

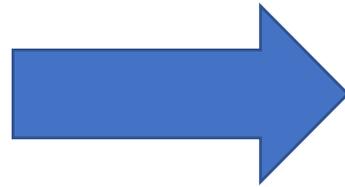


Edinburgh: 1770 CO₂ discovery

Net zero and beyond

Professor Stuart Haszeldine
GeoSciences, University of Edinburgh

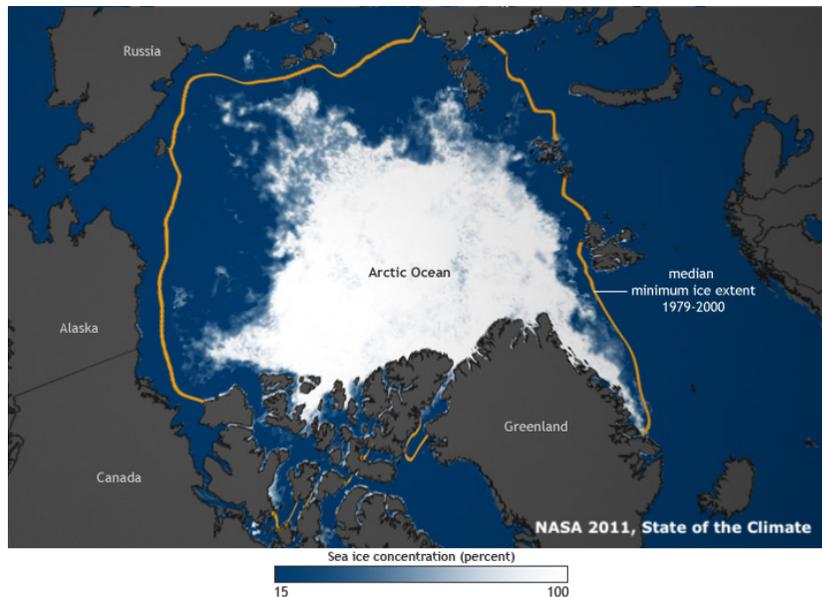
WHY CO₂ storage is required ?



Burning: Arctic, California, Australia



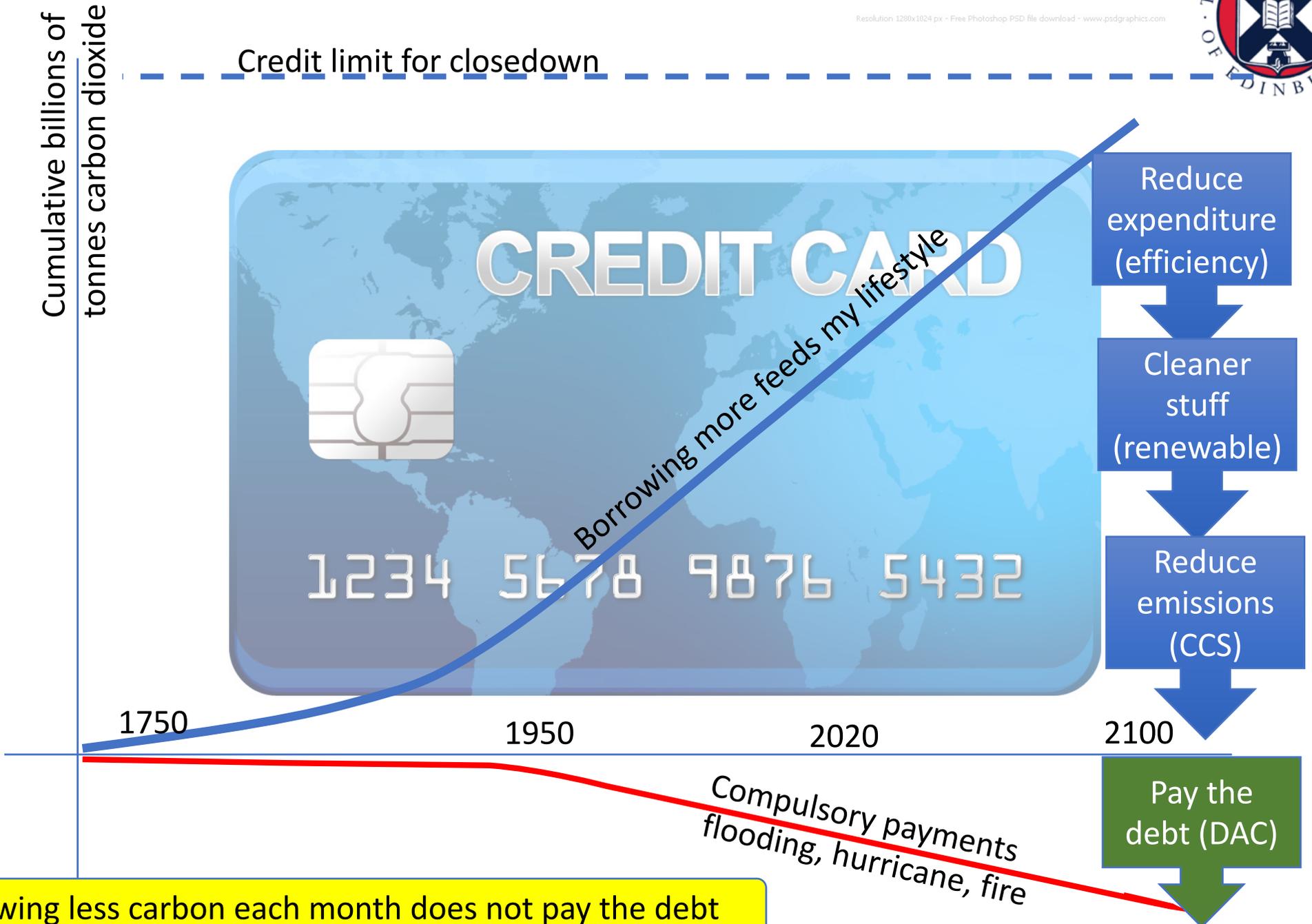
Melting: ice melt, sun reflection, UK Floods



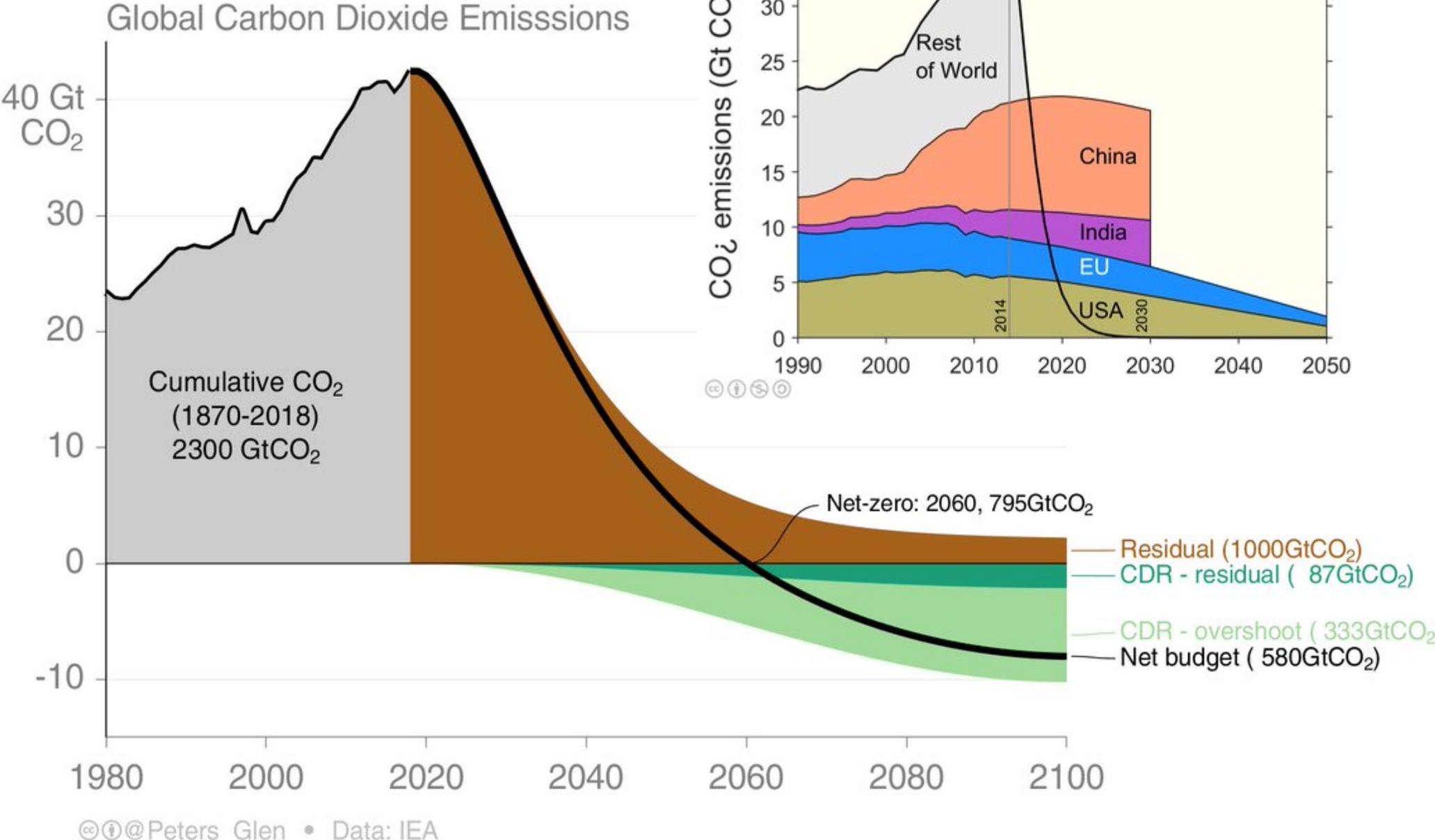
Carbon on credit



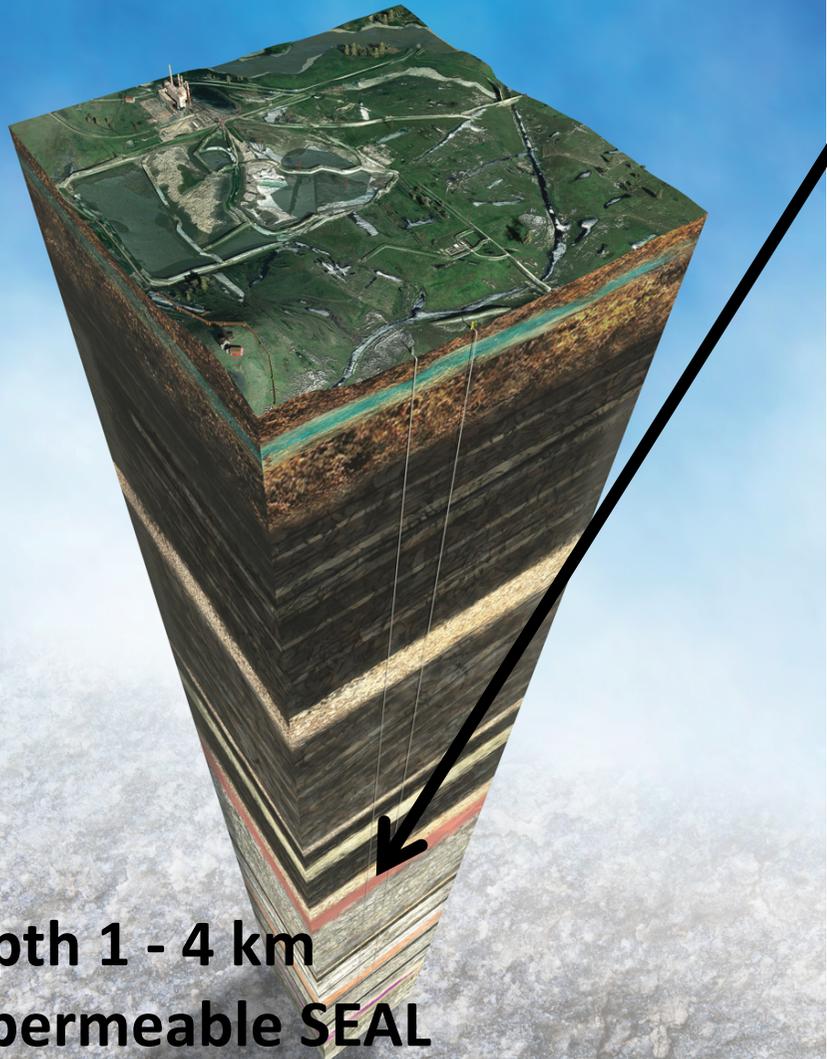
Resolution 1280x1024 px - Free Photoshop PSD file download - www.psdgraphics.com



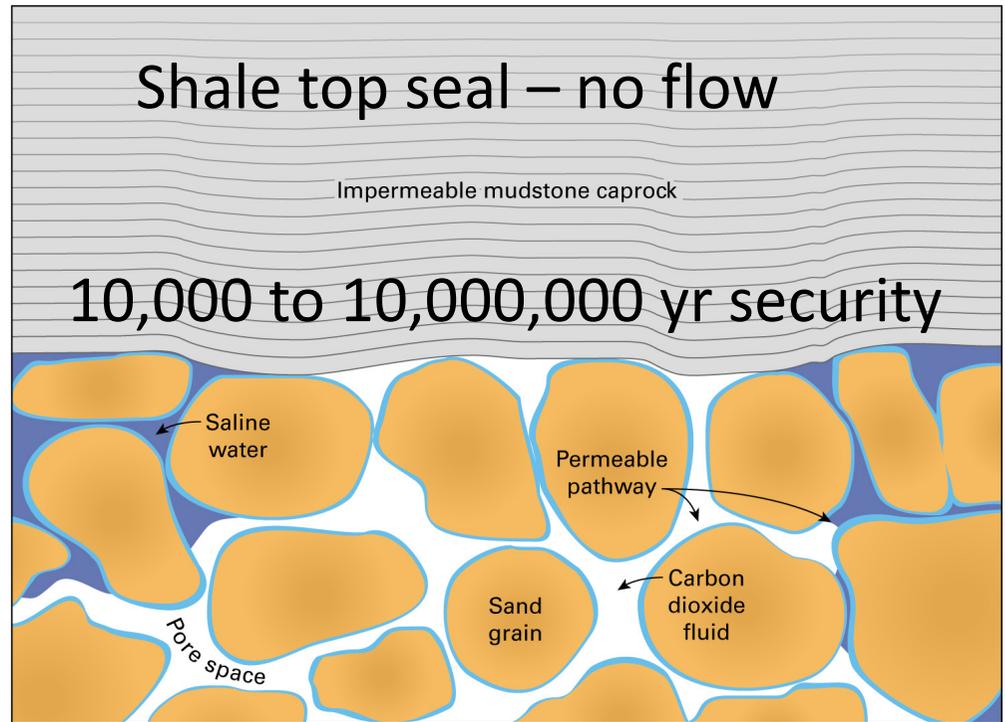
Pathways to Net Zero



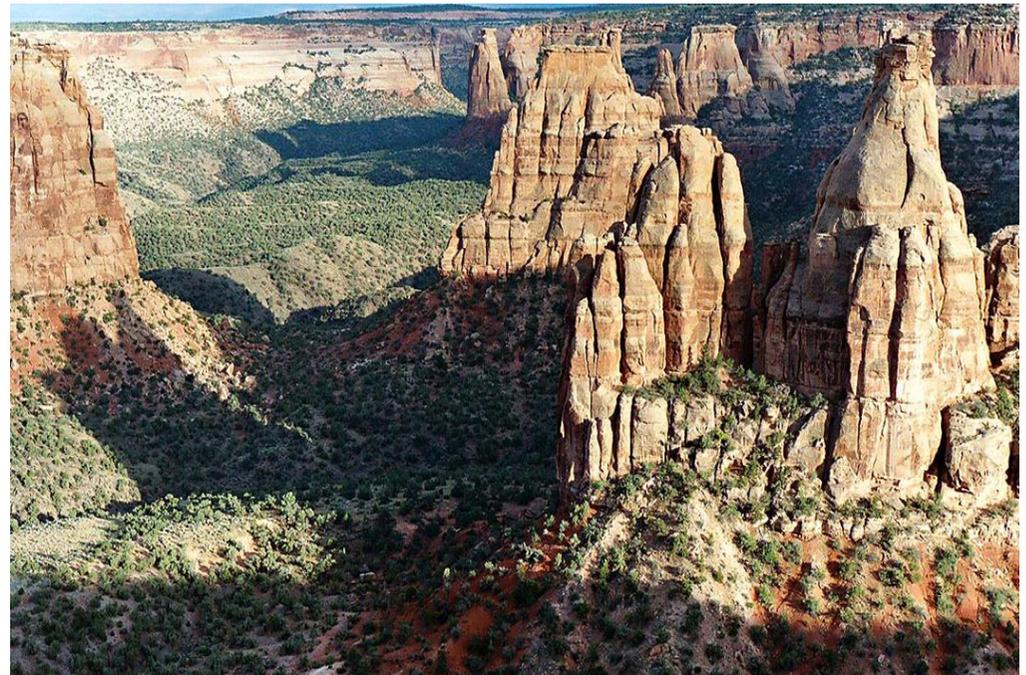
CO2 storage is a long way down



Depth 1 - 4 km
Impermeable SEAL
Overlies
Porous RESERVOIR



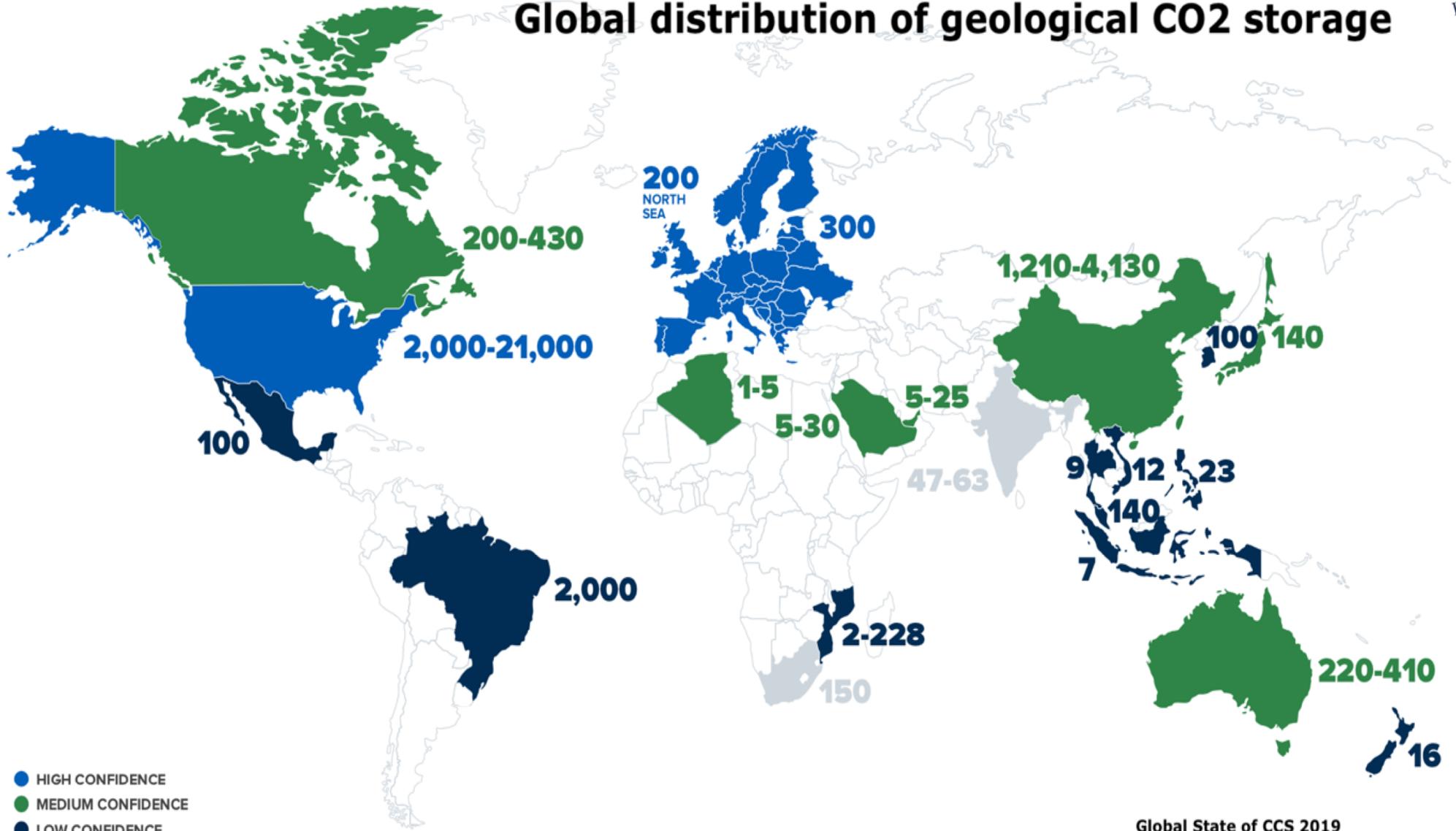
© British Geological Survey



Abundant geological storage



Global distribution of geological CO2 storage



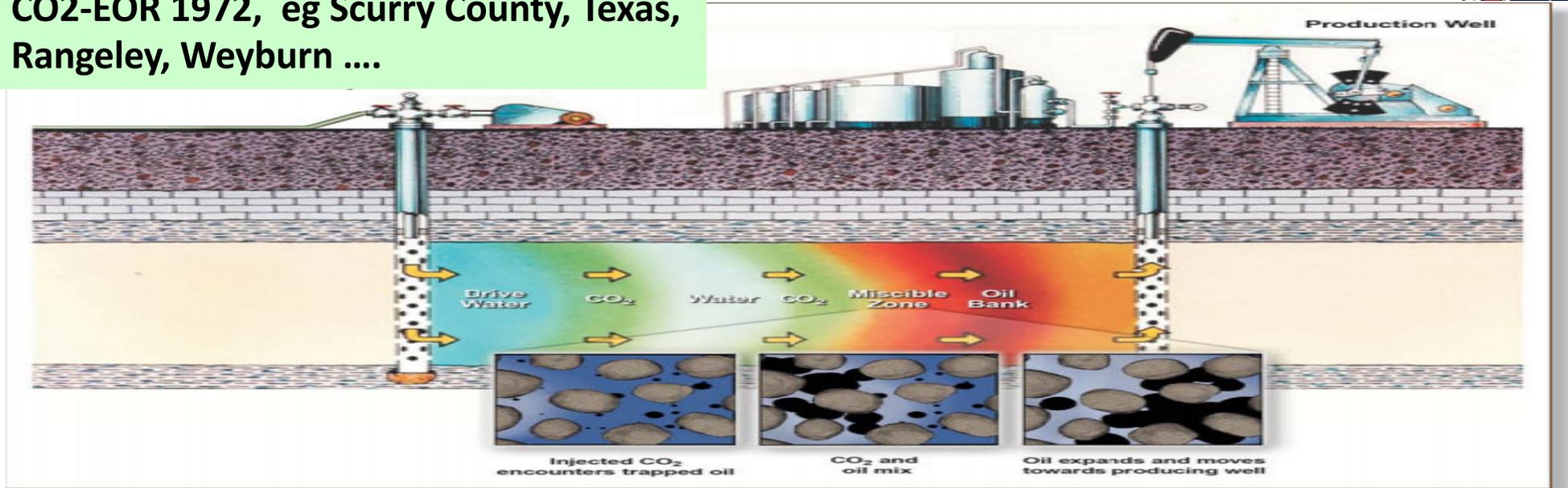
- HIGH CONFIDENCE
- MEDIUM CONFIDENCE
- LOW CONFIDENCE
- VERY LOW CONFIDENCE

Global State of CCS 2019
Global Carbon Capture and Storage Institute Ltd

CCS exists : decades of injection & monitoring

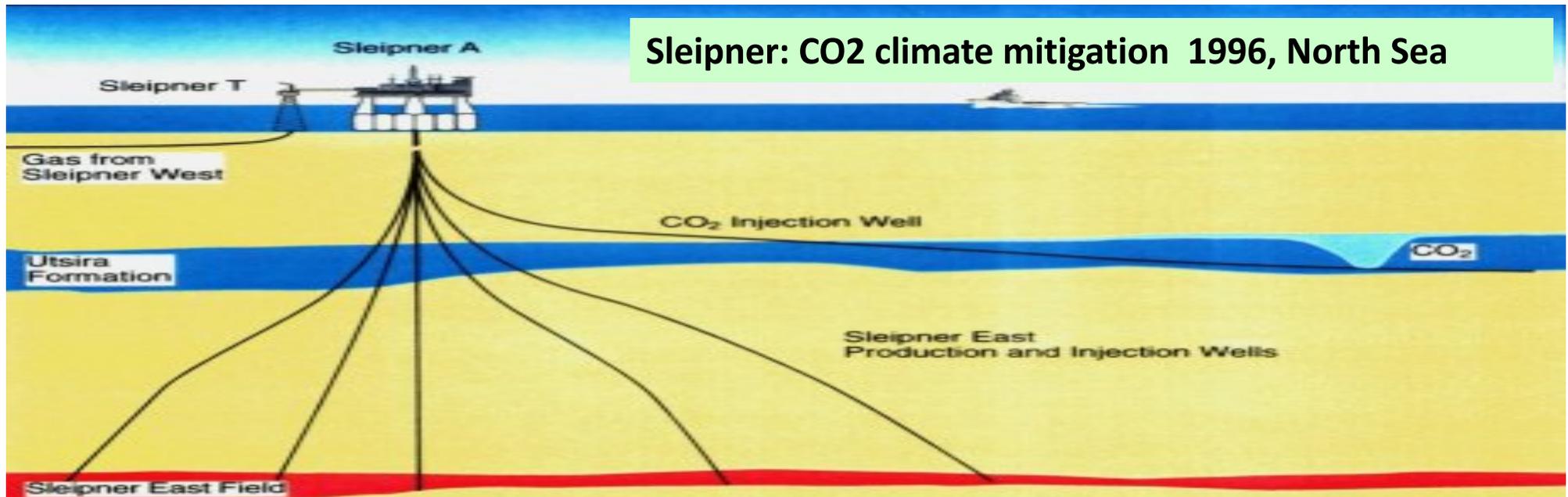


CO₂-EOR 1972, eg Scurry County, Texas, Rangeley, Weyburn



Cross section illustrating how water, fluids and water can be used to push residual oil from a subsurface rock formation between wells

Sleipner: CO₂ climate mitigation 1996, North Sea

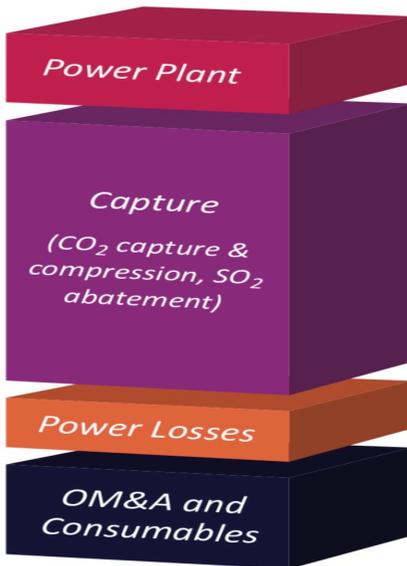


Boundary Dam coal CCS

CCS \$140/ton



BD3



SHAND
Shand coal power plant (1992),
Retrofit 300 MW, 2Mt CO₂/yr



Valero refinery H₂

Coal: Amine post-combustion
Gases: Pressure swing adsorbtion



Air Products 2 x units vacuum swing solid adsorbtion, 90% capture, 97% purity.

1 Mt CO₂/yr 159km pipe to Hastings field
EOR 1.6 – 3 Mbbbl/yr.

28 MWe steam and operations. Upscale
potential 56 Mt CO₂/yr in USA

<https://ccsknowledge.com/news/cost-of-capturing-co2-drops-67-for-next-carbon-capture-plant>

Evolution of CCS, UK, Europe, China



1995 Coal : post combustion, amine
Seen as method to retrofit coal fuelled power plant, to maintain life span, and enable use of low cost fuel

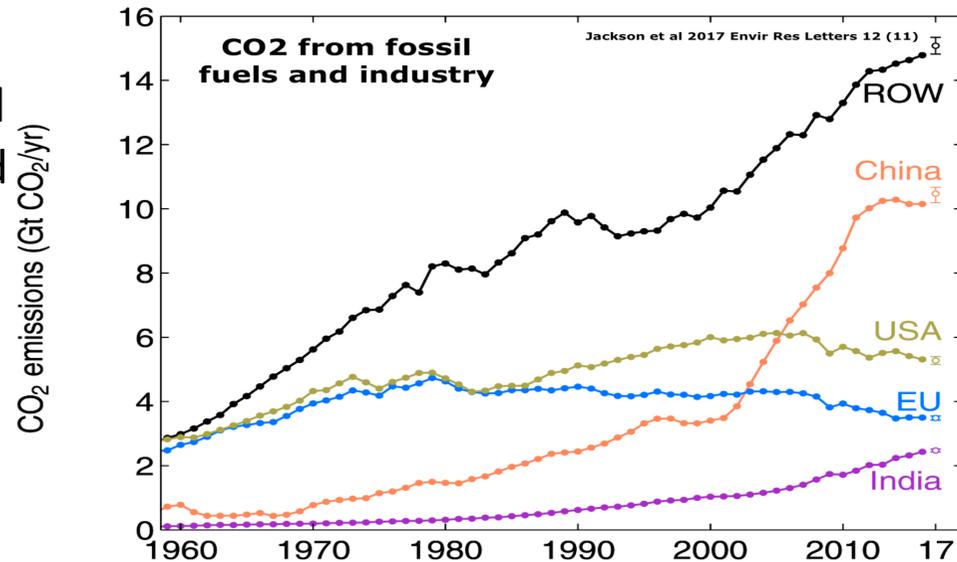
Coal : pre combustion IGCC
More efficient use of poor quality fuel and easier CO2 capture : expensive

2015 Gas : post combustion, amine
Cleaner fuel, less CO2, easier separation, refit or new-build

Cement + industry : post combustion amine Heating, and process emissions from calcine limestone

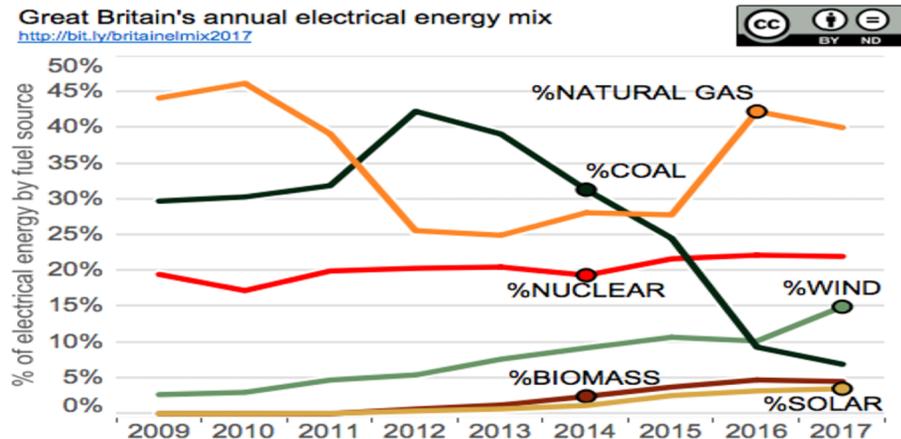
Hydrogen : amine or pressure swing
Cleaner gas mix, level continuous operation, pure CO2

2020 GGR : nature based or technology?
Trees, soil
Direct Air Capture, BECCS, minerals



Coal retrofit or closure essential in China, USA, India

22 Sept 2020. President Xi 75th UN General Assembly
“We aim to have carbon emissions peak before 2030 and achieve carbon neutrality before 2060”



Coal in UK closed due to age, carbon tax and CCS price



Industry capture in the UK?



BEIS road map

Industry Strategy Challenge Fund

Increase funding in research and development by **£4.7 billion** over 4 years to strengthen UK science and business

Stage 1 projects

[Net Zero Tees Valley - Decarbonising the Full Cluster: Roadmap Pathfinder](#)

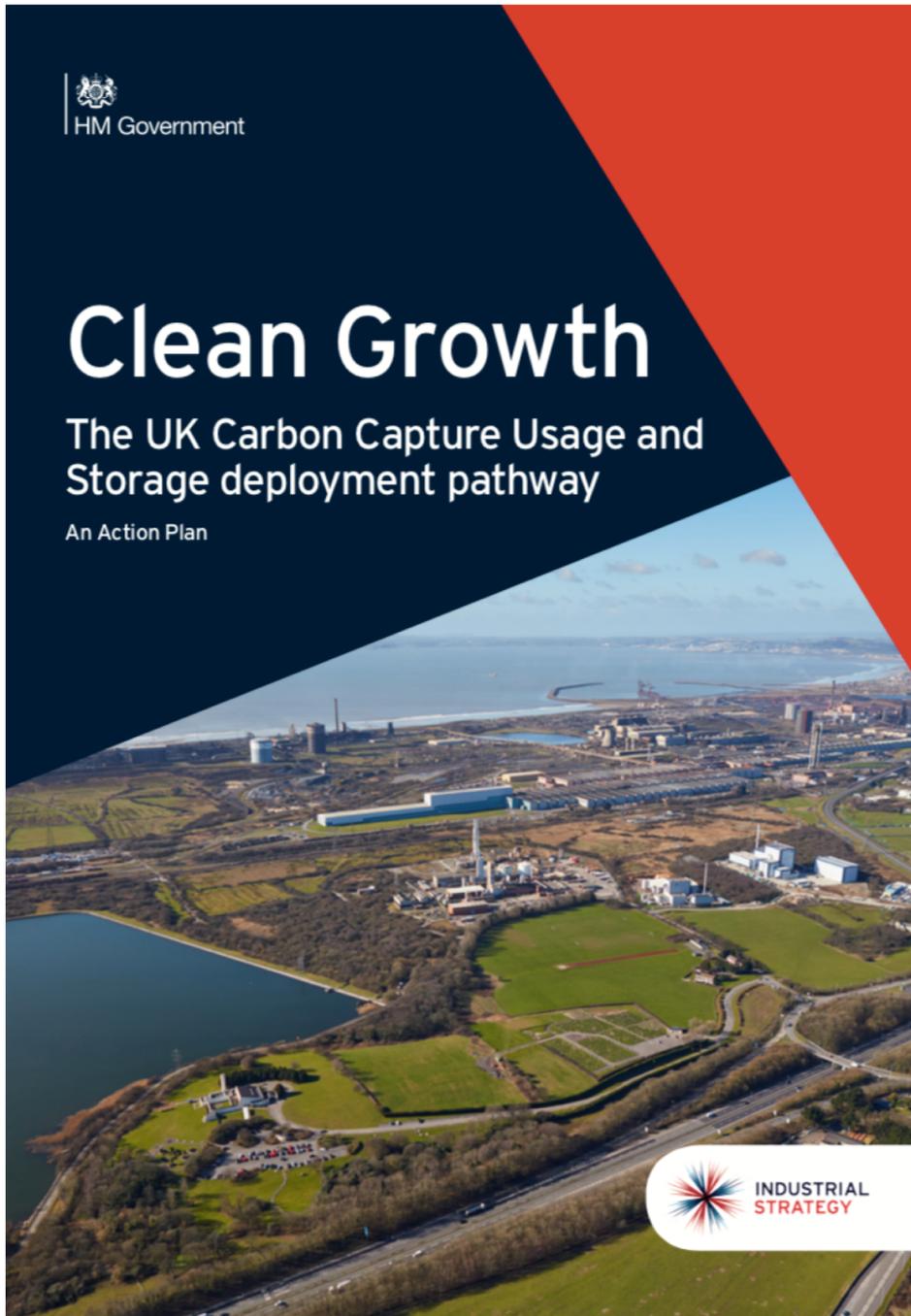
[Scotland's Net Zero Roadmap \(SNZR\)](#)

[Humber Industrial Decarbonisation Roadmap](#)

[North West Hydrogen and Energy Cluster: Route to Net Zero](#)

[South Wales Industrial Cluster \(SWIC\) Repowering the Black Country](#)

To deliver (more than) one cluster out of 6 industrial areas of the UK Starting by 2027 (mid 2020's)



Industry cluster decarbonisation



CCUS

Carbon Capture Utilisation & Storage

- Flue Gas Capture
- Direct Air Capture (DAC)
- Utilisation Solutions
- Storage Solutions
- Membrane Technologies

Fuel Switching

Alternative Fuel Power Generation

- Replacement of methane (and / or diesel) in power generation
- Using lower carbon fuel and modifying would allow CO₂ emissions to be reduced for more assets at lower cost.



Technology Screening



Hydrogen Generation

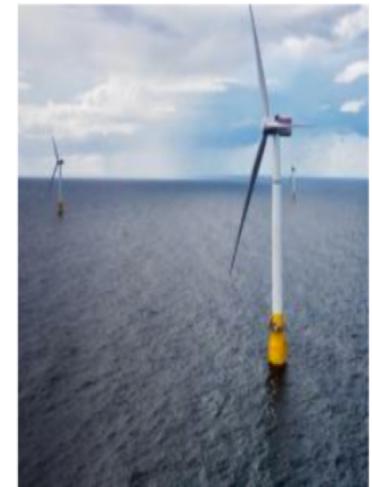
Green & Blue Hydrogen Supply

- Steam Methane Reforming
- Electrolysis
- Biomass Gasification
- Hydrogen Storage

Electrification

Low emission energy supply

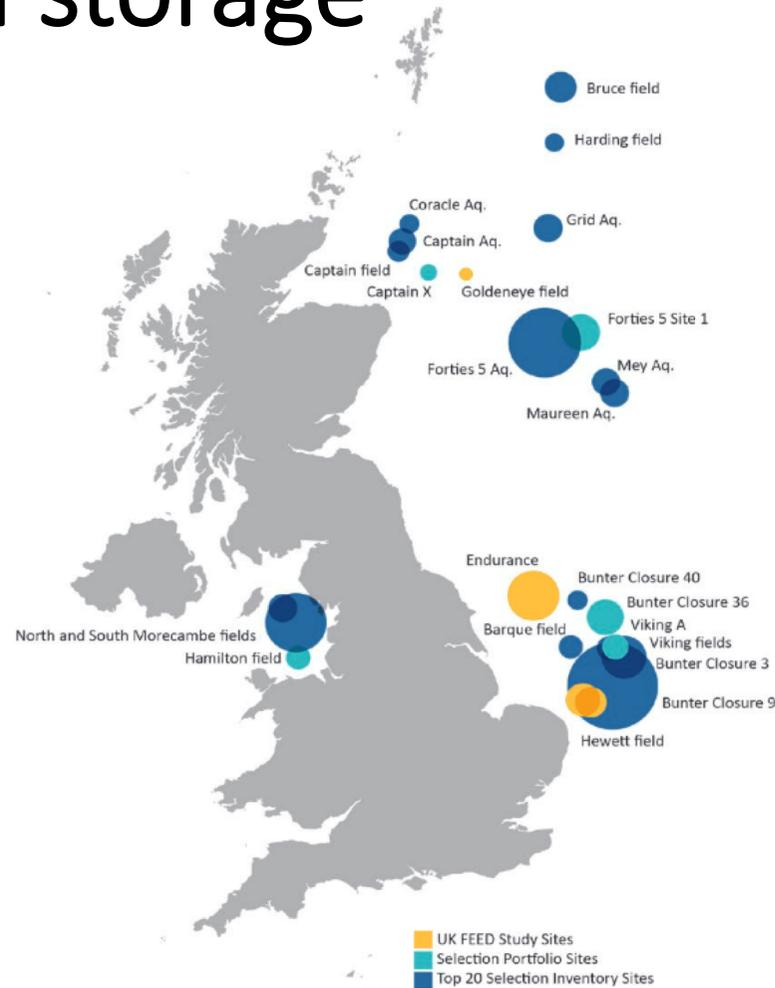
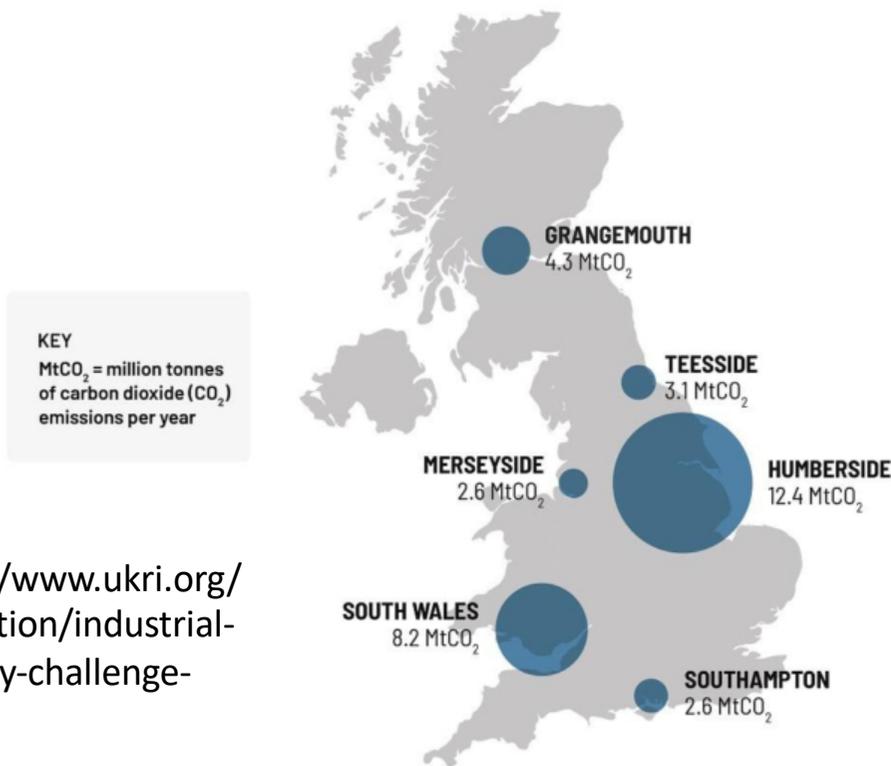
- Energy optimisation
- Renewable Integration
- Connection to Grid
- Energy Storage



UK de-carbonisation and storage



THE UK'S LARGEST CLUSTERS BY INDUSTRIAL EMISSIONS ONLY

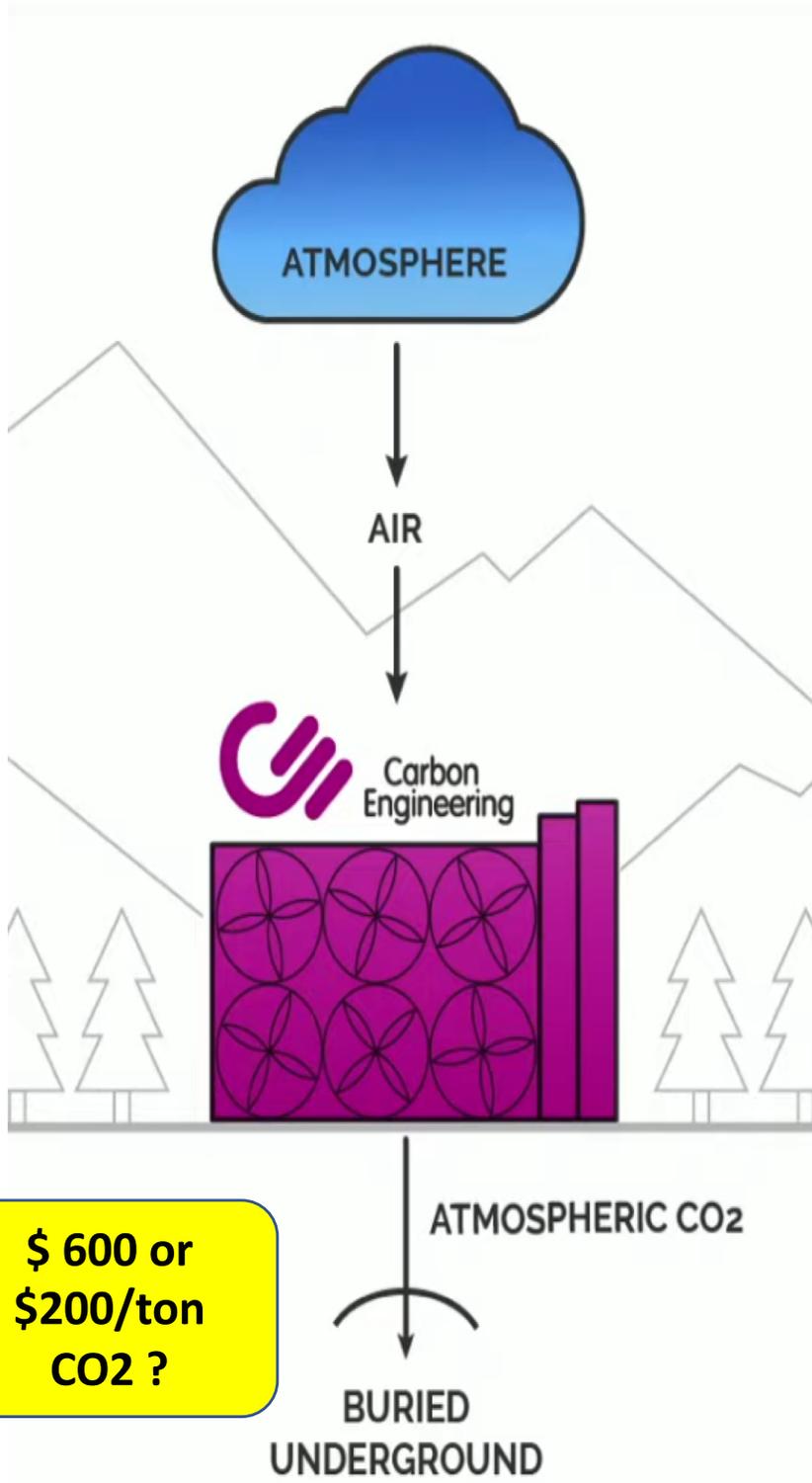


<https://www.ukri.org/innovation/industrial-strategy-challenge-fund/>

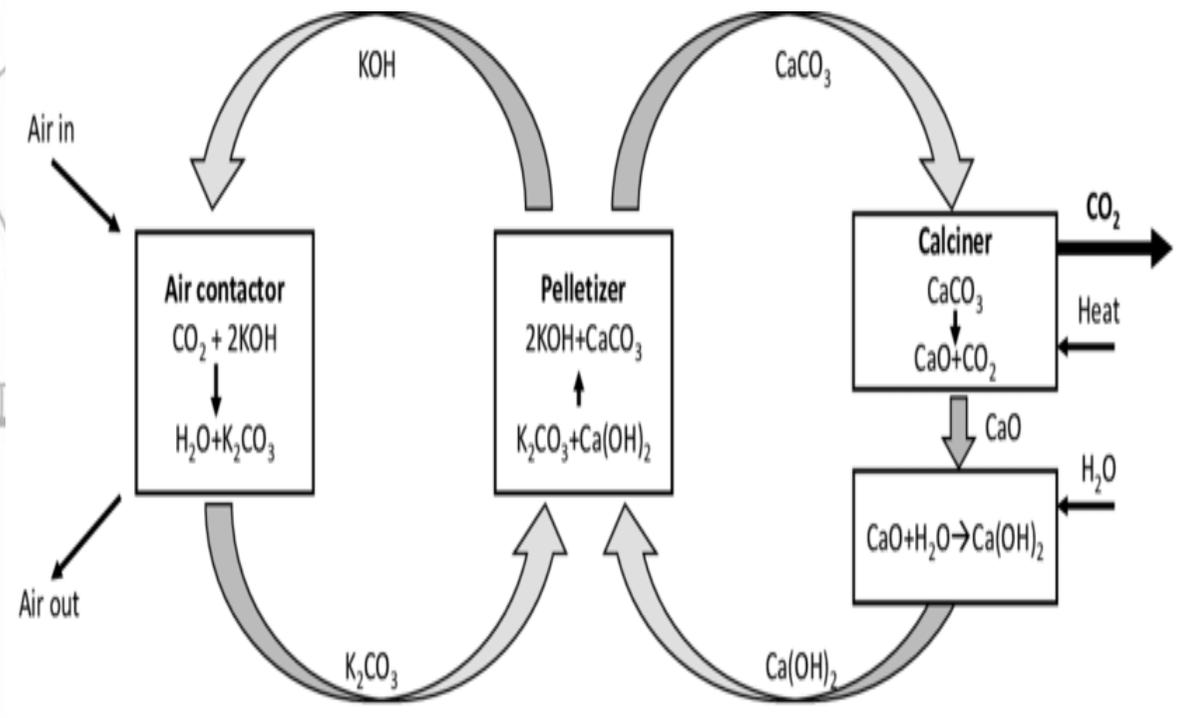
Industrial decarbonization challenge. 6 x clusters 40 Mt/yr CO₂ [Industrial Clusters Mission](#) 1.5 million jobs, annual export goods and services £320 billion Govt **£170 million** from the Industrial Strategy Challenge Fund (ISCF) and will be **matched by £261 million** from industry.

£ 800M +£200M for CCS infrastructure
£ 315 Industrial Energy Transform
£ 62M Scottish Energy Transition Fund
£100M for DAC (GGR & Air Capture)

DAC: Carbon Engineering



\$ 600 or \$200/ton CO₂ ?



Nature Based Forest



**\$ 100 or
\$50/ton CO2 ?**

**Each European
needs 3 football
pitches of trees
during their
lifetime, continually.
= 2 x India land area**

Permanence?? Fire ??



Utilisation: Carbon8 aggregate CONCRETE



Demolition
Concrete
Iron slag
Sand
Glass aggregate
Fly Ash

**\$ 50 or
\$20/ton CO2 ?**

Spinout Univ Greenwich 2006
Employs 90 people, 3 UK plants
£ 15 M /year turnover
Makes 300,000 tonne/year aggregate
LCA - carbon negative

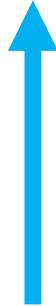
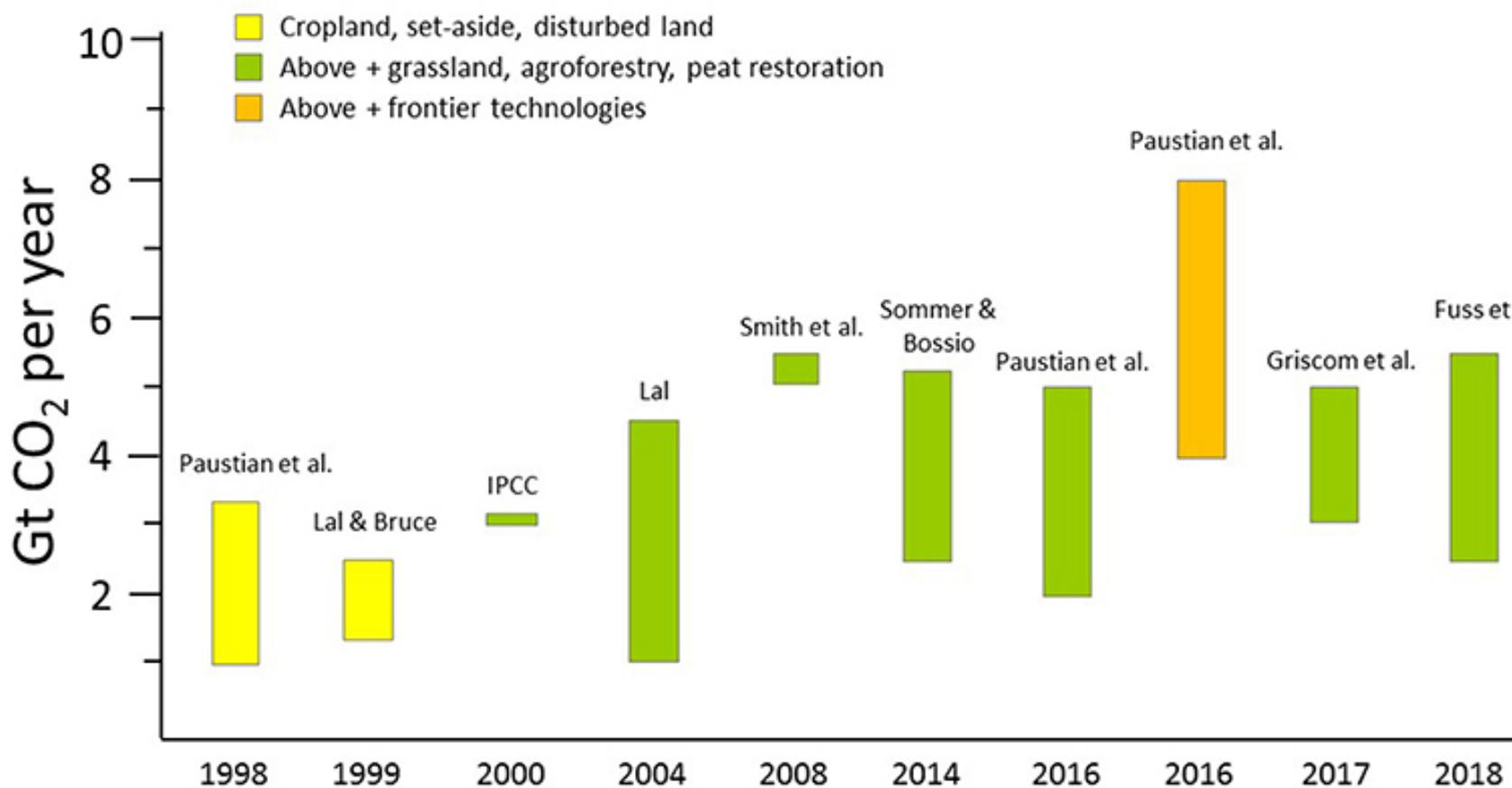
Waste based Accelerated CO2 Utilisation





Bumps and potholes ahead

Size scale - materiality. E.g. soil



Annual global 40 Gt CO₂ eq /yr

\$ 5 or \$100/ton CO₂ ?

Global soil stock 2020 1,500 Gt C at 1 metre; 2,400 Gt C (8,640 Gt CO₂ eq) to 2 metres
 Most minerals soils have lost 50% of organic components

Changed management to restore carbon to soil : rotation, tillage , grazing, biochar

Time to gradually introduce 10-40yr, How to monitor and verify ?

Total CO2 emissions dwarf the first carbon capture efforts from coal-fired plants

CO2 captured at Boundary Dam plant in Canada, 2018

625,996 tonnes

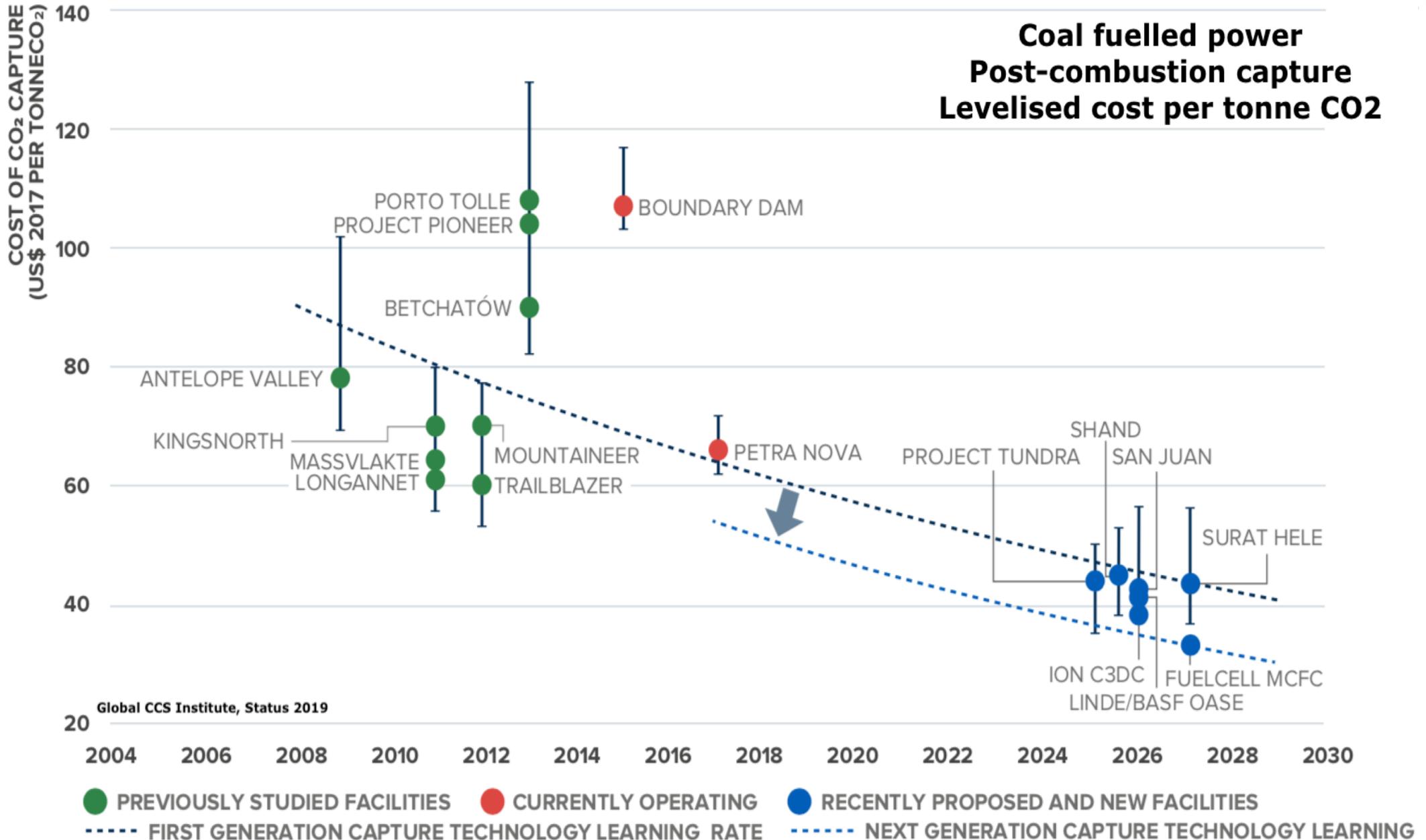
Total CO2 emissions from coal-fired power plants, 2018

10bn tonnes

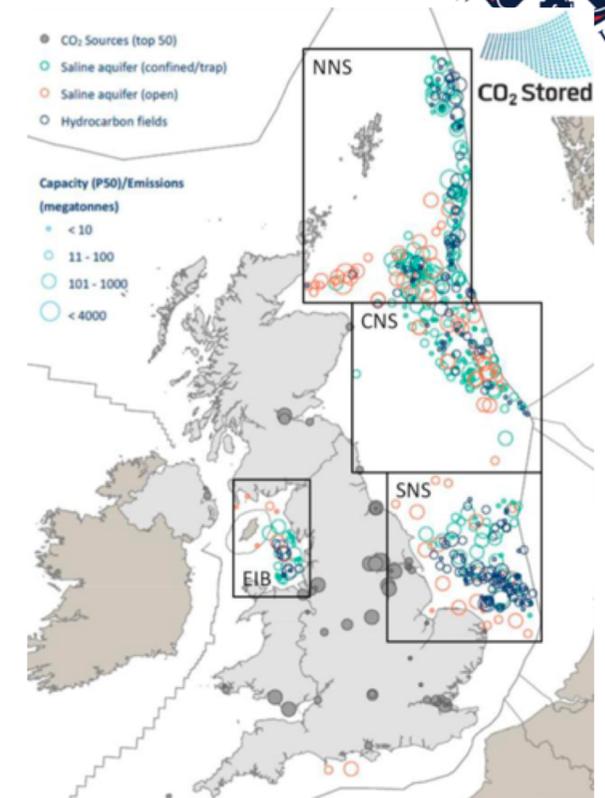
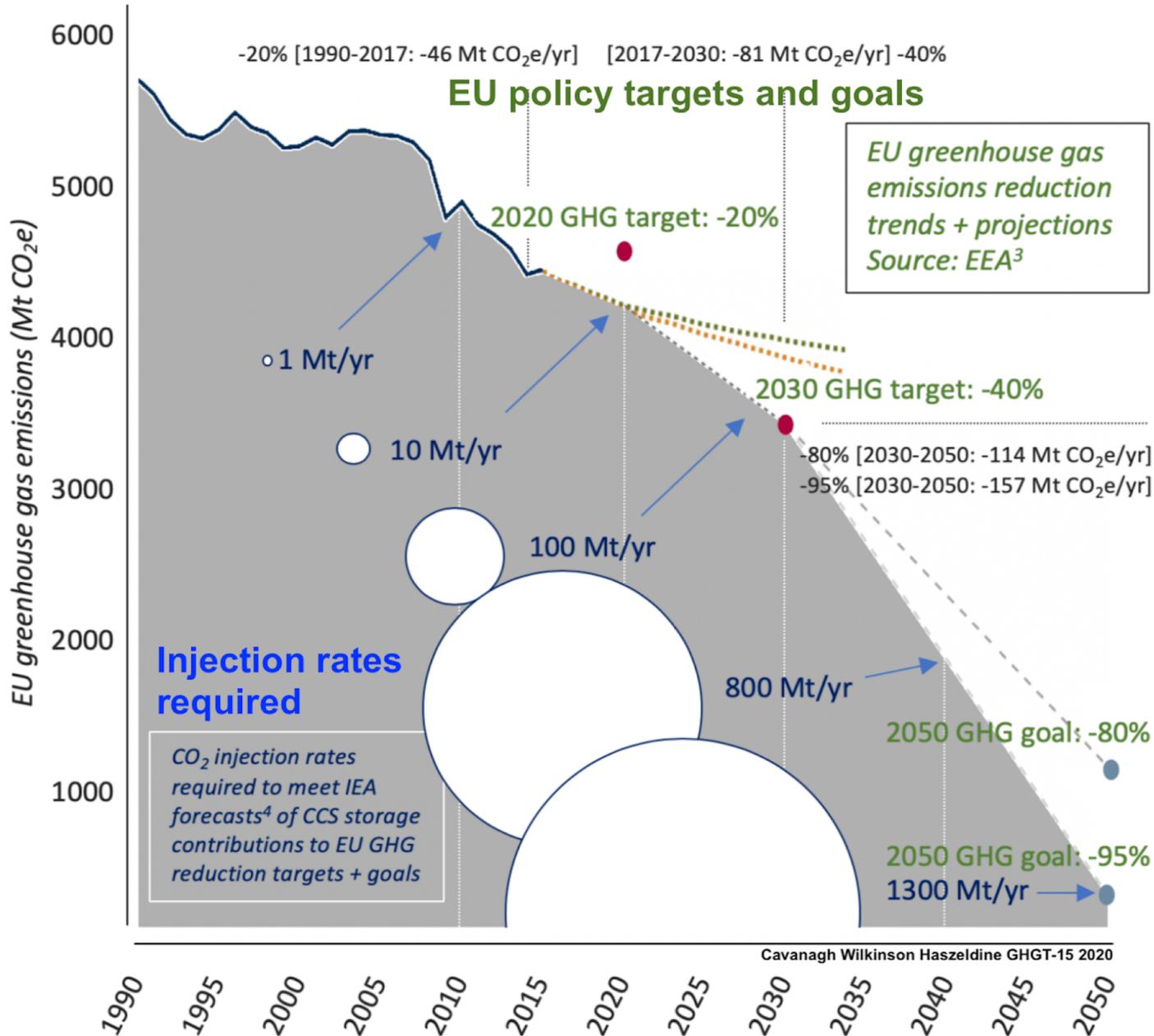
How ready and proven is coal-based CCS ?

Sources: SaskPower; IEA
© FT

Cost reduction pathways for CCS

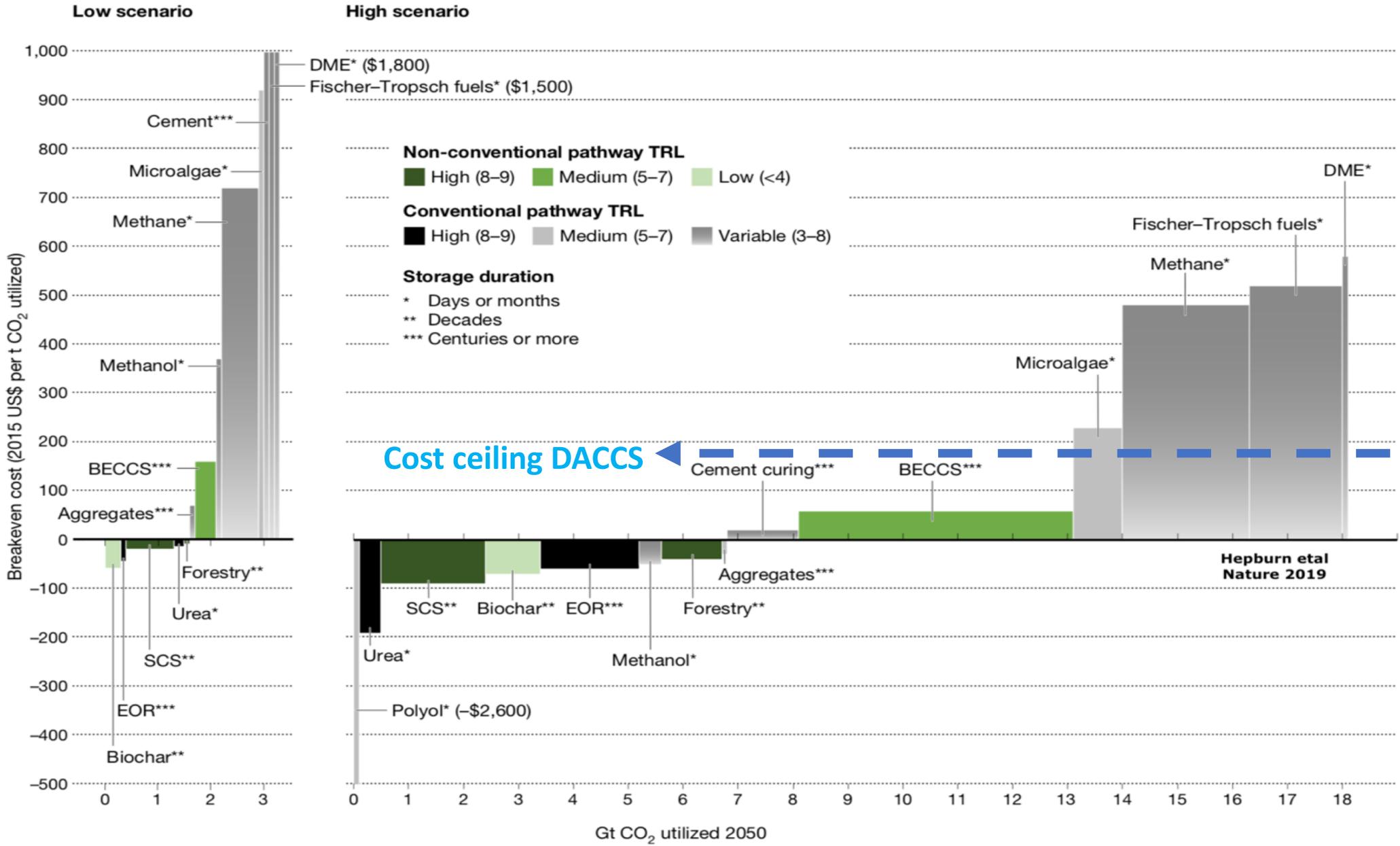


Scaling up EU CO2 storage 2000 - 2050



70 Gt CO₂ UK storage resource exists. Converting EU to commercial reserve means injecting **10 borehole/yr from 2025**
100/yr from 2030

Utilisation: profit, or storage ?



HOW to get paid ?

Regulation
✓

Cost
?

**Market &
Revenue**
X



BEIS Business models

Contract for difference CfD

Familiar to BEIS
Good for electricity
Top up to guaranteed minimum price

Baseload type CfD for BECCS and DACCS sites (GGR - NET)

Who pays the revenue?

**Startup grant / CO2 CfD?
Decarbonised product markets**

Good start
- but enduring regime ?

**H production business
Cross-sector H customers**

Synchronised delivery risk

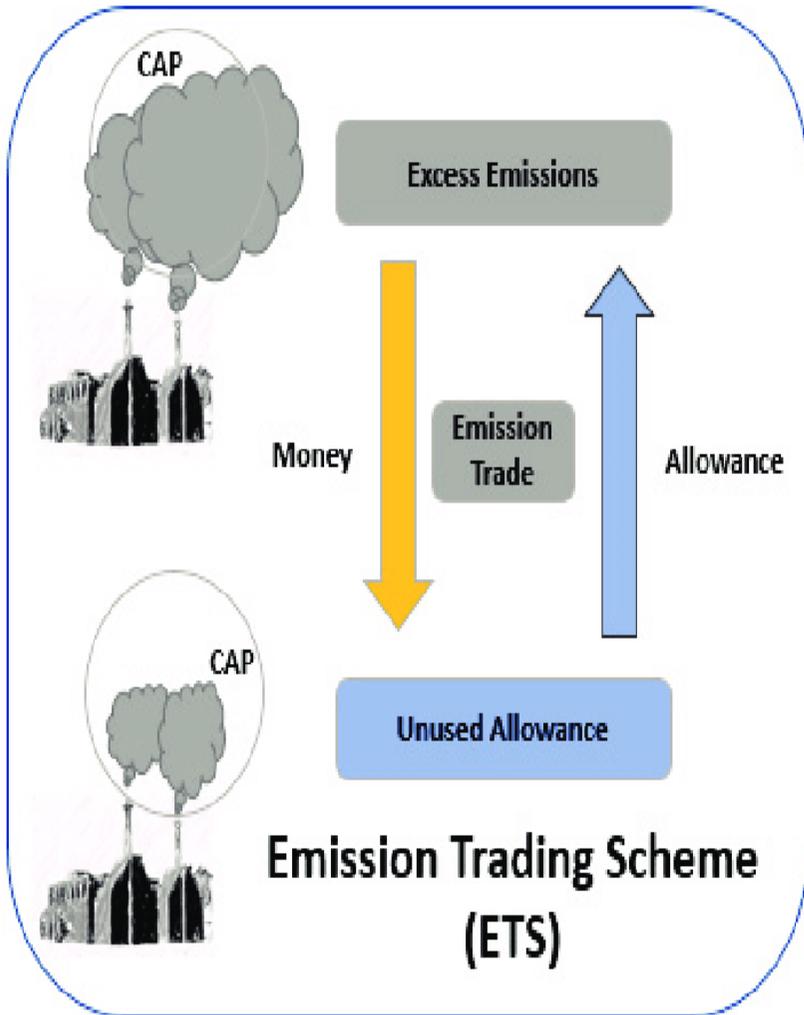
Regulated Asset Base model

Who builds the first networks
Good capture separate from T&S

Carbon Take Back Obligation

Least cost, Least regulation
Seamless transfer to Net Zero

Pricing of emissions : polluter pays



The Economist
 Price (much) too low; Price unstable, un-bankable

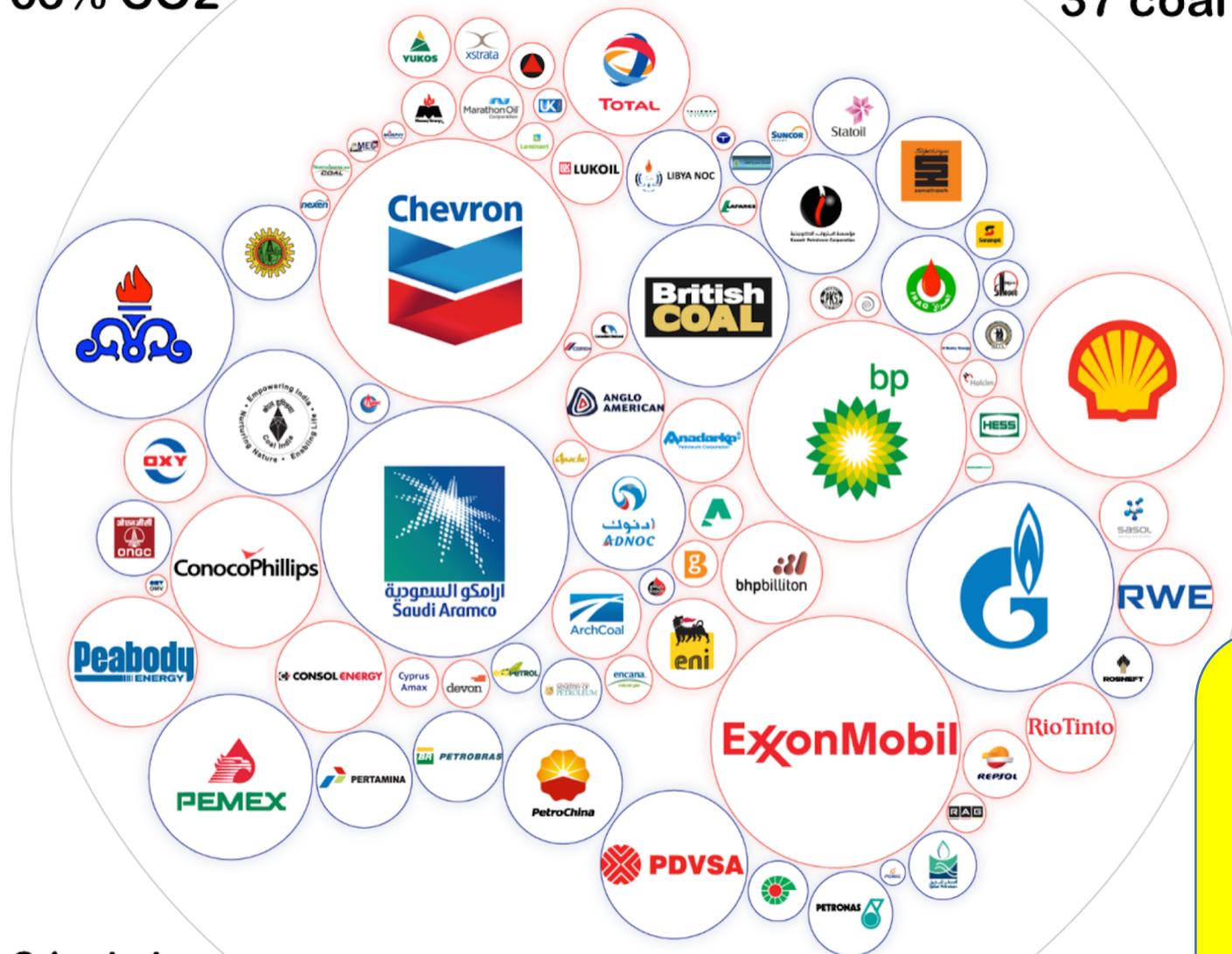
**Treating the symptoms (emissions)
 Or tackling the causes (vaccinations)**

90 companies
1751 - 2010
63% CO2

56 oil and gas
7 cement
37 coal



**Target 9
billion
consumers
DEMAND,
or 90
corporates
SUPPLY ?**



31 state co.
50 public co.
9 government

www.carbonmajors.org

**Continued fossil
fuel production
depends on about
90 organisations
and nations**

Producer pays: Certificates of Obligation

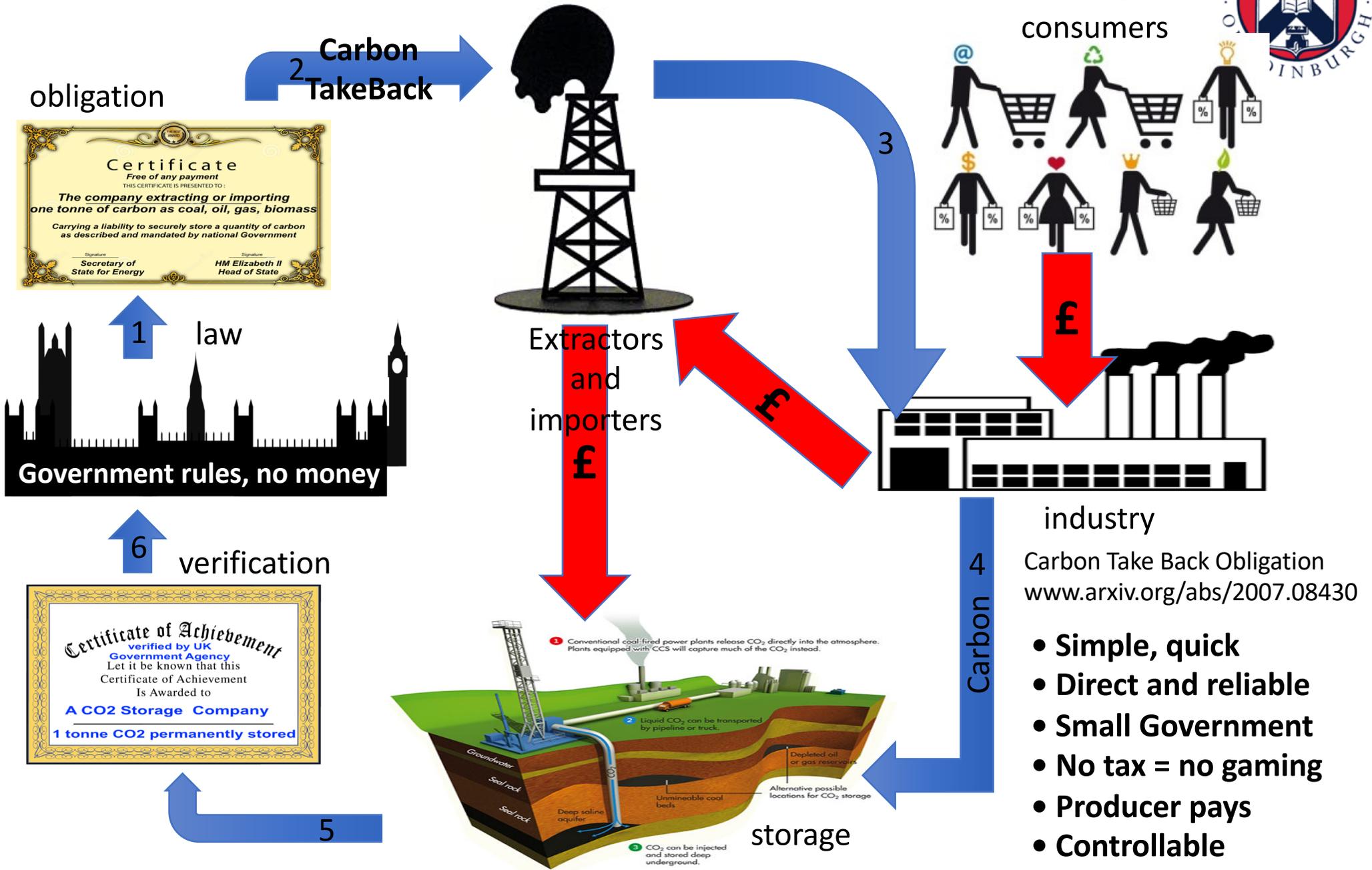


Allen, Haszeldine, Hepburn, Certificates for CCS at reduced public cost: Energy Bill 2015 <http://hdl.handle.net/1842/15698>

CTBO: Carbon TakeBack Obligation
ENVIRONMENTAL carbon certificate GIVEN at border – fuels (and goods)
NO MONEY : develop CO2 storage - at low cost - competition
OBLIGATION cancelled on PROOF of storage. Flexible and direct
Similar to: Extended Producer Responsibility Obligation : Circular

Haszeldine
2016 Oxford Rev
Economic Policy,
32, 304–322

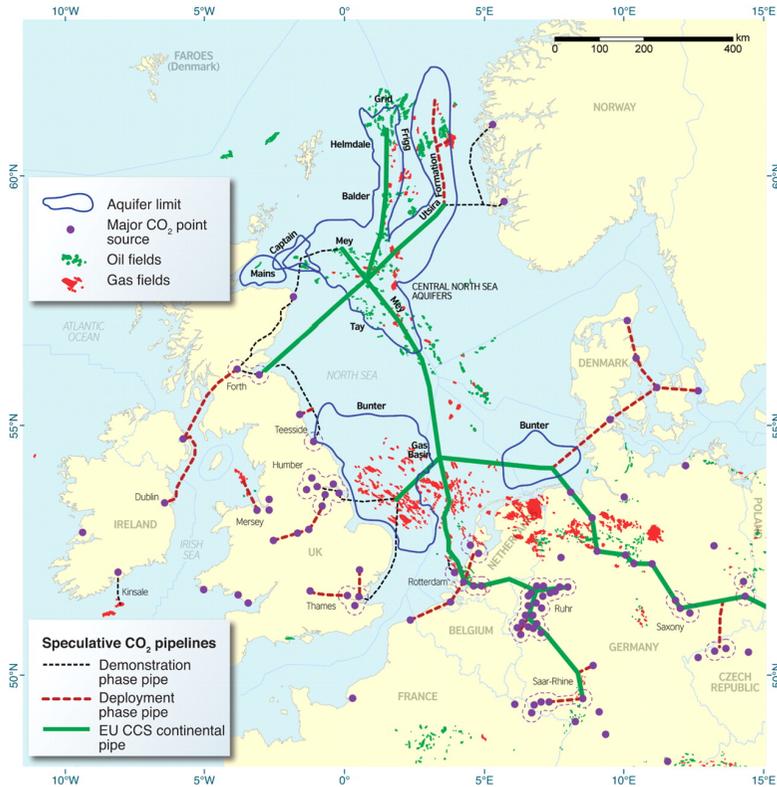
Carbon TakeBack Obligation, cancelled by Storage



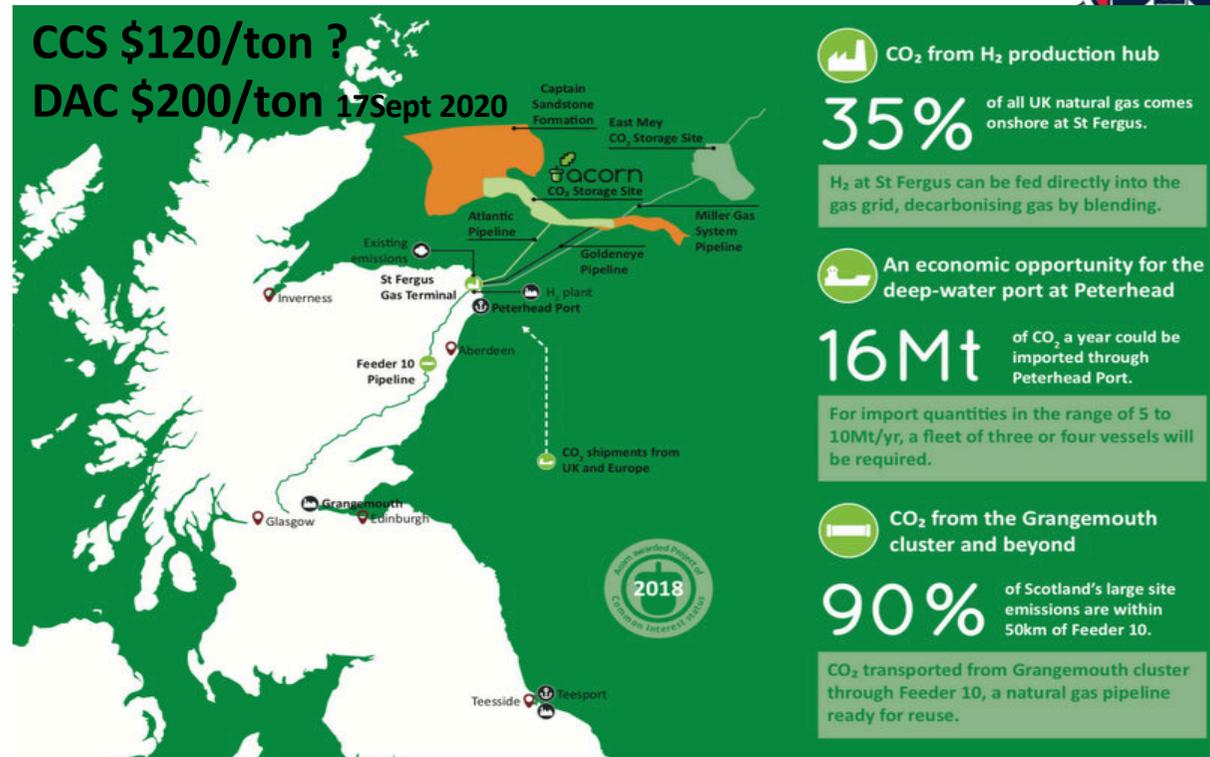
Example projects



Acorn North Sea CO2 : pipes & ships

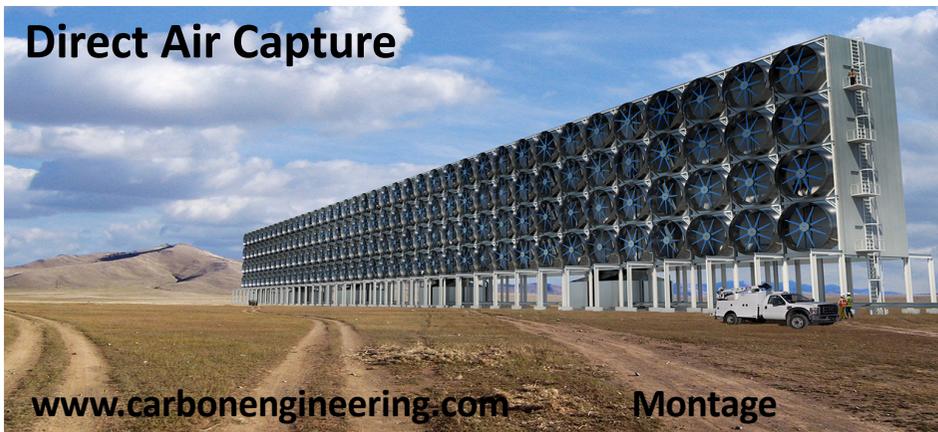


Haszeldine 2009 *Science*, 325, 1647-1652.



www.pale-blu.com/acorn/

Rapid, low cost, re-uses existing pipes



SUMMARY

Emissions markets
Low price, unbankable
Very slow , cannot reach Net Zero

GGR
Emerging demonstrators globally
Needs replication and learning
Nature and Land
And /or
Technology
Essential for Net Zero

Cost cleanup
1% GDP
= one more
Christmas
Day £ /yr

UK
Very well suited for CCS
Regulation well established
Costs are well understood
Negotiating diverse business
models and RAB for payment.
CTBO simple but radical
Minimum governance
10Mt/yr commit and review
2030 - this is 3x too small ?
Govt. co-ordination complexity

TIMELINE

2020	2021	2022-24	2024-28	2030
Evaluation	First FEED x 2	Construction x2	Repeat project 1&2	Scale-up