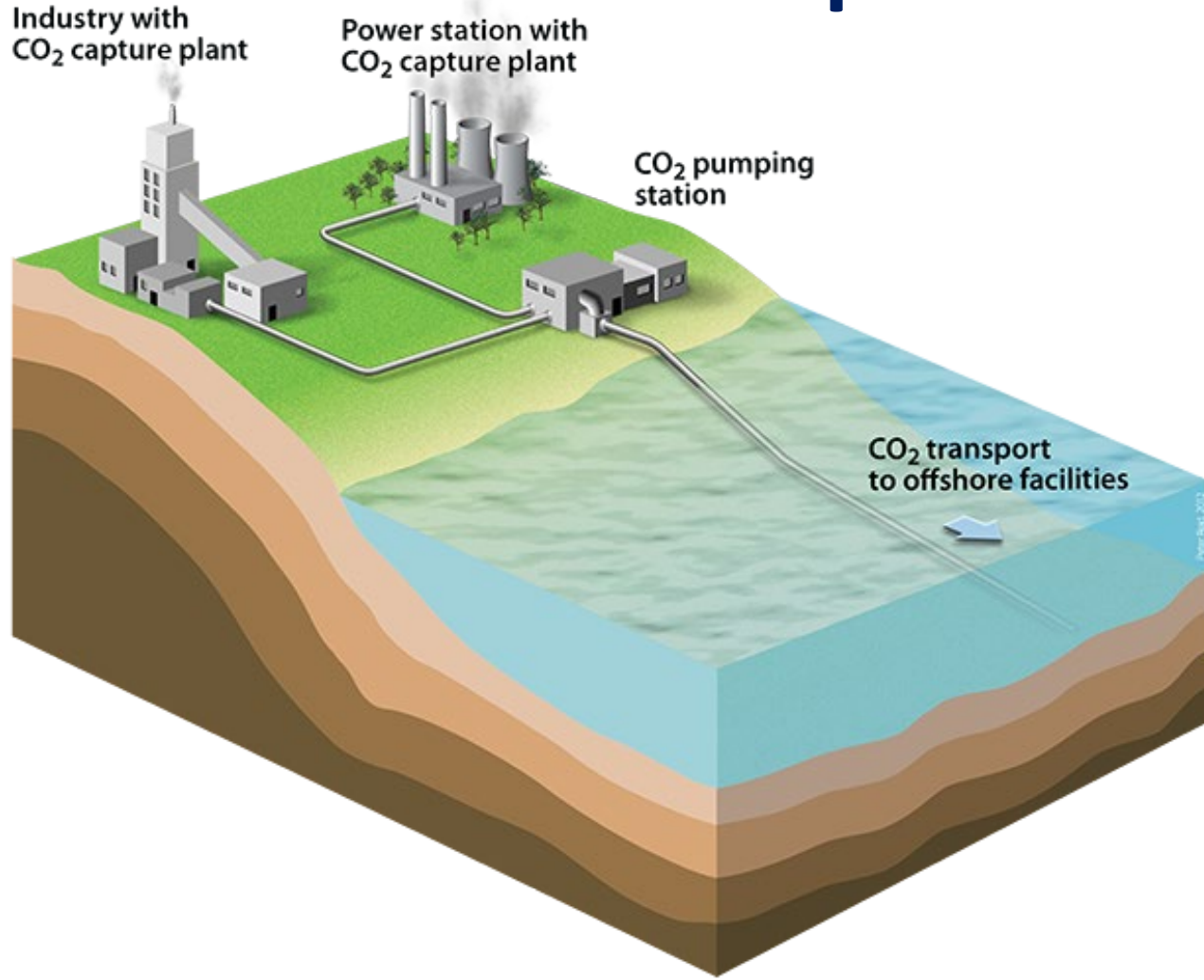
3. Carbon dioxide stored under the North Sea



Source: BBC research

BBC

What is Carbon Capture and Storage?



CO₂ stored in old oil fields and rocks containing saltwater



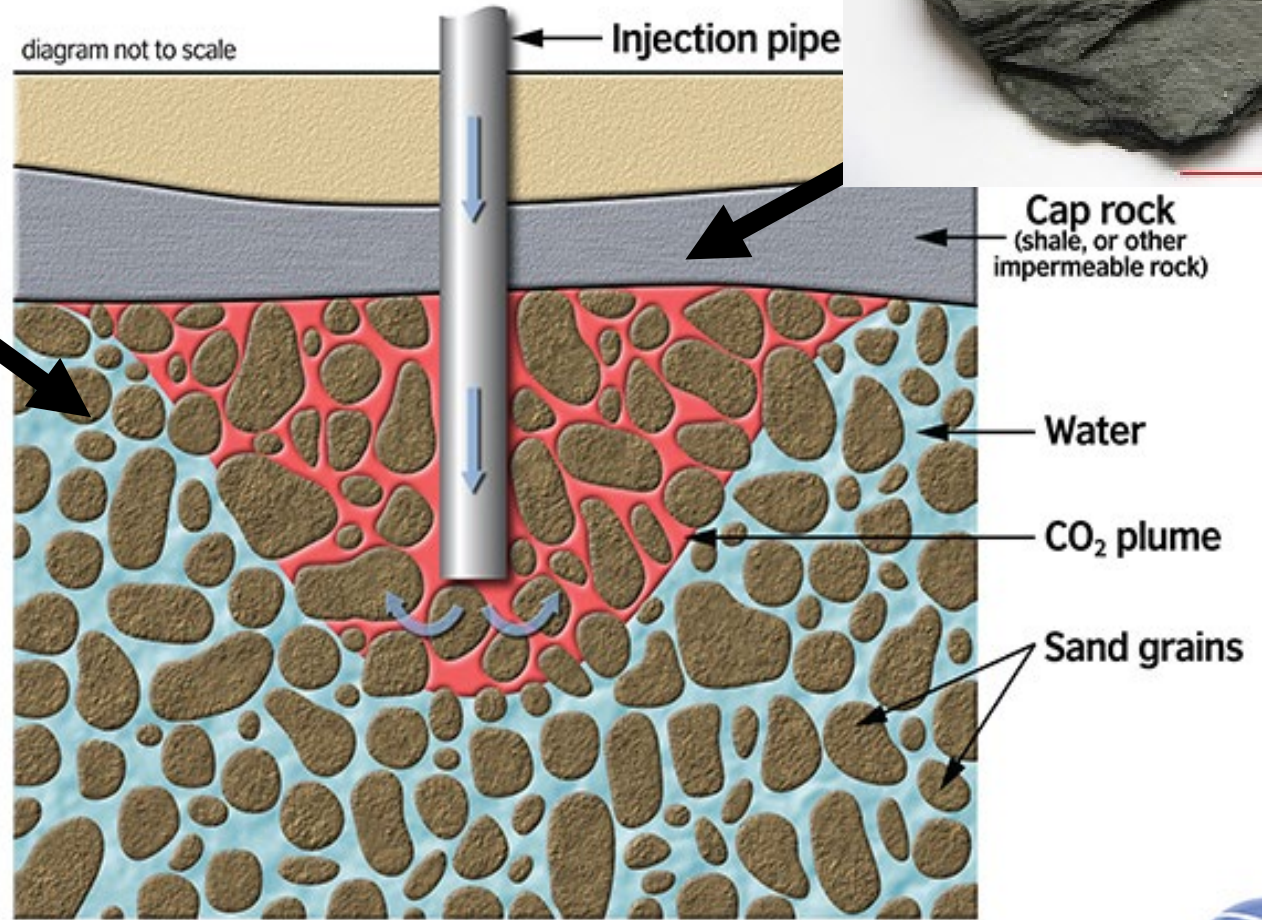
THE UNIVERSITY of EDINBURGH
School of GeoSciences



Storing CO₂ – where?



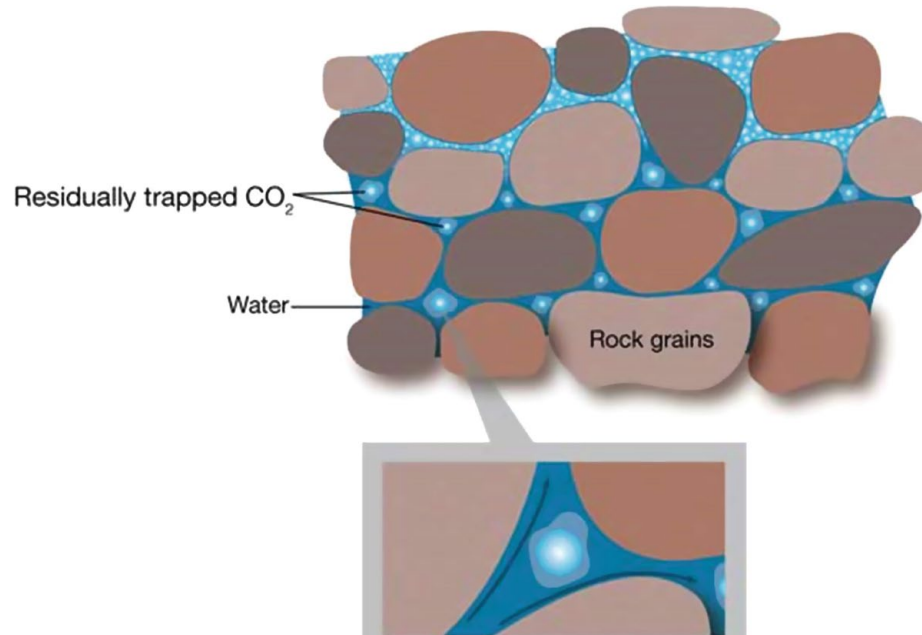
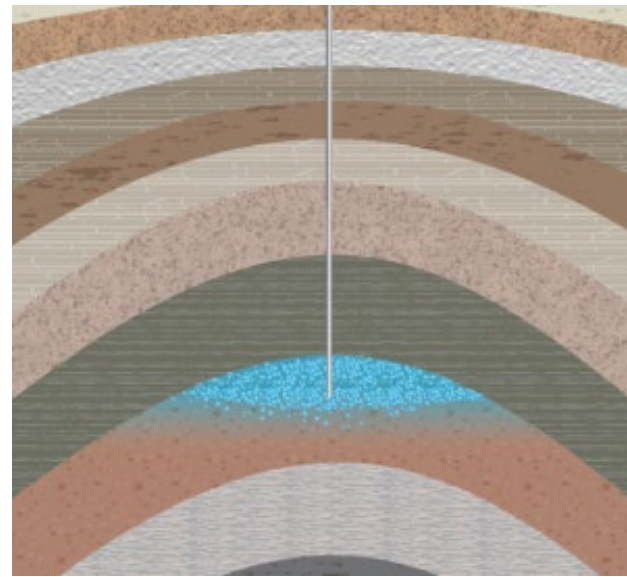
Old oil or gas reservoir (e.g. sandstone)



5cm

Impermeable shale layers trap CO₂ – same as oil and gas

Storing CO₂ – what keeps it there?



CO₂ dissolves in water



© CO2CRC

1. Structural trapping

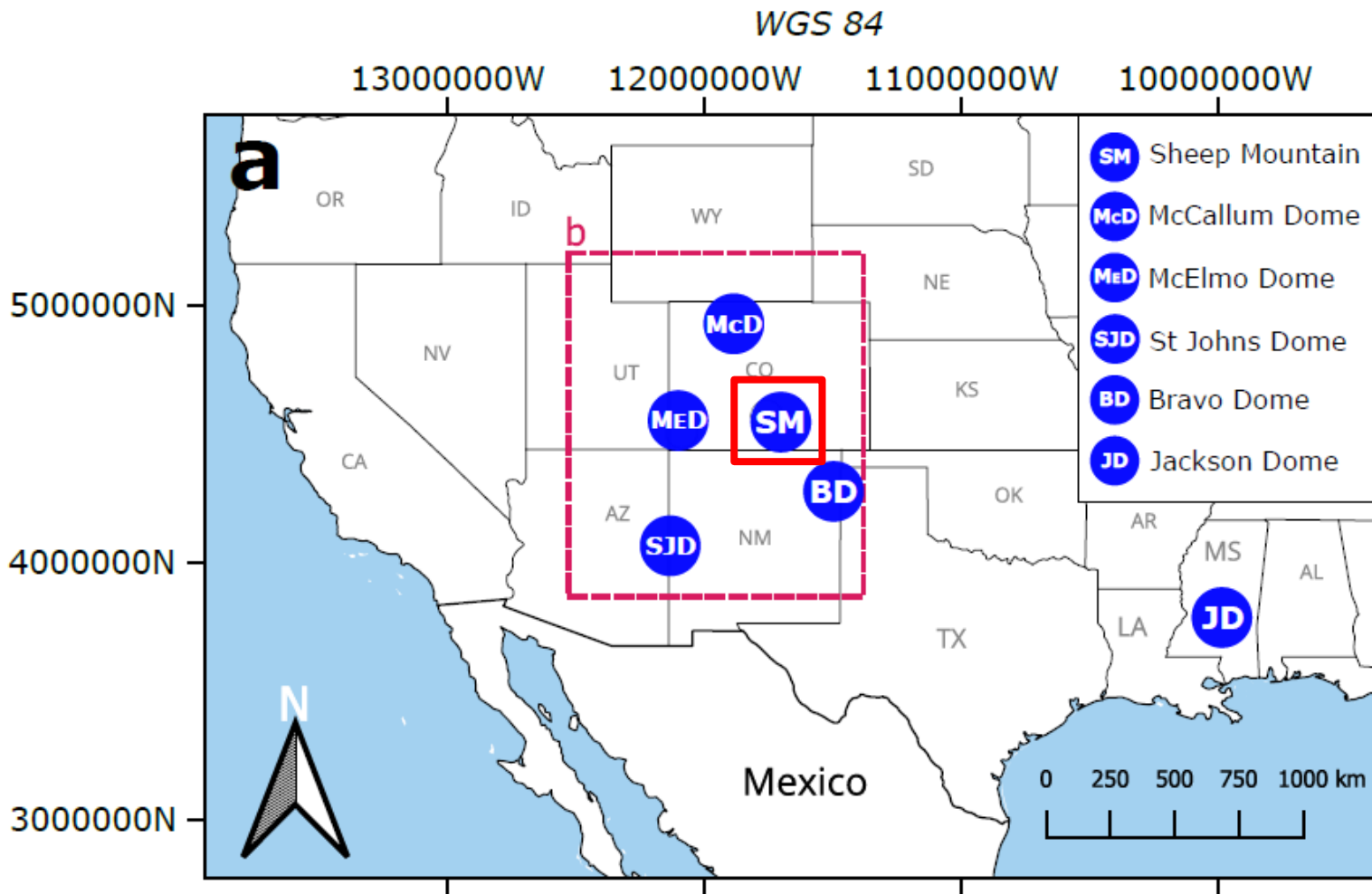


2. Residual trapping

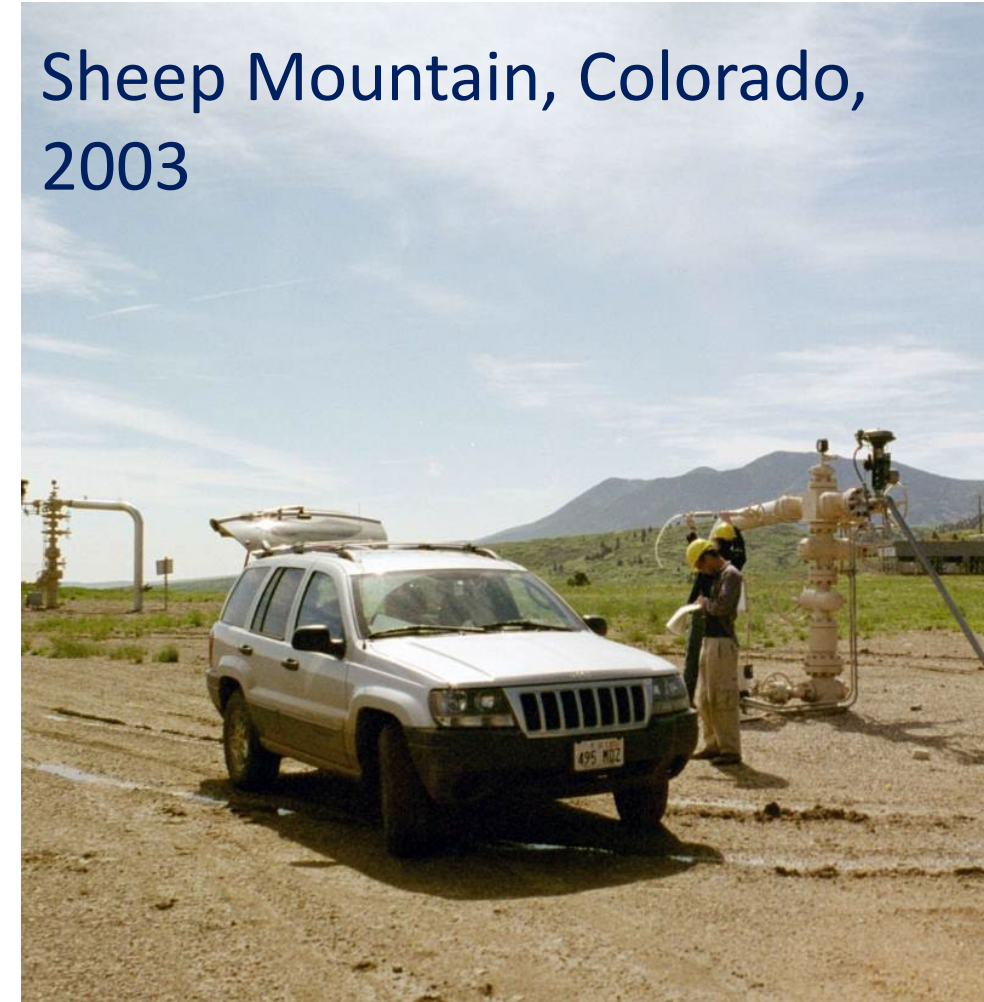
3. Dissolution trapping



Storing CO₂ - how do we know it will stay stored?



Sheep Mountain, Colorado, 2003



Studied reservoirs have stored ~4.7 Gt of CO₂ over geological timescales

Fingerprinting CO₂?

Anthropogenic CO₂ molecule



Natural CO₂ molecule



www.phenomenica.com

12^C 12.00000 98.89% Stable	13^C 13.00335 1.11% Stable	14^C 14.0 t _{1/2} = 5715yrs Radioactive Cosmogenic/ anthropogenic
16^O 15.9949 99.76% Stable	18^O 17.9991 0.20% Stable	

web.sahara.arizona.edu

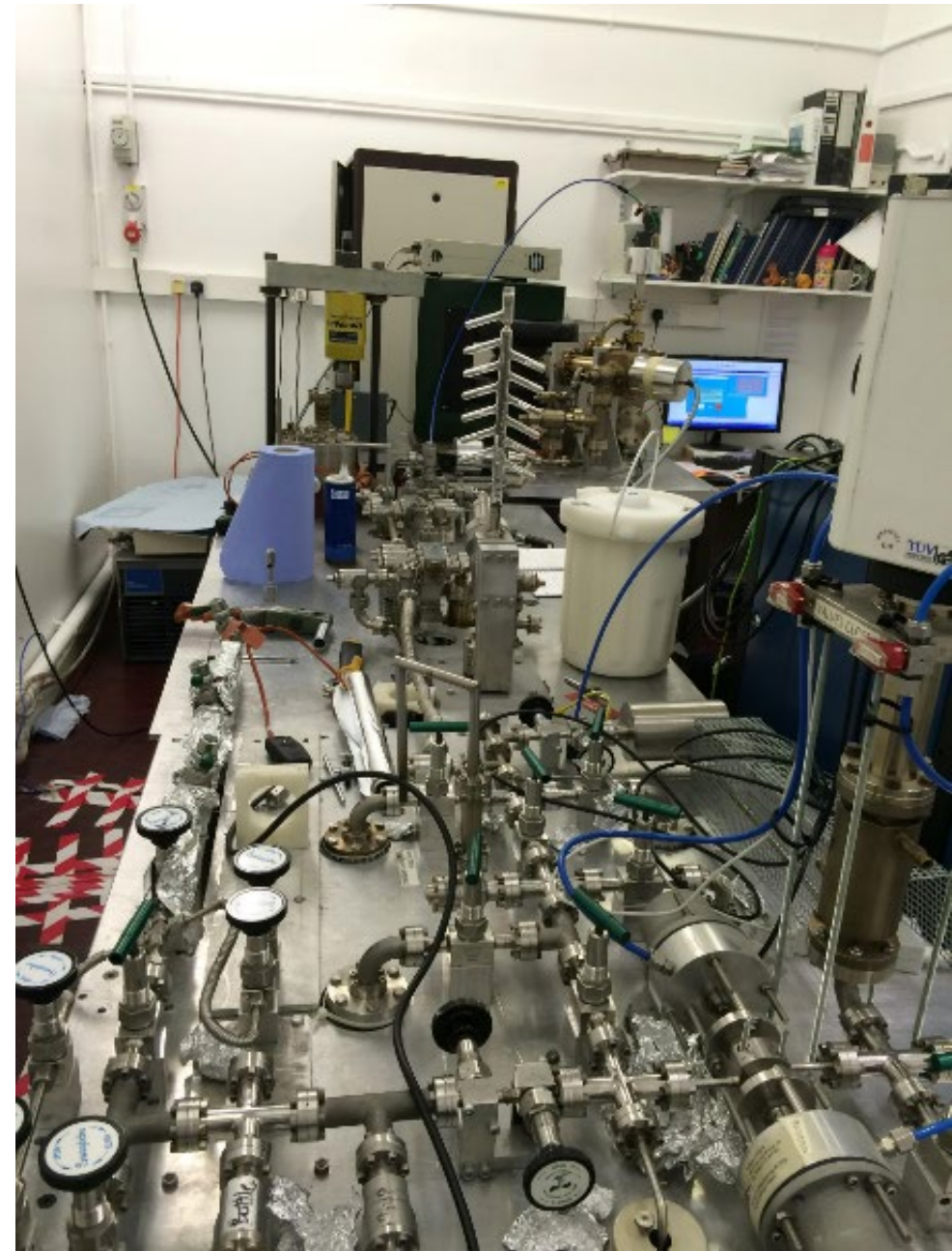


commons.wikimedia.org

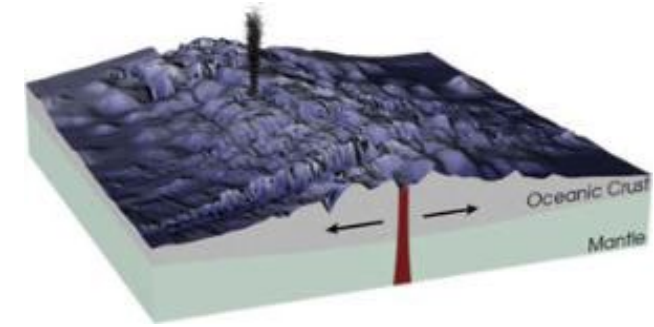
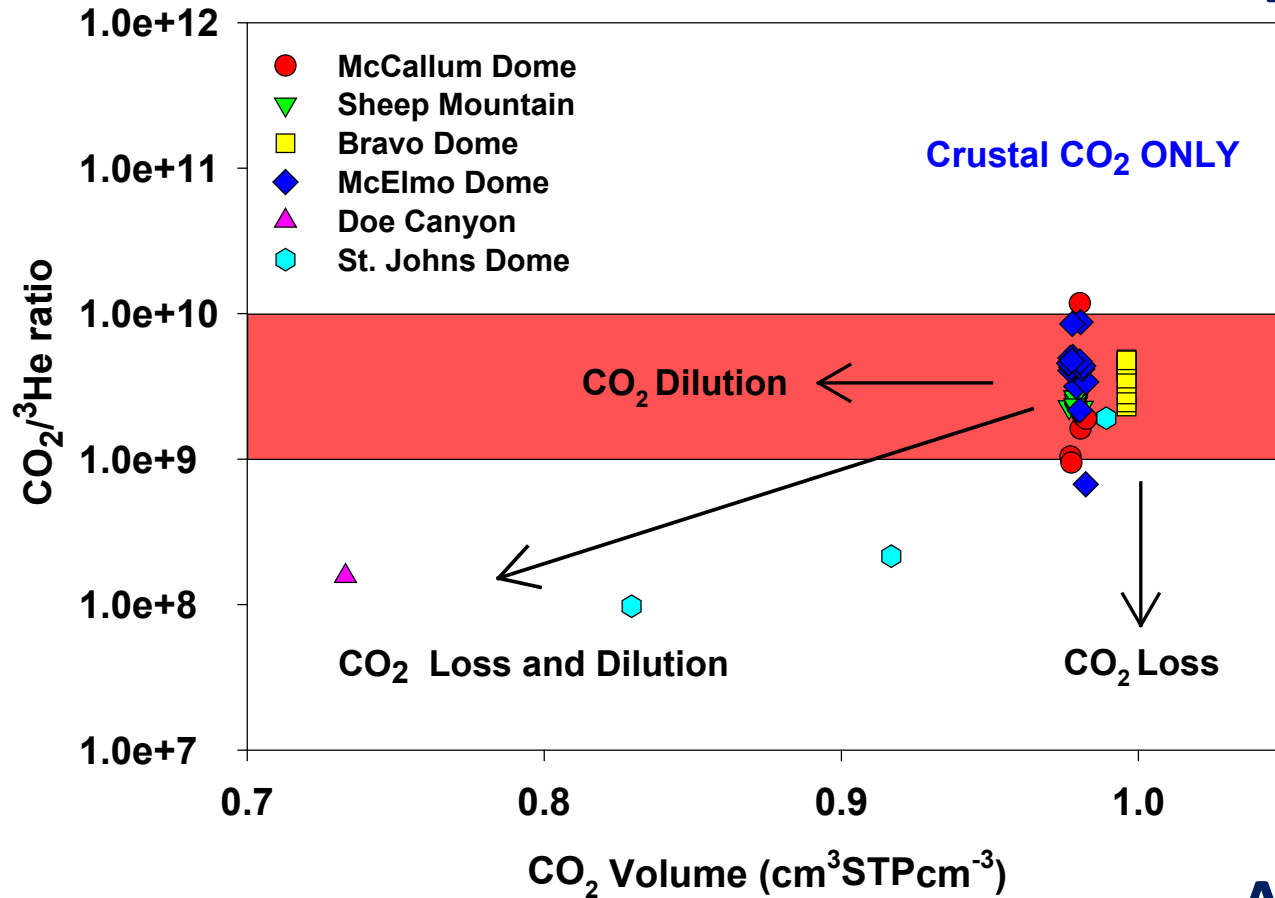
Stuart.Gilfillan@ed.ac.uk



CO₂ sampling and analysis



How long can CO₂ be stored for?



Mid ocean ridge

Magmatic CO₂ Range



Carbon Dioxide Has Been Naturally Stored For A Million Years In Colorado And Rocky Mountains

ScienceDaily (Feb. 17, 2008) — Earth scientists at The University of Manchester have found that carbon dioxide has been naturally stored for more than a million years in several gas fields in the Colorado Plateau and Rocky Mountains of the United States.



All CO₂ originates from mantle

Age of nearby volcanic rocks indicate CO₂ filling age:

1.2 to 42 millions of years

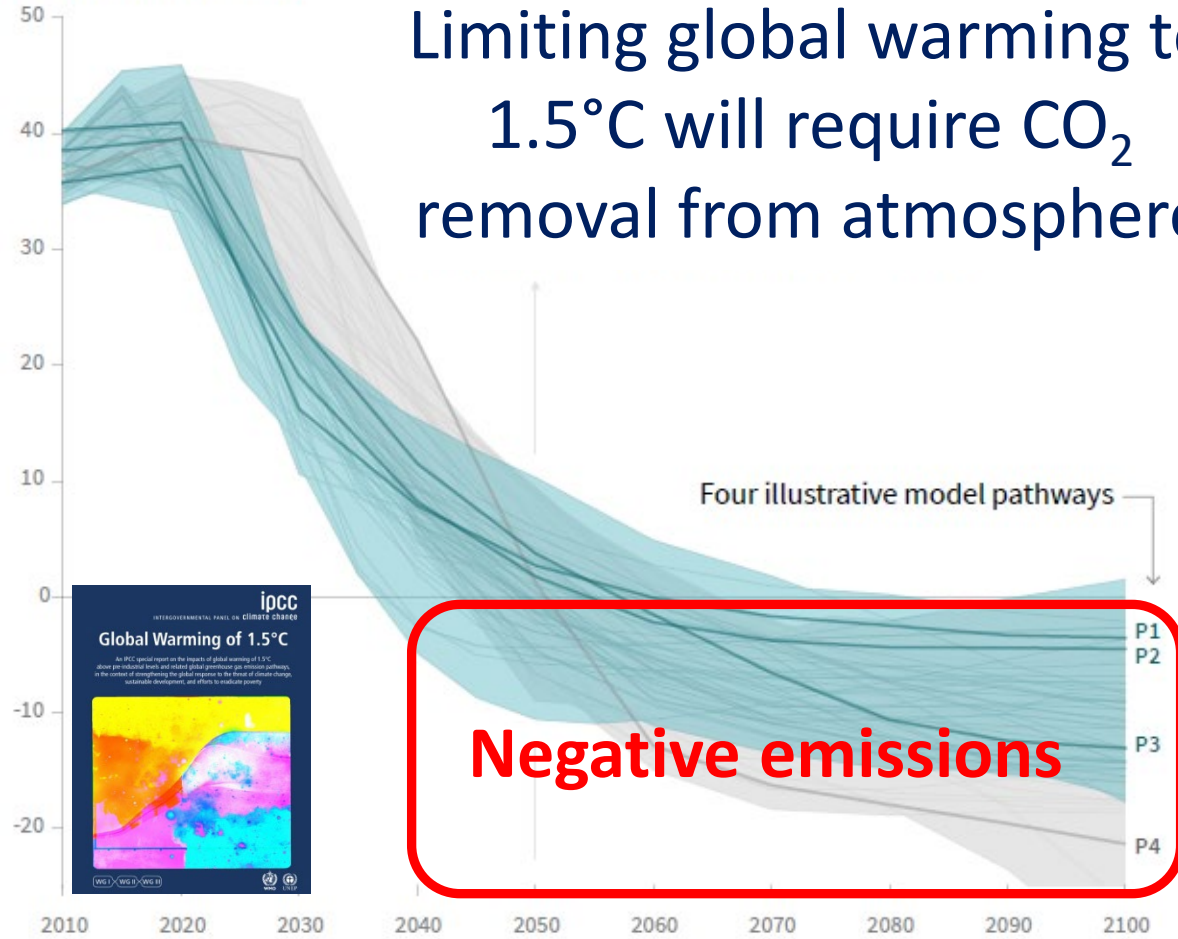
Stuart.Gilfillan@ed.ac.uk



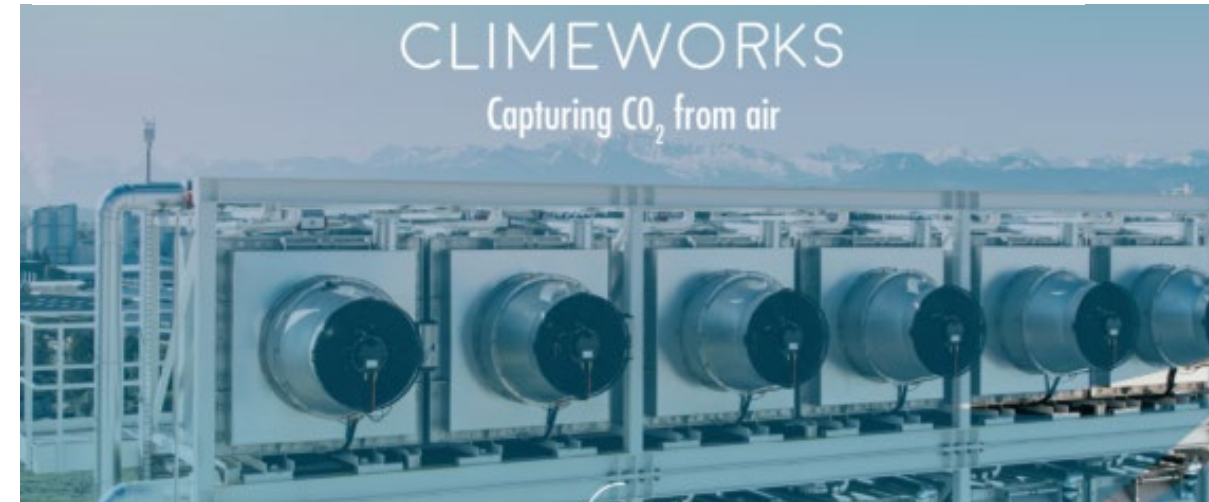
Negative emissions technologies

Billion tonnes of CO₂/yr

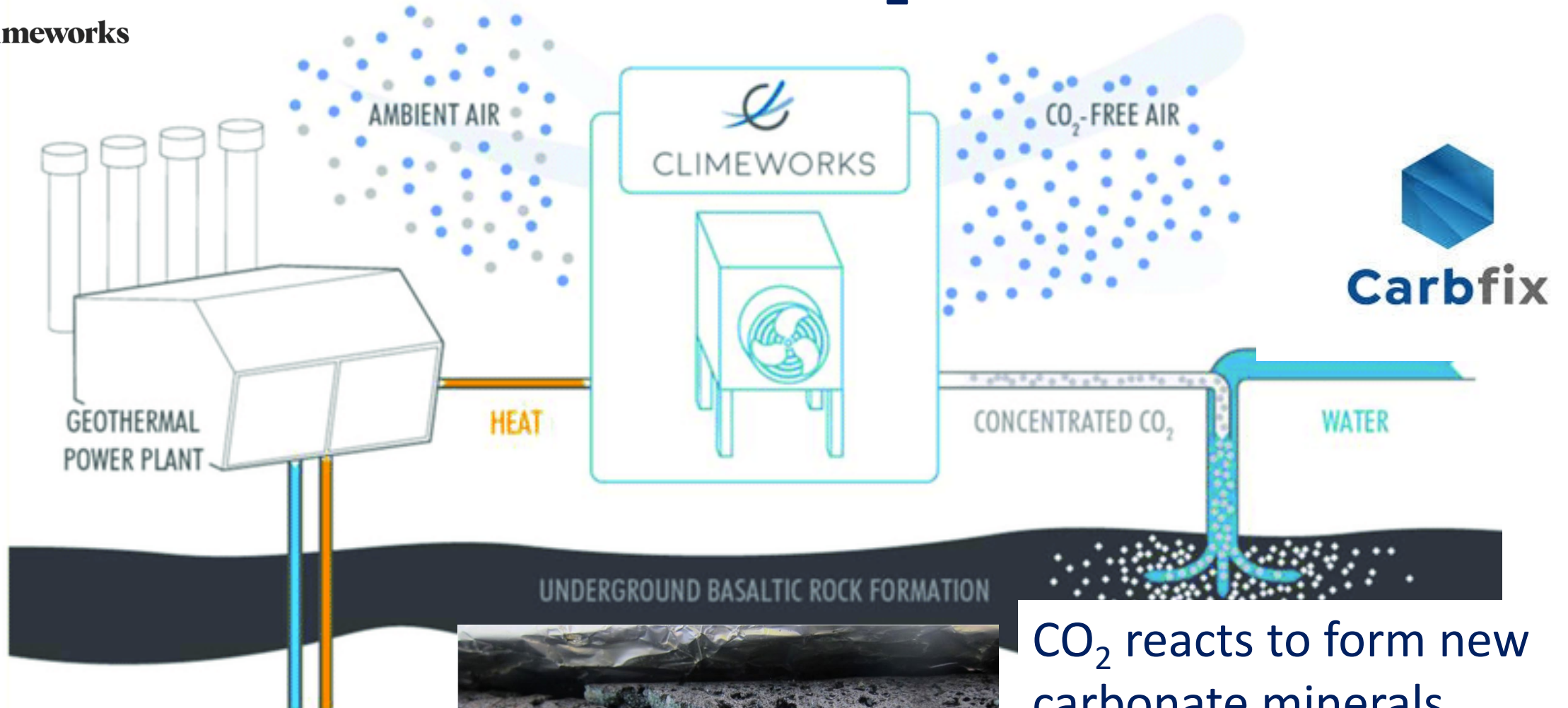
Limiting global warming to 1.5°C will require CO₂ removal from atmosphere



Bioenergy with CCS



Direct air capture and CO₂ mineralisation

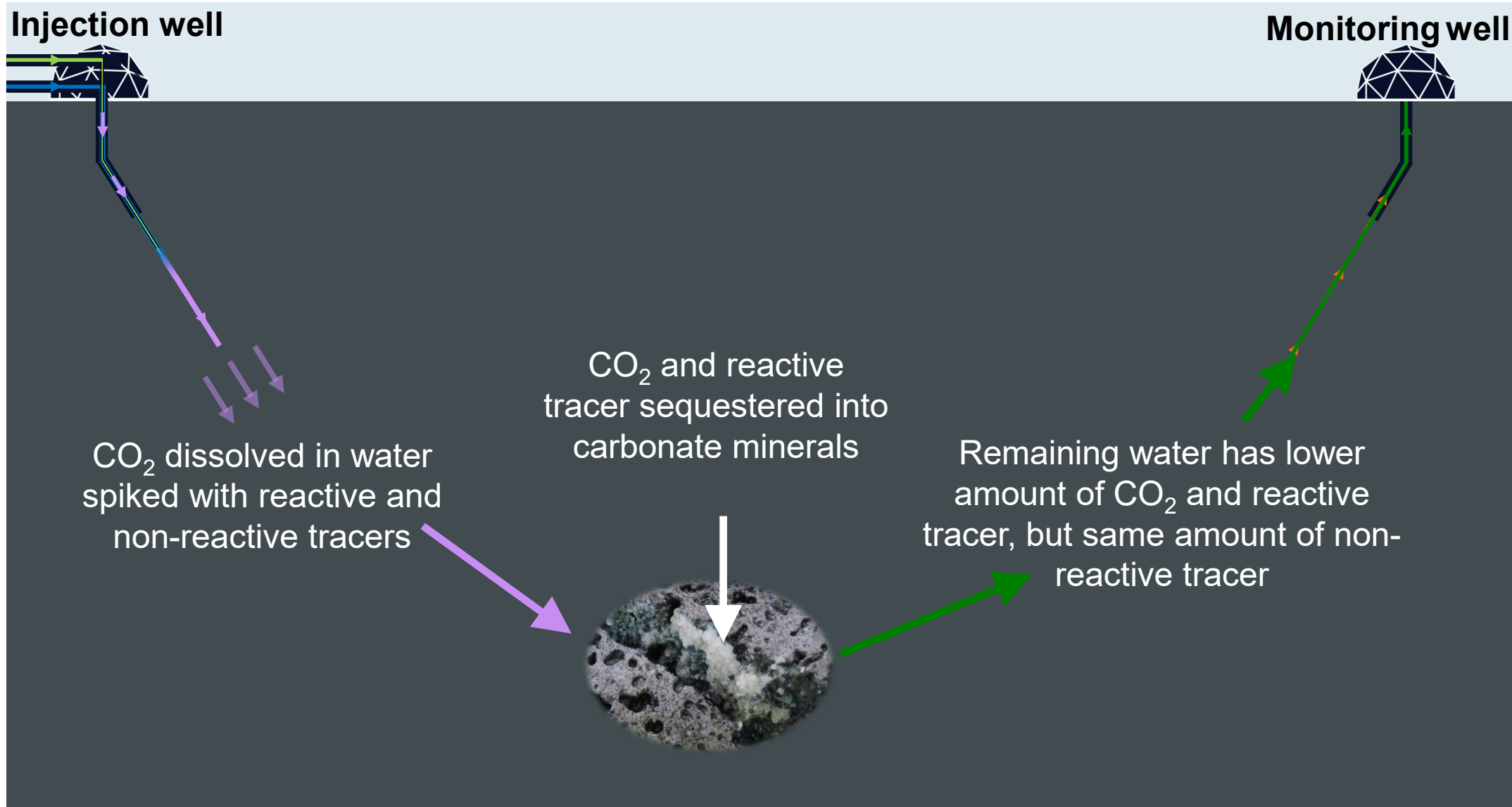


CO₂ reacts to form new carbonate minerals underground

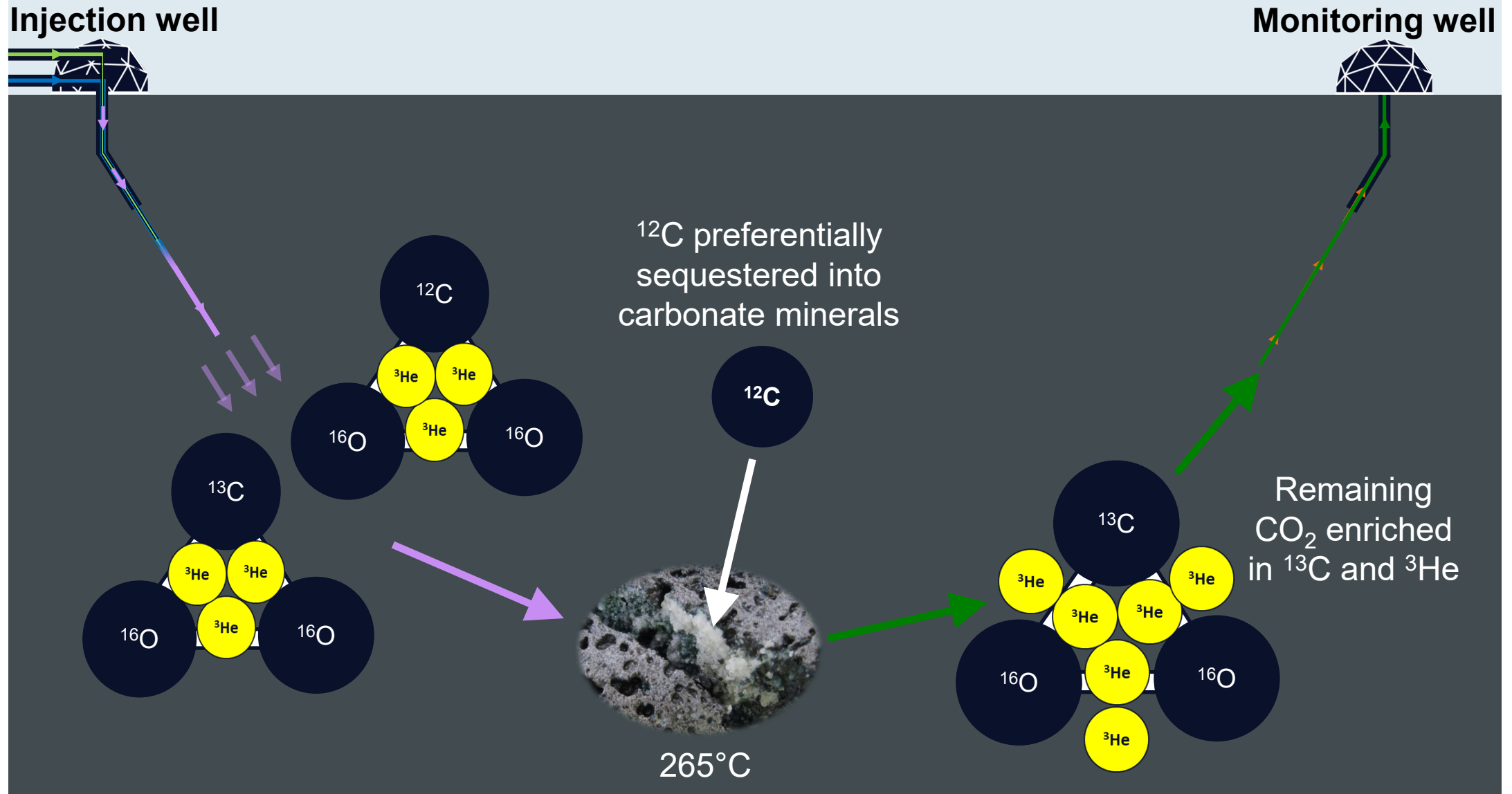


Credit: Sandra Ósk Snæbjörnsdóttir

Current Verification Method



Inherent Tracer Verification Method



CO₂ mineralisation potential in UK

Climate > News



Ancient rock formations could store millions of tonnes of CO₂, research says

Scientists at the University of Edinburgh have identified several underground volcanic formations around the UK that they say could store more than 3,000 million tonnes of industrial CO₂ waste, which they say is approximately equivalent to 45 years worth of UK industrial emissions.

Research article

ES3
Earth Science, Systems and Society

<https://doi.org/10.1144/esss2024-001> | Vol. 5 | 2025 | esss2024-001

In situ mineralisation of UK onshore igneous rocks offers significant CO₂ storage potential

Angus W. Montgomery^{1*}, Chris M. Holdsworth¹, Emma Martin-Roberts^{1,2}, Ian Watt¹ and Stuart M. V. Gilfillan¹

¹ School of GeoSciences, University of Edinburgh, James Hutton Road, Edinburgh EH9 3FE, UK

² Department of Energy Security and Net Zero, 3-8 Whitehall Place, London SW1A 2EG

AWM, 0009-0004-8496-6108; CMH, 0000-0003-3025-7037; EM-R, 0000-0002-6718-601X; IW, 0009-0004-5559-1669; SMVG, 0000-0003-1929-2843

* Correspondence: angus.montgomery@ed.ac.uk



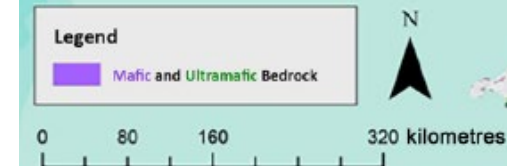
THE UNIVERSITY of EDINBURGH
School of GeoSciences



UK Mafic and Ultramafic Formations

Studied Formations

- A Shetland Ophiolite Complex
- B Esha Ness Volcanics
- C Skye Lava Group
- D Rum Peridotite
- E Mull Lava Group
- F Ochil Volcanic Formation
- G Lorne Plateau Lavas
- H Bathgate Hills Volcanic Formation
- I Garleton Hills Volcanic Formation
- J Clyde Plateau Volcanic Formation
- K Midland Valley Sill Complex
- L Arthur's Seat Lavas
- M Cheviot Hills Volcanic Formation
- N Ayrshire Volcanics
- O Ballantrae Ophiolite Complex
- P Antrim Lava Group
- Q Eycott Volcanic Group
- R The Whin Sill
- S Borrowdale Volcanic Formation
- T Rhobell Volcanic Group
- U Lizard Ophiolite Complex



Summary

- The CO₂ concentration of the atmosphere is still rising
- Global climate change is caused by cumulative emissions of CO₂
- Fossil fuels are still needed for current industries, societies and livelihoods
- **Carbon Capture and Storage is essential to combat climate change**

→ How is CO₂ stored deep underground?

Beneath impermeable seals, trapped in rock pores, dissolved and mineralised

→ How long can CO₂ be stored for?

- **Natural CO₂ reservoirs show for millions of years**

→ Direct air capture and bioenergy with CCS can remove CO₂ from atmosphere

CO₂ can react with volcanic rocks to form new minerals underground for storage

→ UK volcanic rocks could potentially store >3,000 million tonnes of CO₂

