



Edinburgh: 1770 CO₂ discovery

Net zero and beyond

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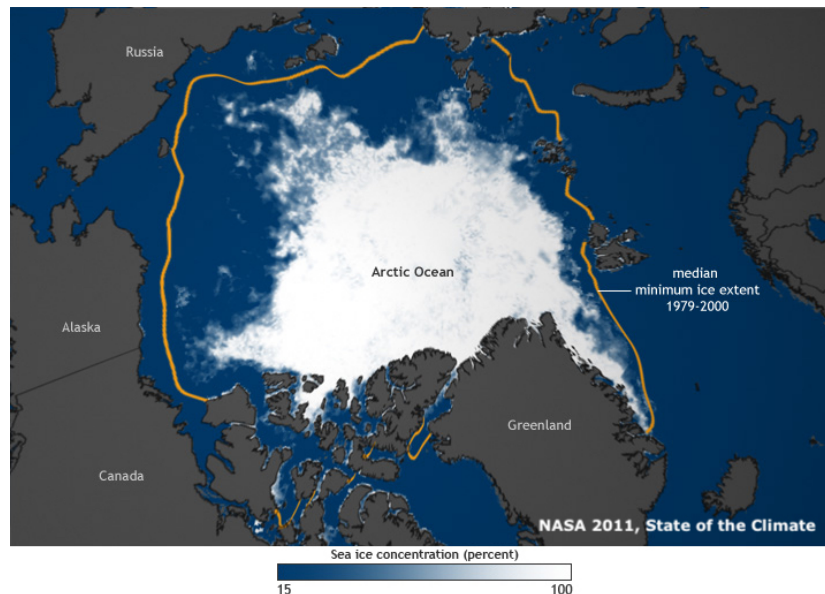
WHY CO₂ storage is required ?



Burning: Arctic, California, Australia



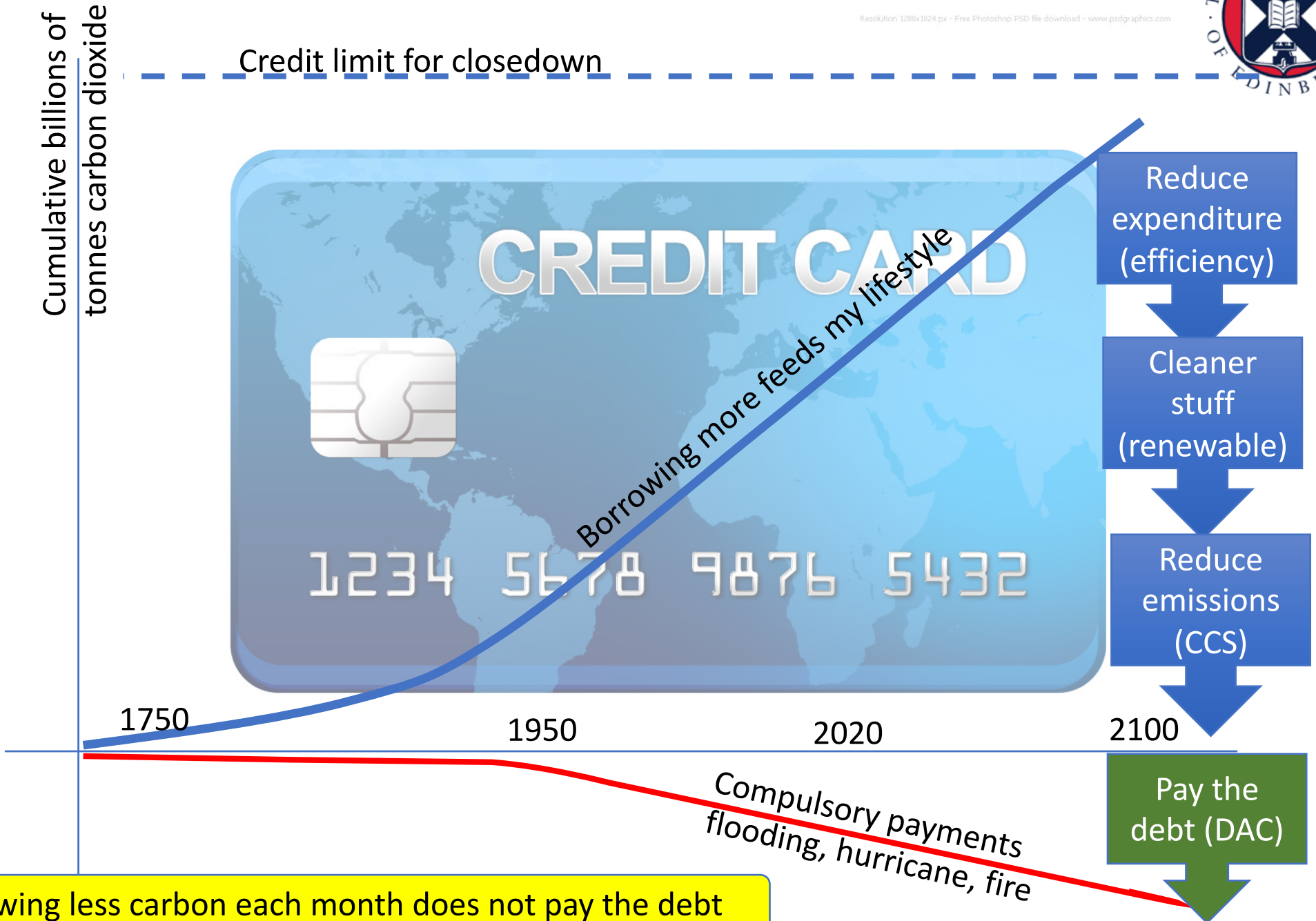
Melting: ice melt, sun reflection, UK Floods



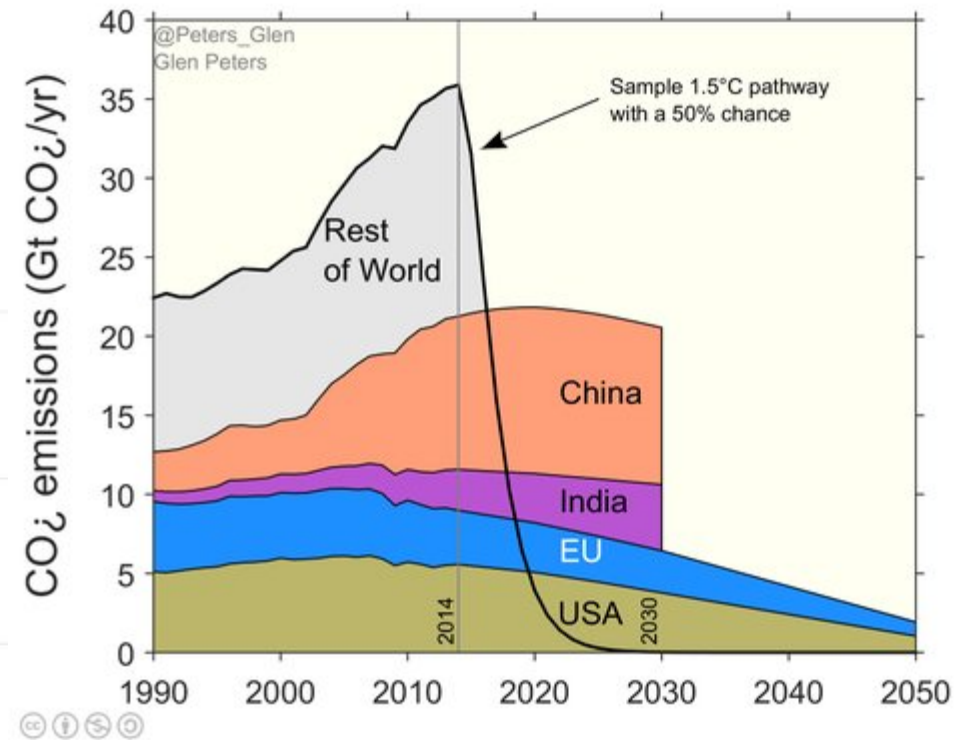
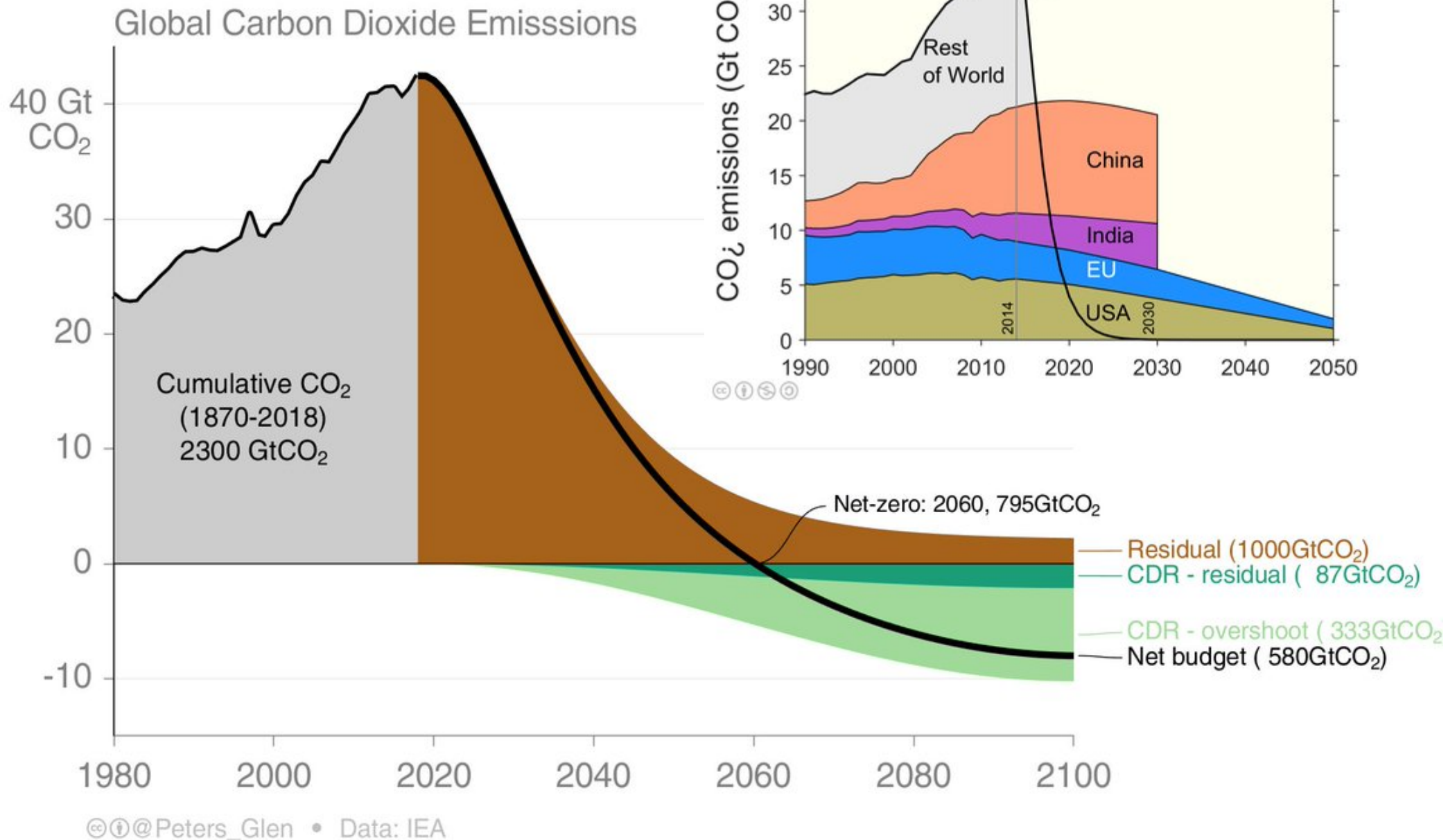
Carbon on credit



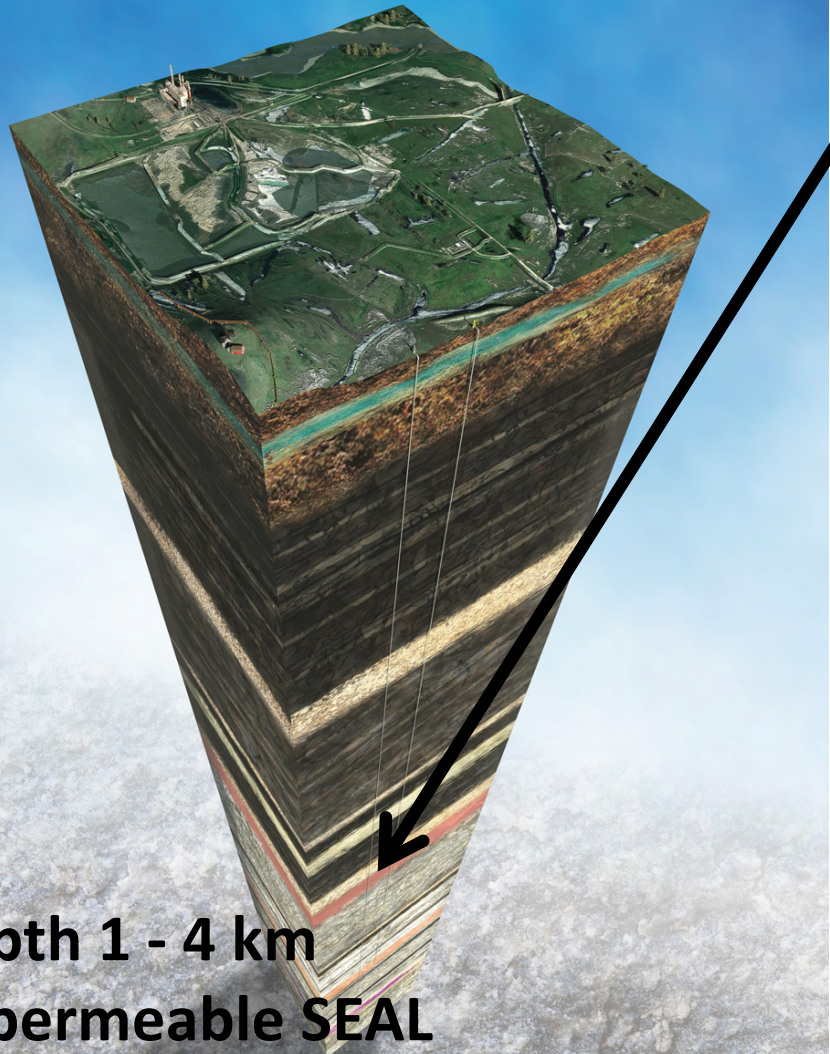
Resolution 1280x1024 px - Free Photoshop PSD file download - www.psdgraphics.com



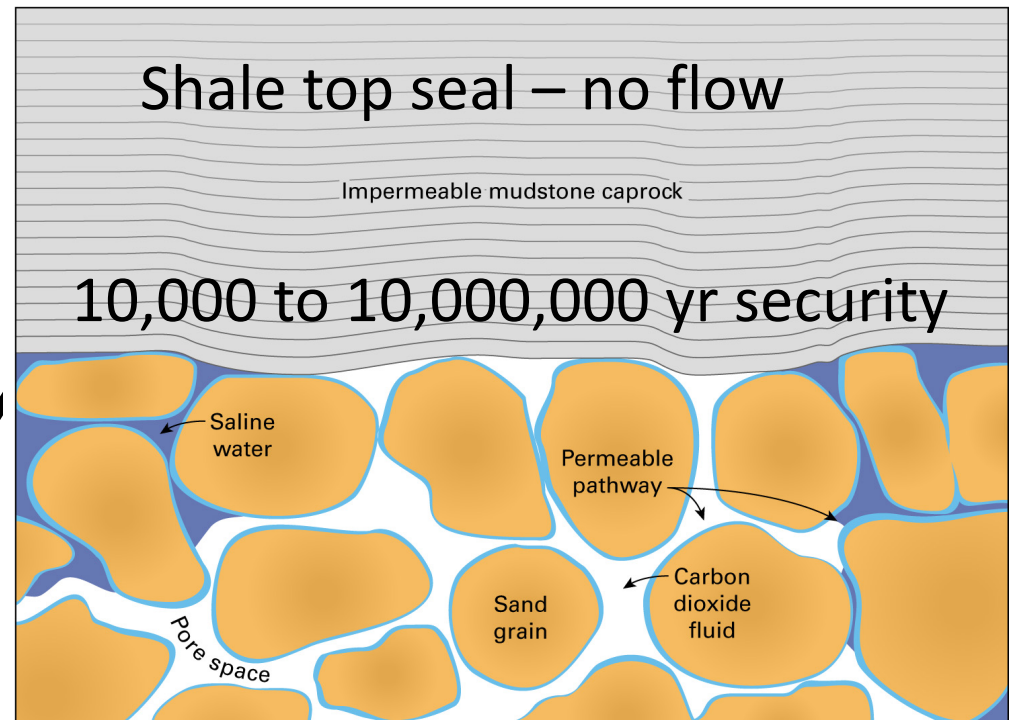
Pathways to Net Zero



CO2 storage is a long way down



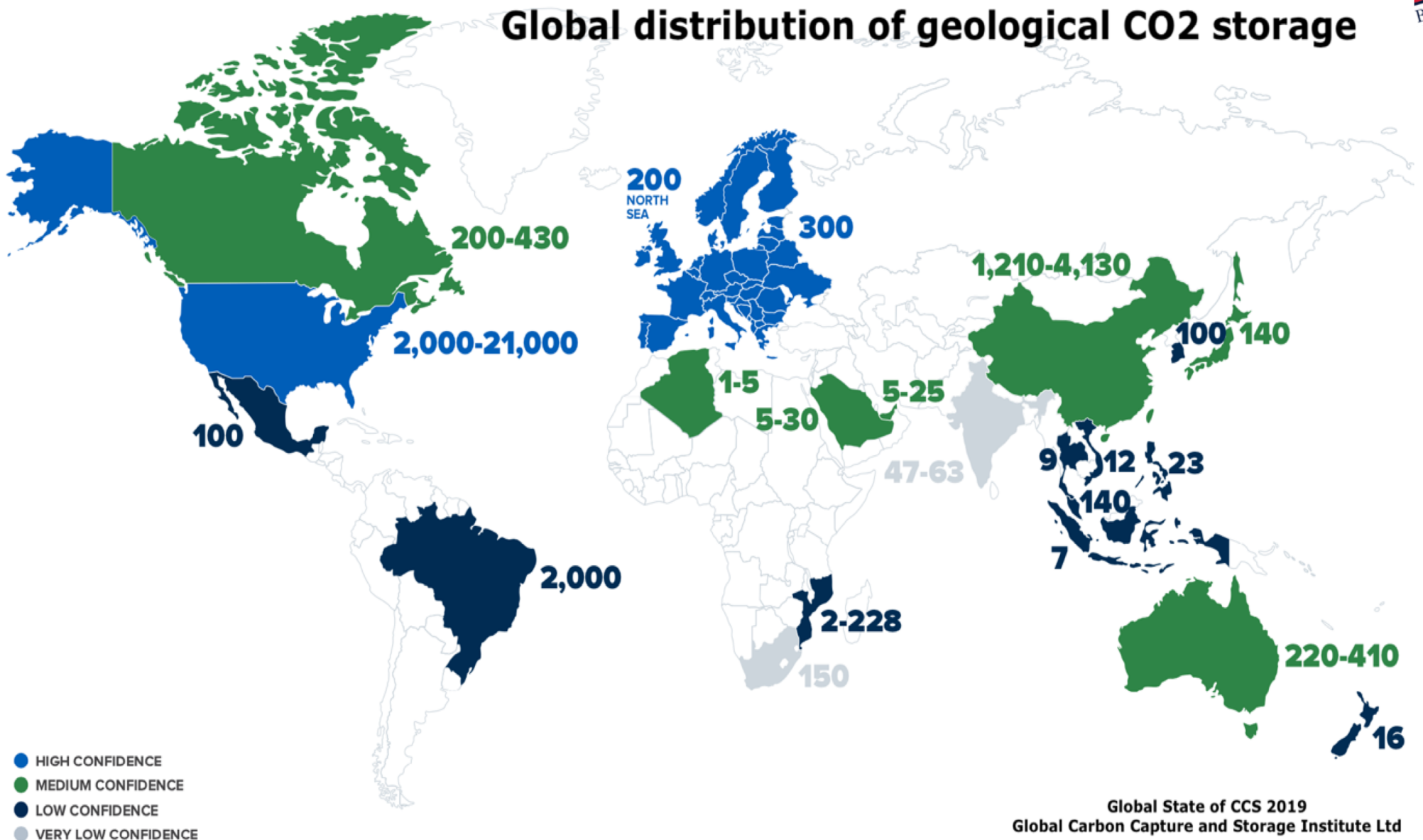
Depth 1 - 4 km
Impermeable SEAL
Overlies
Porous RESERVOIR



© British Geological Survey

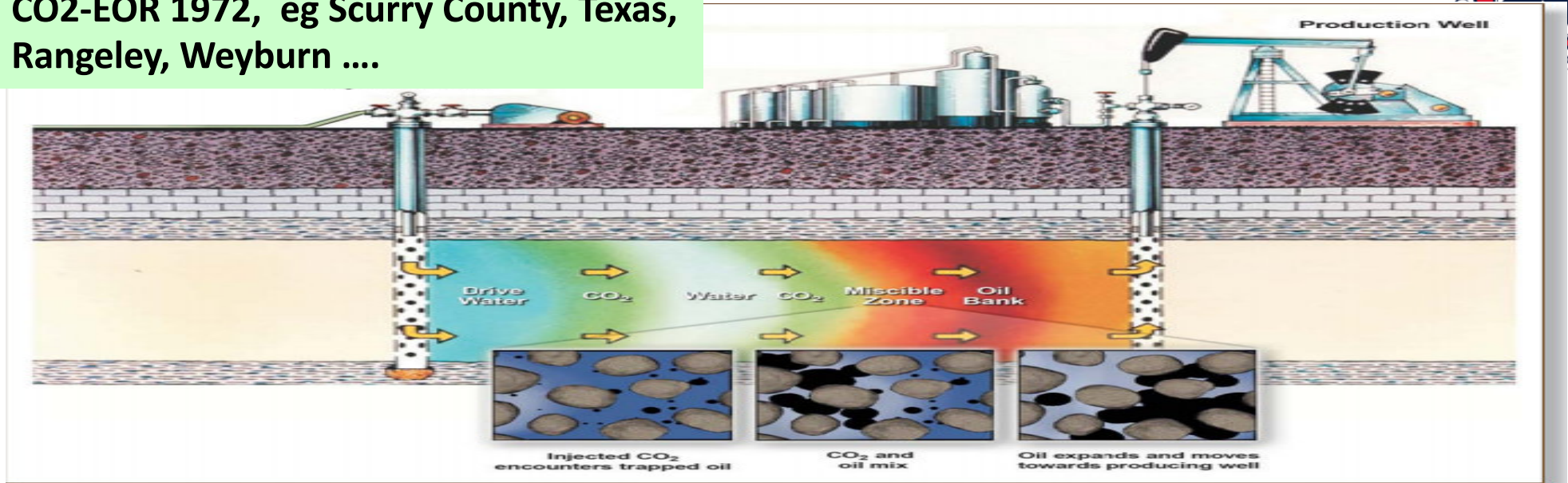


Abundant geological storage



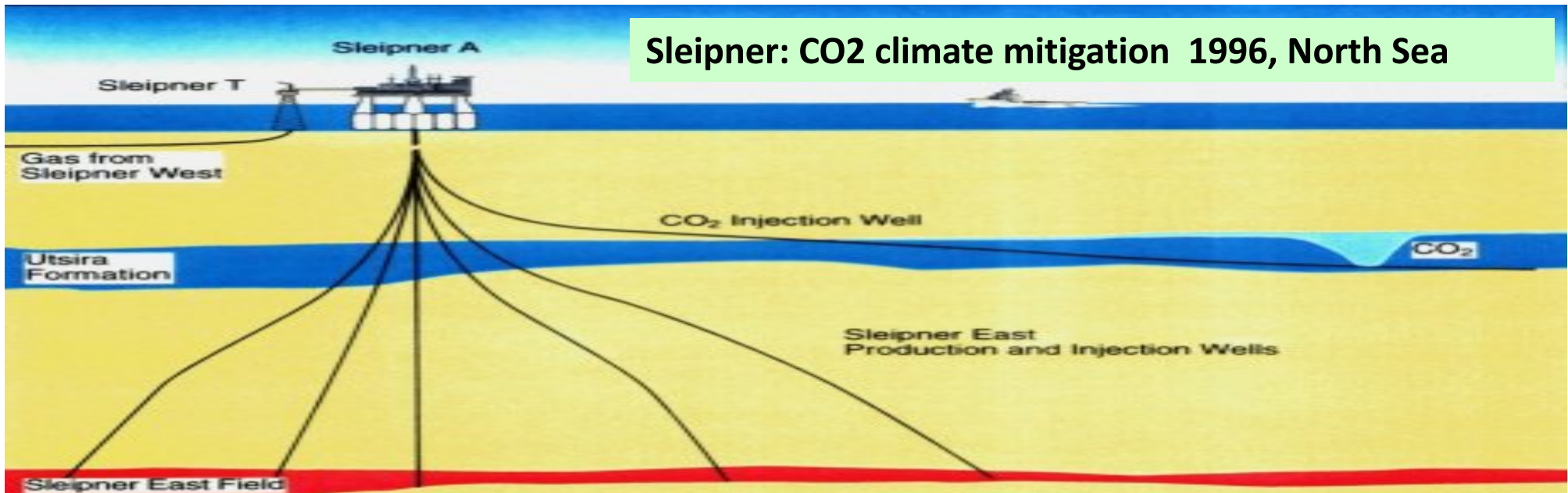
CCS exists : decades of injection & monitoring

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



Cross section illustrates how carbon dioxide 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

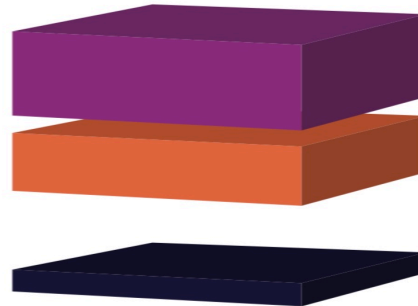


BD 3



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

\$45 /tonne CO2



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

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Valero refinery H₂

Coal: Amine post-combustion

Gases: Pressure swing adsorption



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

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

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

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

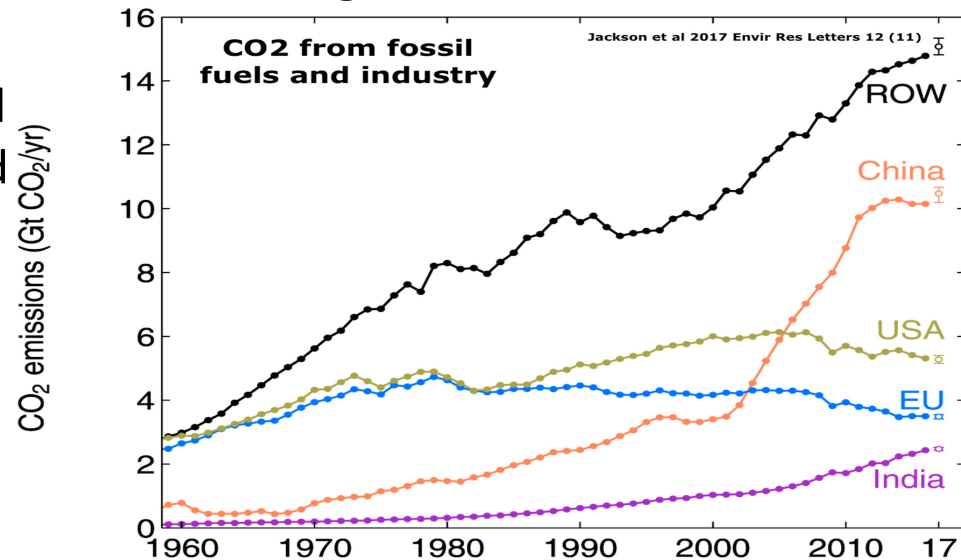
More efficient use of poor quality fuel and easier CO₂ capture : expensive

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

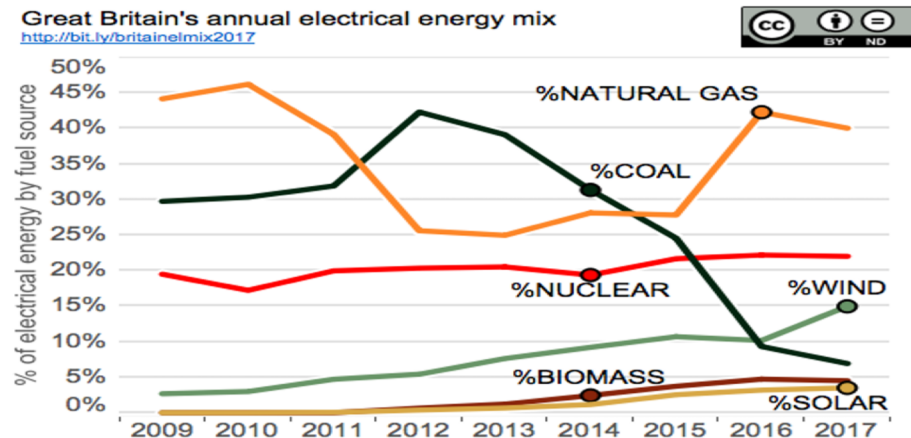
Hydrogen : amine or pressure swing
Cleaner gas mix, level continuous operation, pure CO₂

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](#)

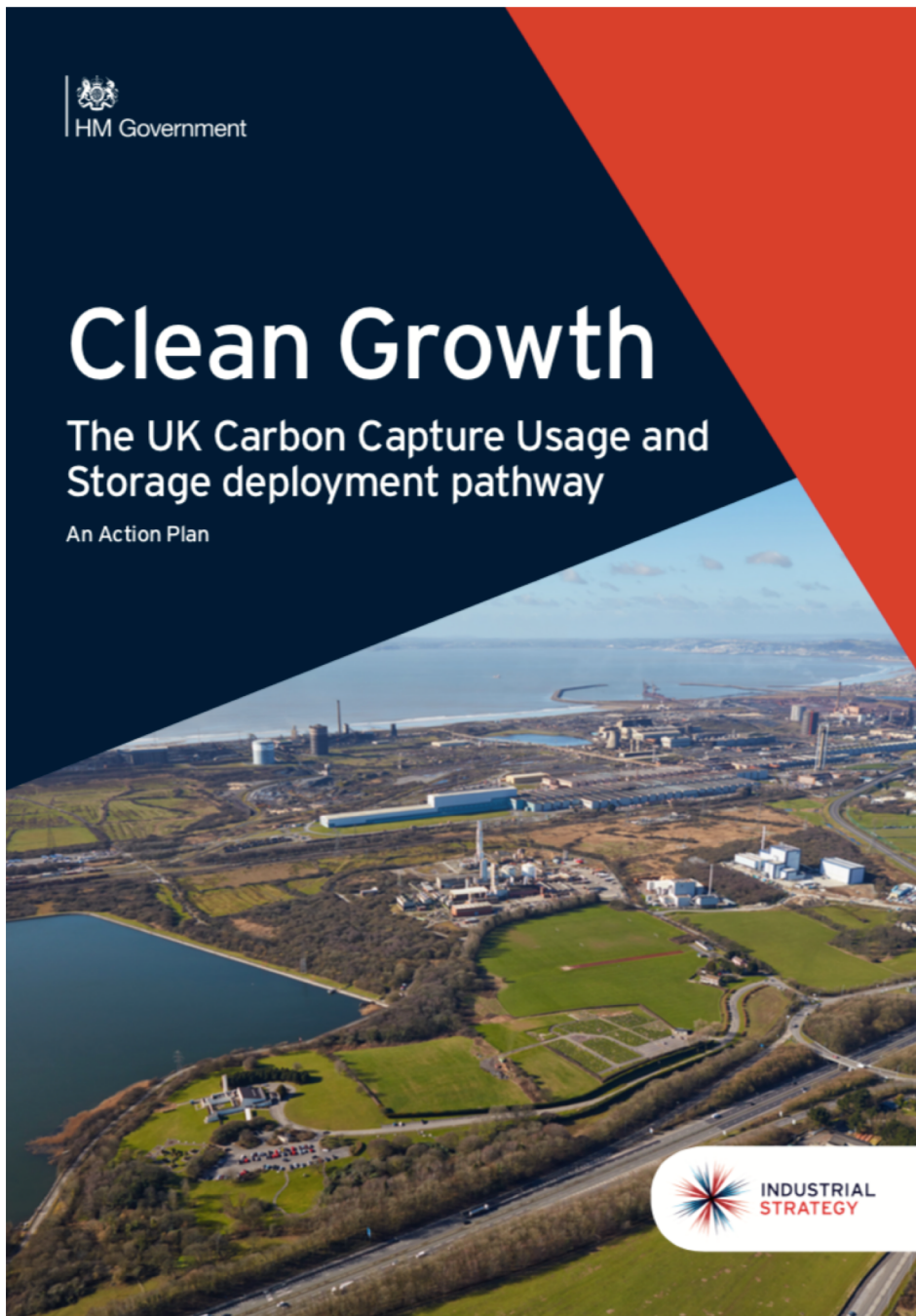
[Scotland's Net Zero Roadmap \(SNZR\)](#)

[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

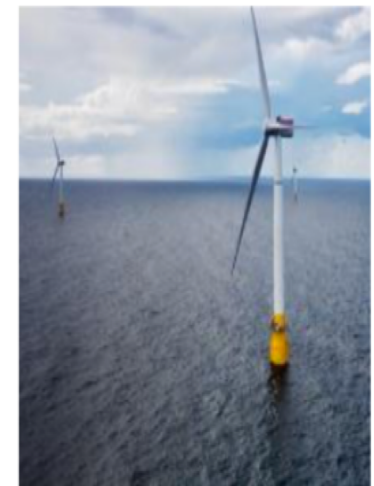
- Steam Methane Reforming
- Electrolysis
- Biomass Gasification
- Hydrogen Storage



Electrification

Low emission energy supply

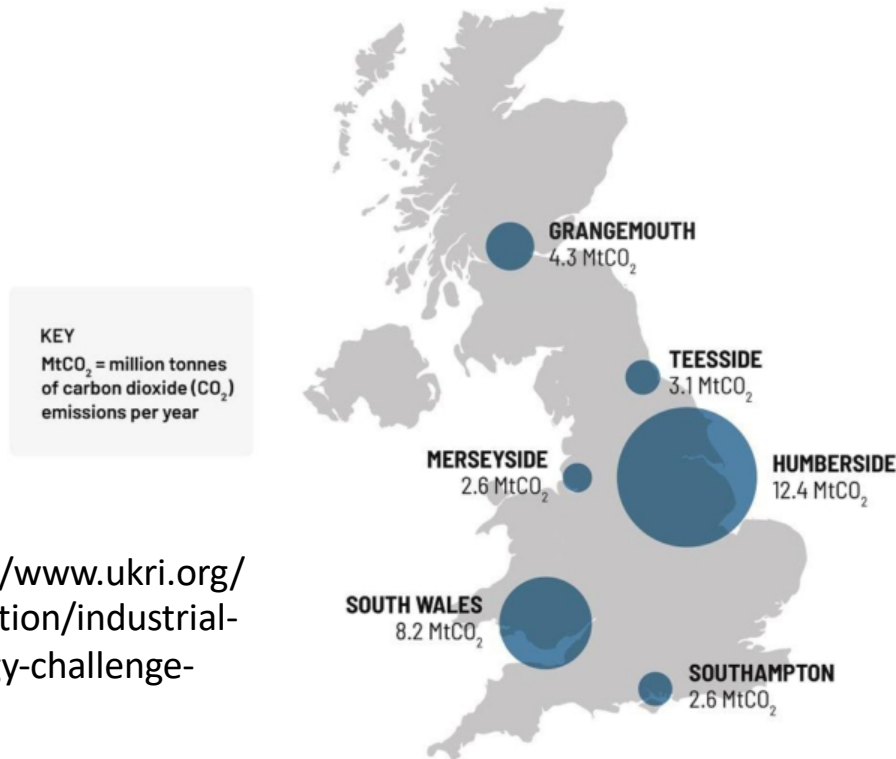
- Energy optimisation
- Renewable Integration
- Connection to Grid
- Energy Storage



UK de-carbonisation and storage



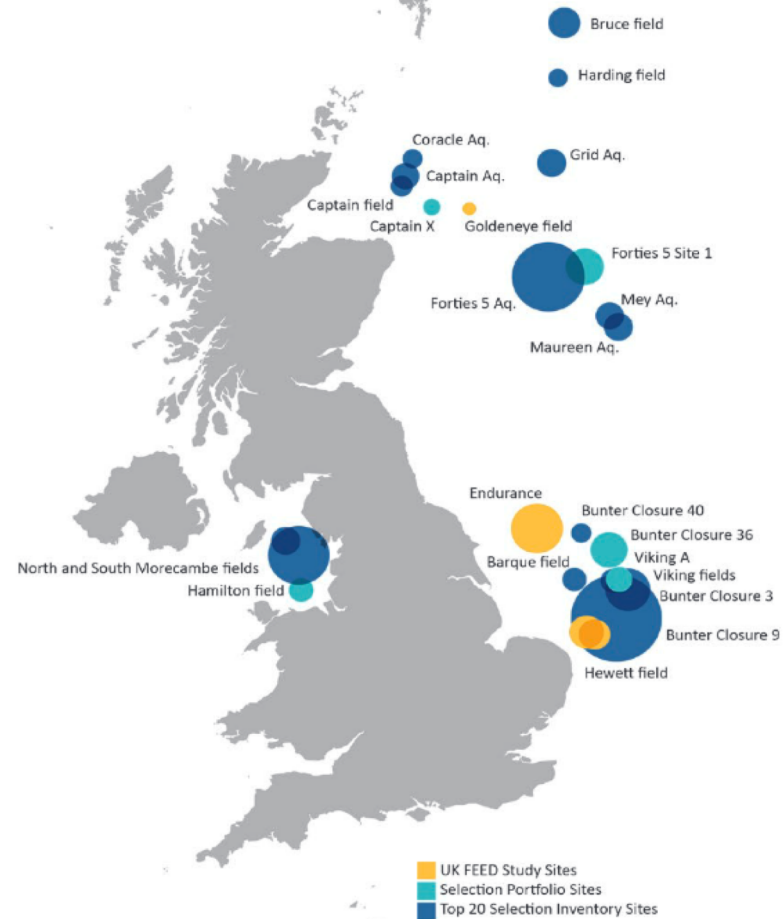
THE UK'S LARGEST CLUSTERS BY INDUSTRIAL EMISSIONS ONLY



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

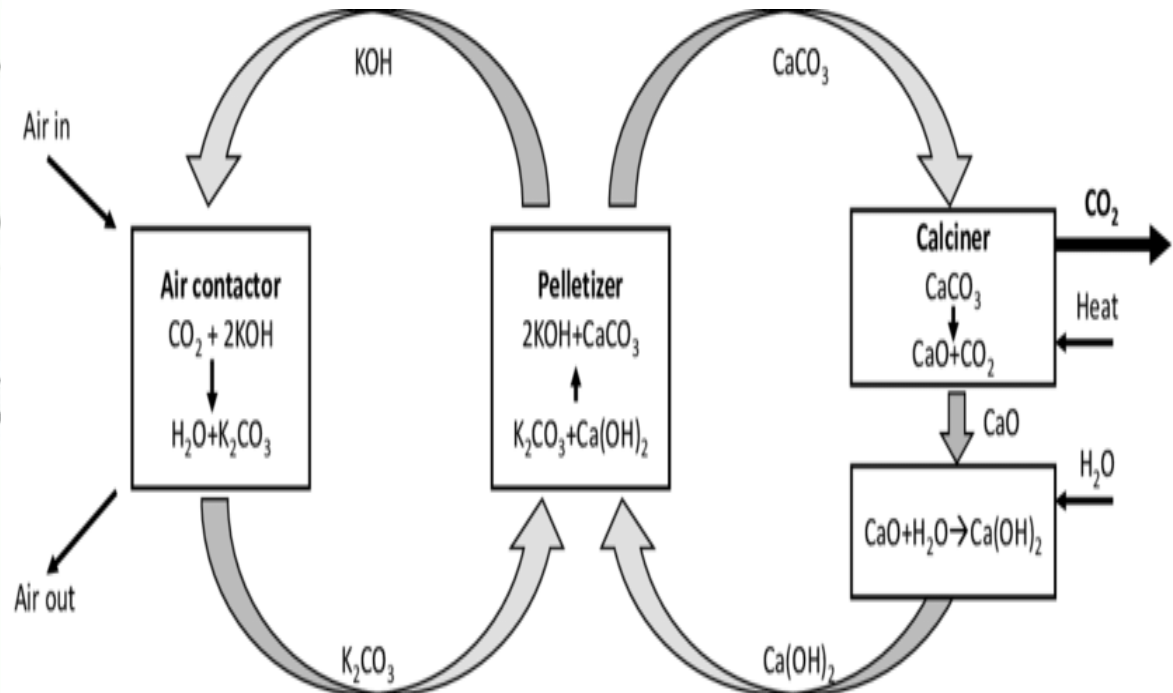
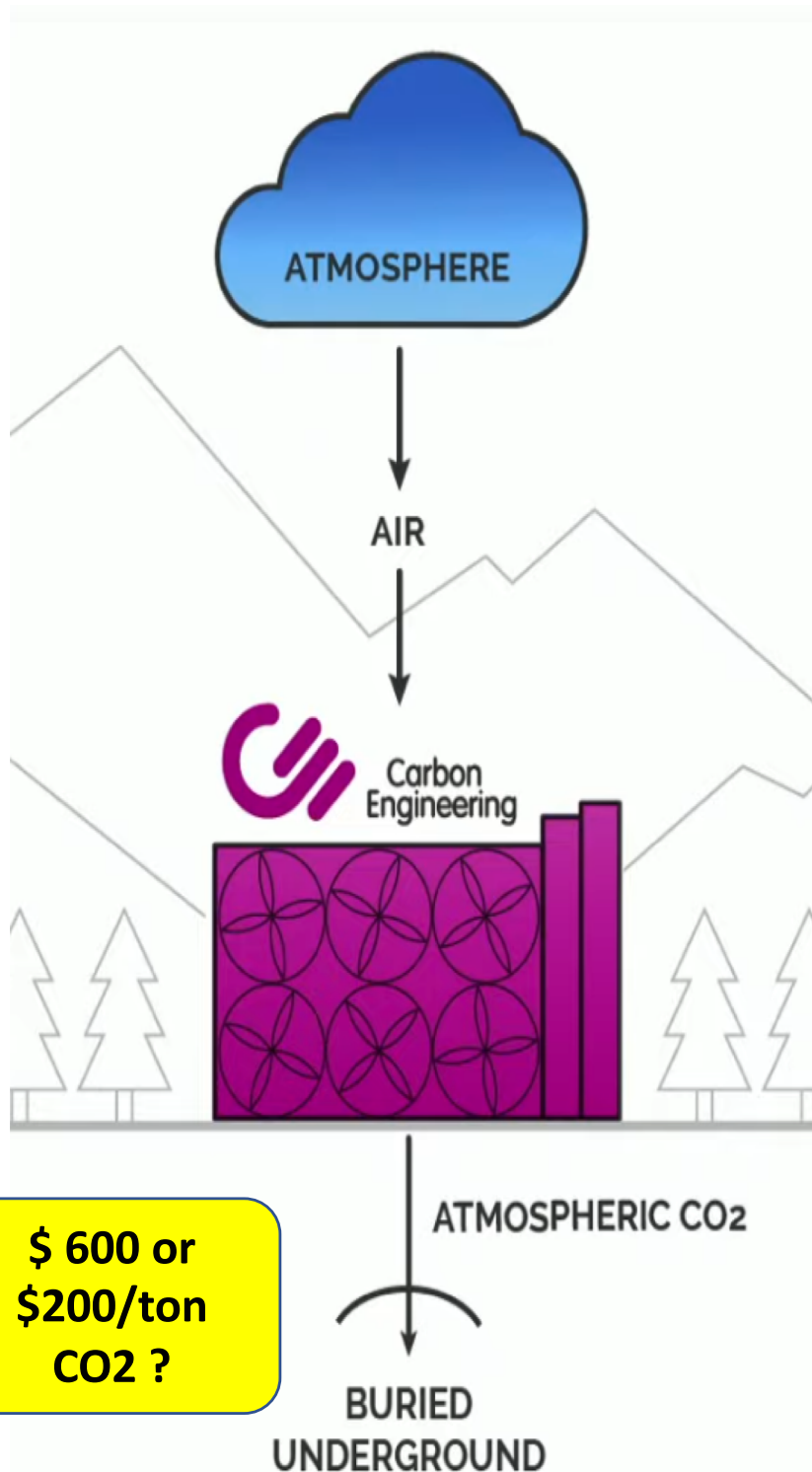
Industrial decarbonization challenge. 6 x clusters 40 Mt/yr CO₂ [Industrial Clusters Mission](#) 1.5 million jobs, annual export goods and services £320 billion Govt **£170 million** from the Industrial Strategy Challenge Fund (ISCF) and will be **matched by £261 million** from industry.

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

DAC: Carbon Engineering



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 ?**

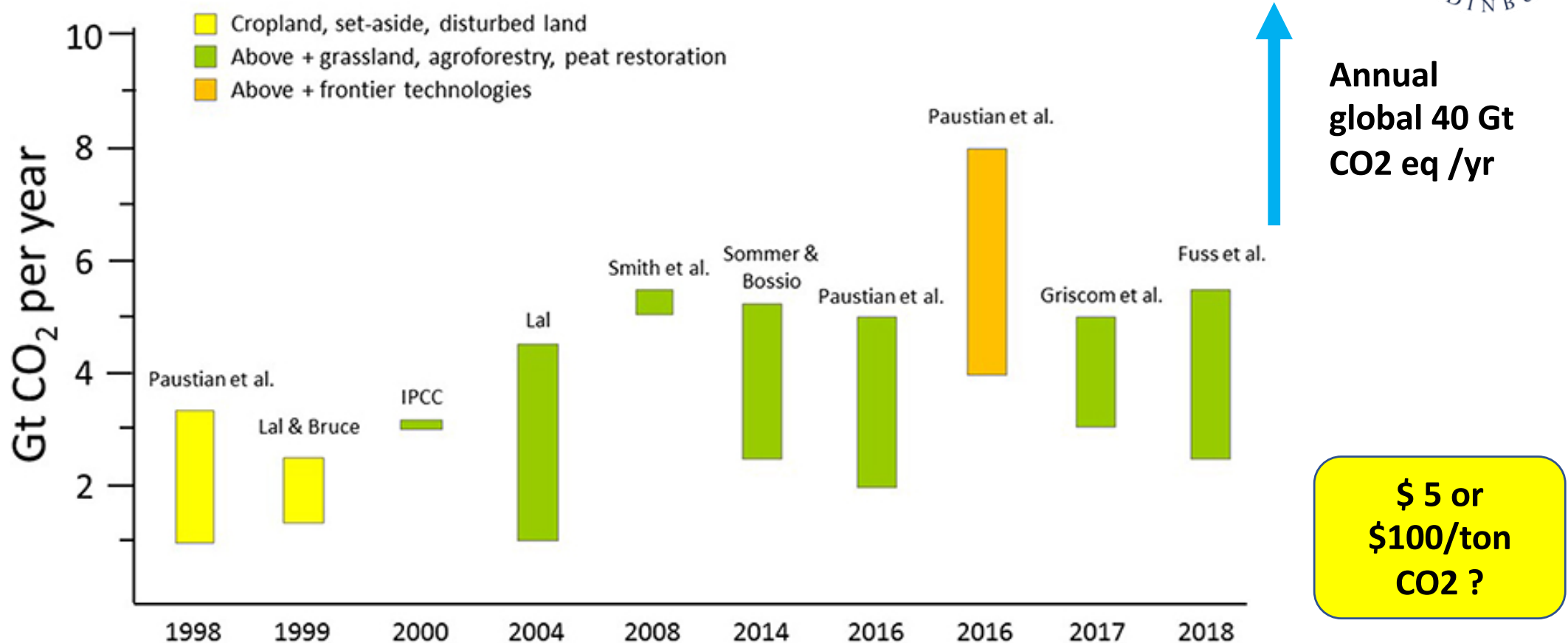
Spinout Univ Greenwich 2006
Employs 90 people, 3 UK plants
£ 15 M /year turnover
Makes 300,000 tonne/year aggregate
LCA - carbon negative

Waste based Accelerated CO2 Utilisation



Bumps and potholes ahead

Size scale - materiality. E.g. soil



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

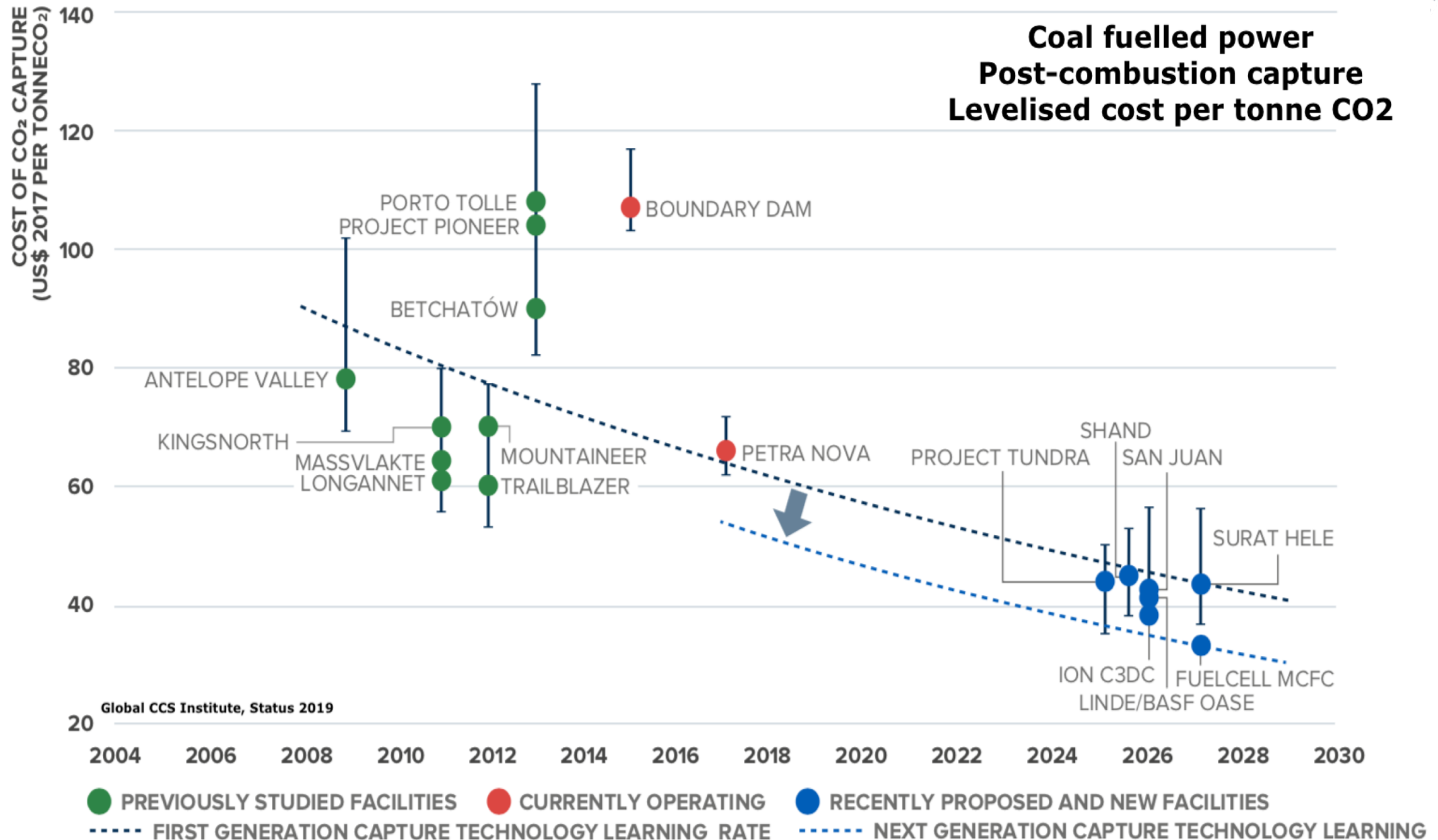
Total CO2 emissions from coal-fired power plants, 2018

10bn tonnes

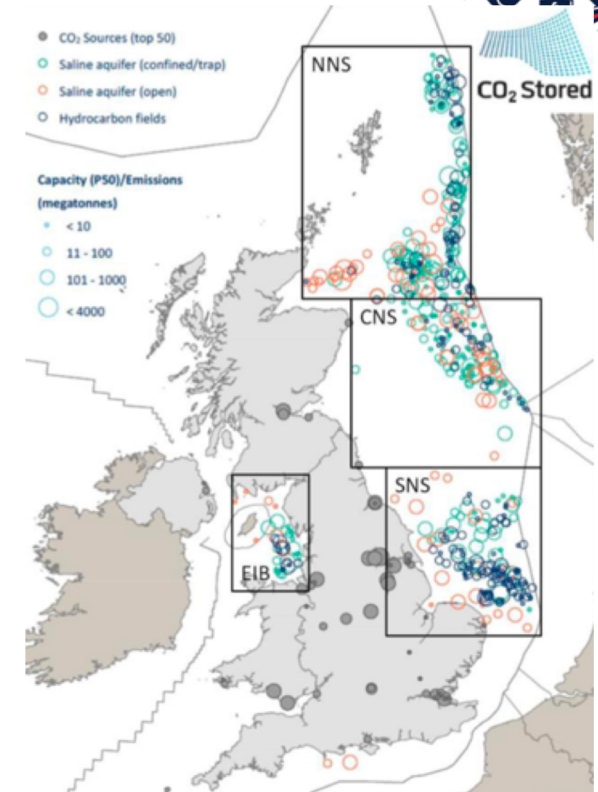
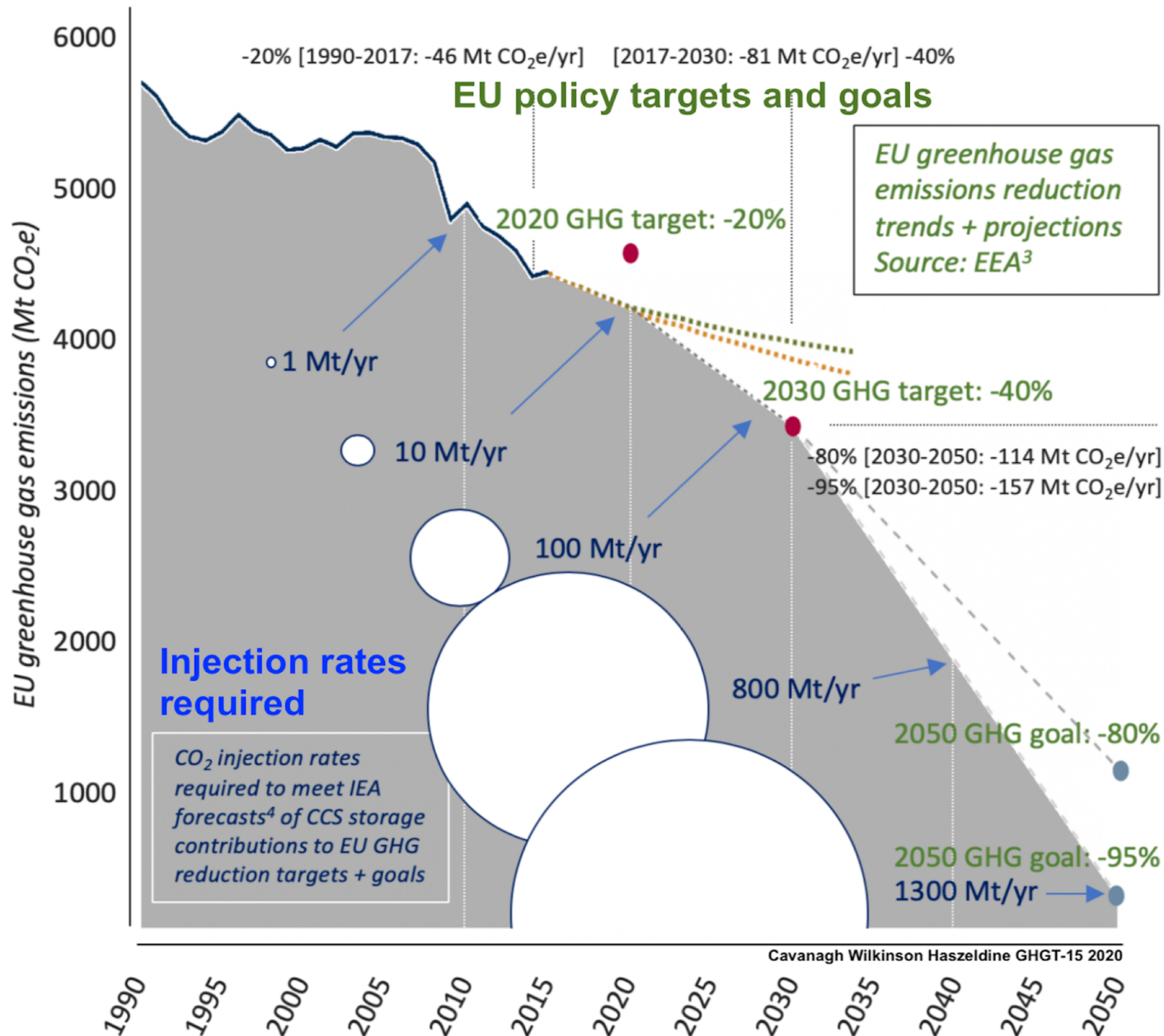
How ready and proven is coal-based CCS ?

Sources: SaskPower; IEA
© FT

Cost reduction pathways for CCS

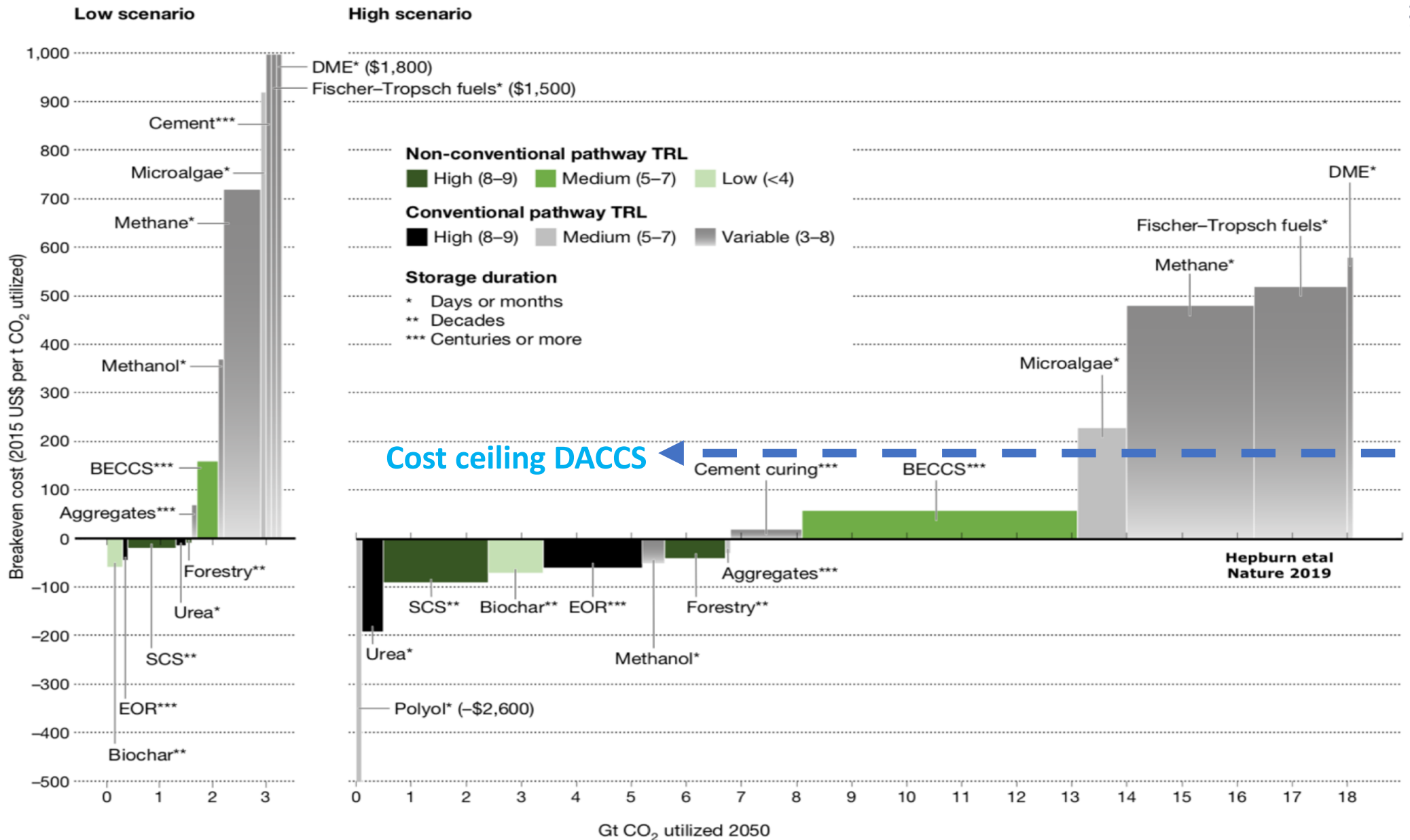


Scaling up EU CO2 storage 2000 - 2050



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

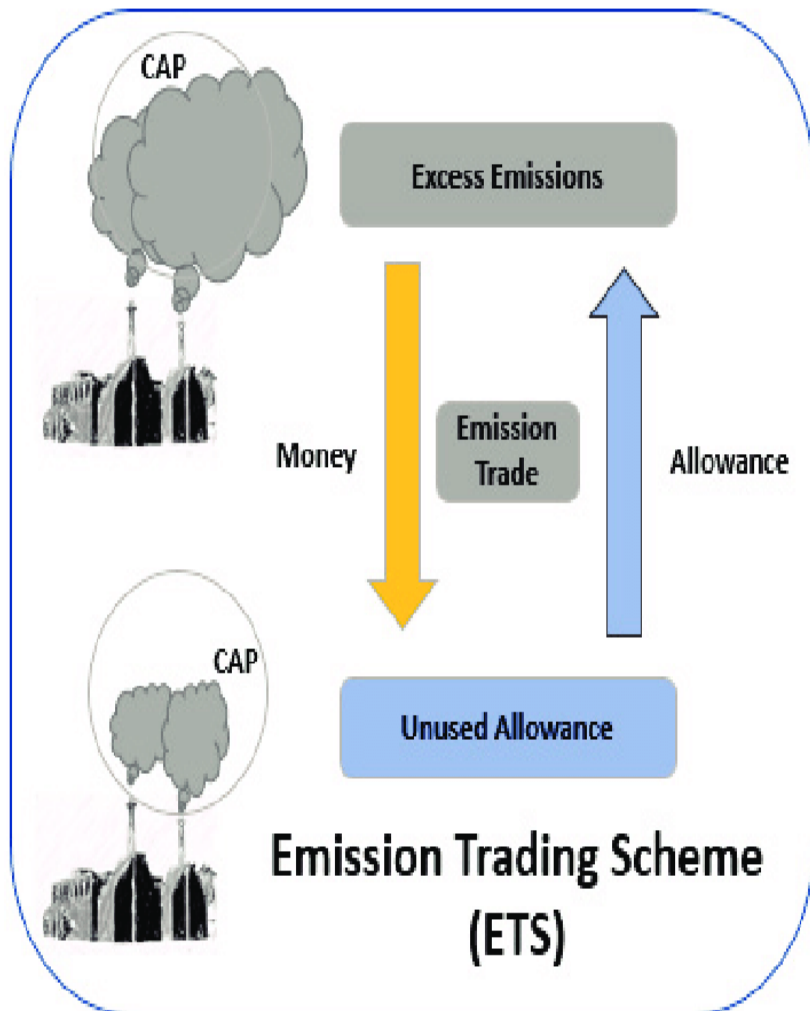
Regulated Asset Base model

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



Well, it's a start

Europe, price per permit to emit one tonne of CO₂
€



Source: Ember

The Economist

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

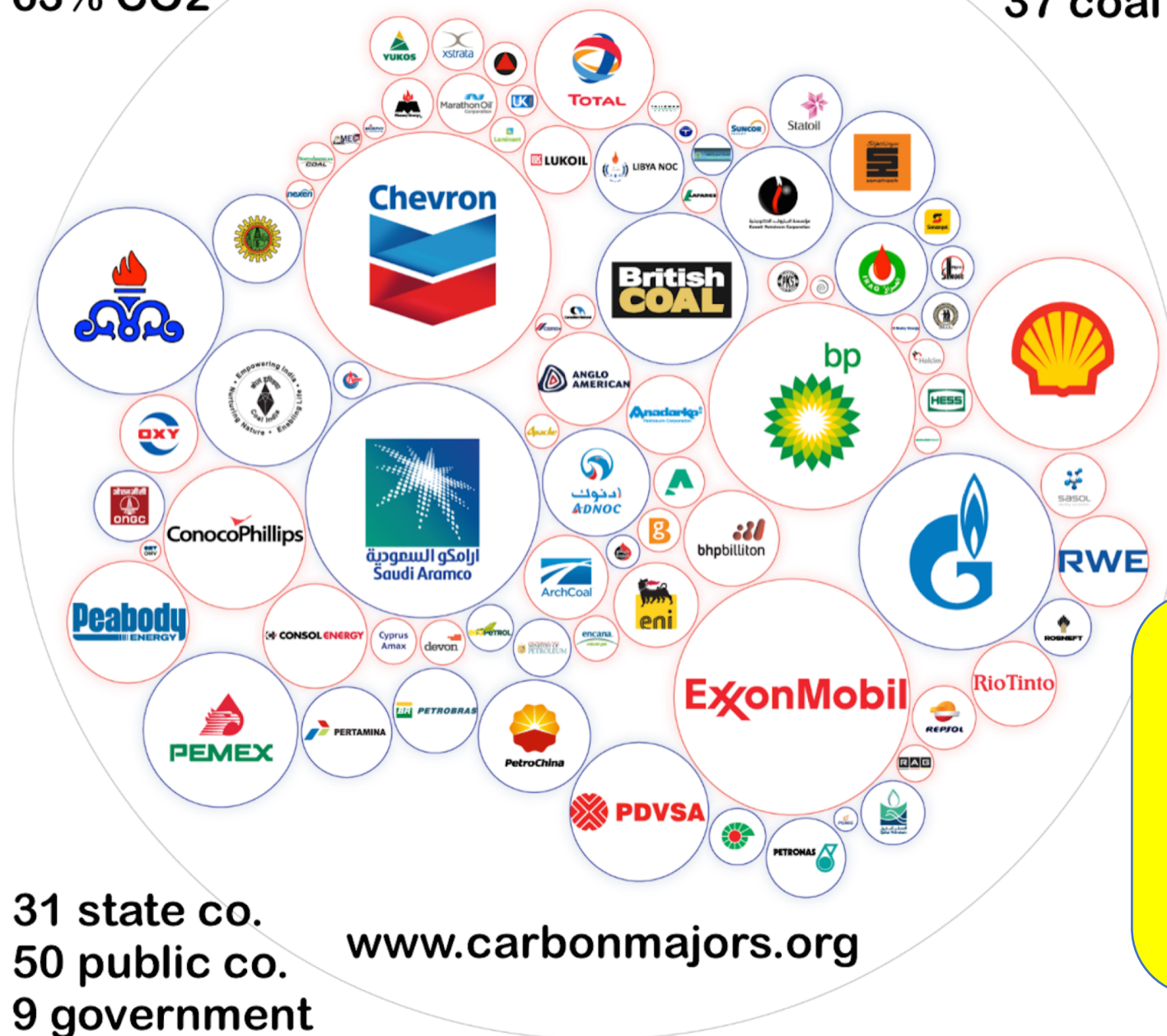
**Treating the symptoms (emissions)
Or tackling the causes (vaccinations)**

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

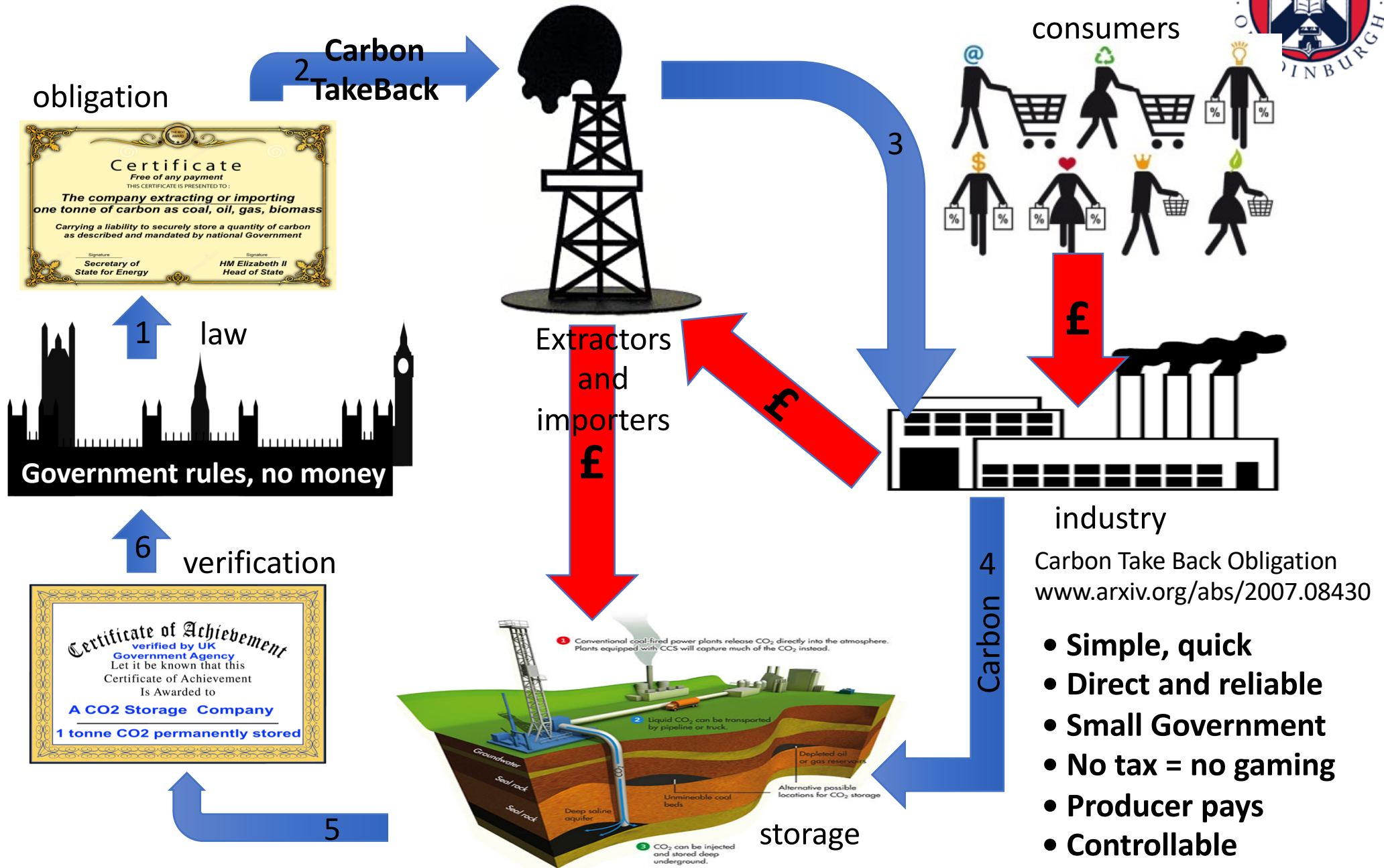


Allen, Haszeldine,
Hepburn,
Certificates for
CCS at reduced
public cost:
Energy Bill 2015
<http://hdl.handle.net/1842/15698>

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



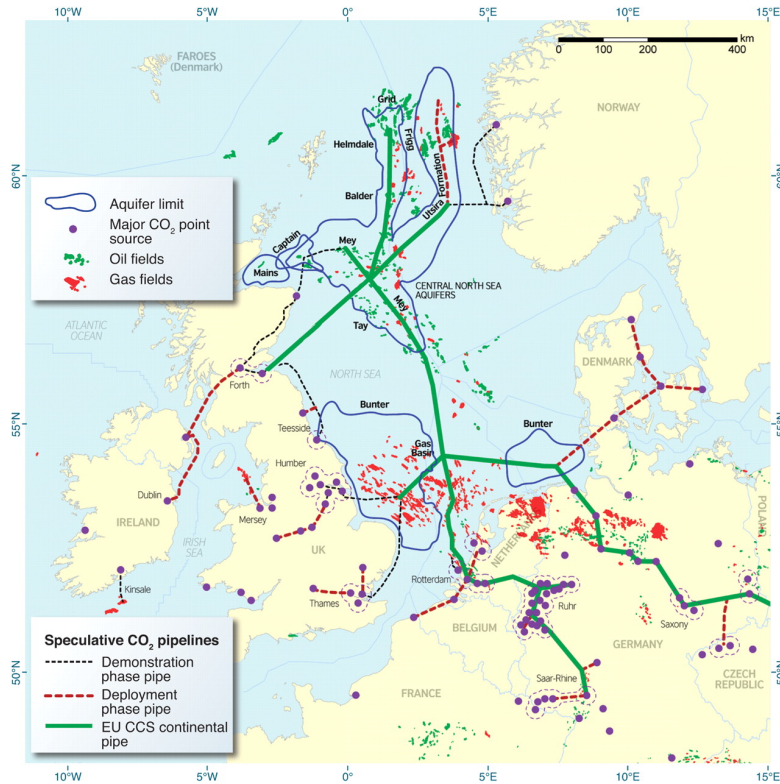
Carbon Take Back Obligation
www.arxiv.org/abs/2007.08430

- Simple, quick
- Direct and reliable
- Small Government
- No tax = no gaming
- Producer pays
- Controllable

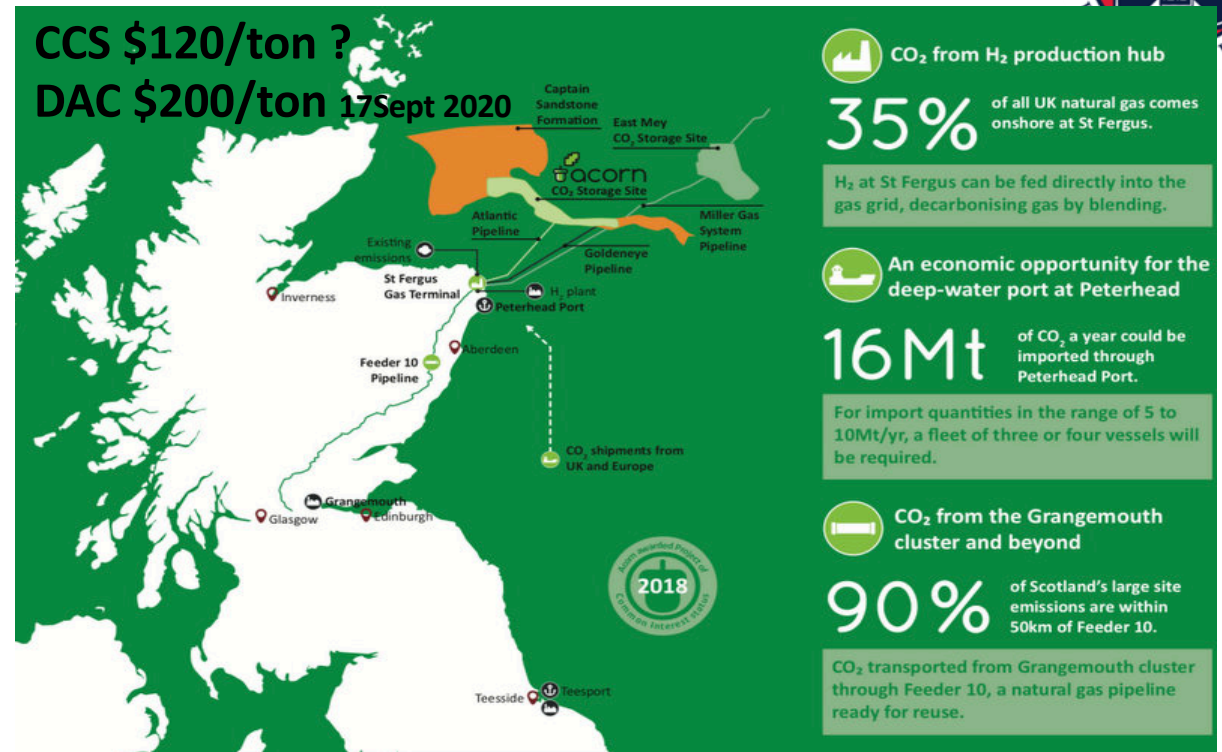
Example projects



Acorn North Sea CO2 : pipes & ships



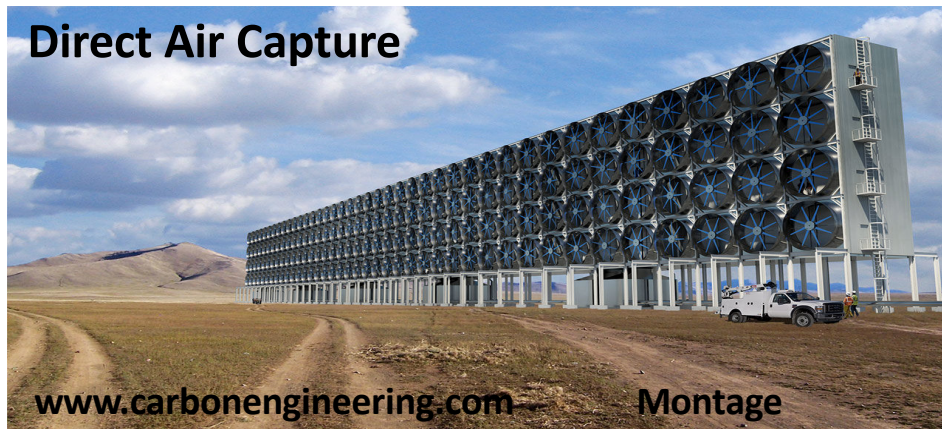
Haszeldine 2009 *Science*, 325, 1647-1652.



www.pale-blu.com/acorn/

Rapid, low cost, re-uses existing pipes

Direct Air Capture



www.carbonengineering.com

Montage



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Net Zero and beyond Oxford Energy 1Dec2020

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