Carbon Capture and Storage
Is it safe ? Will it work ?

Giles Watts
Feb 2023

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- What is CCS / CCUS ?
- What happens in the subsurface ?
- Case Examples
- What is the Status in the UK
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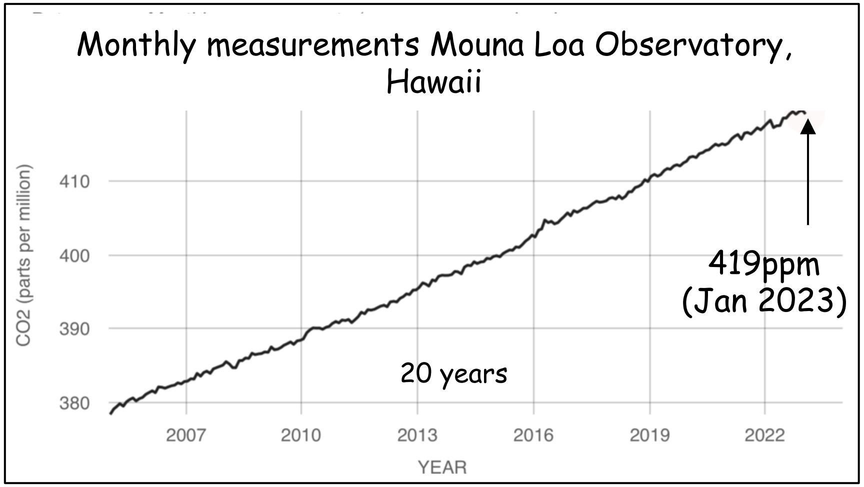
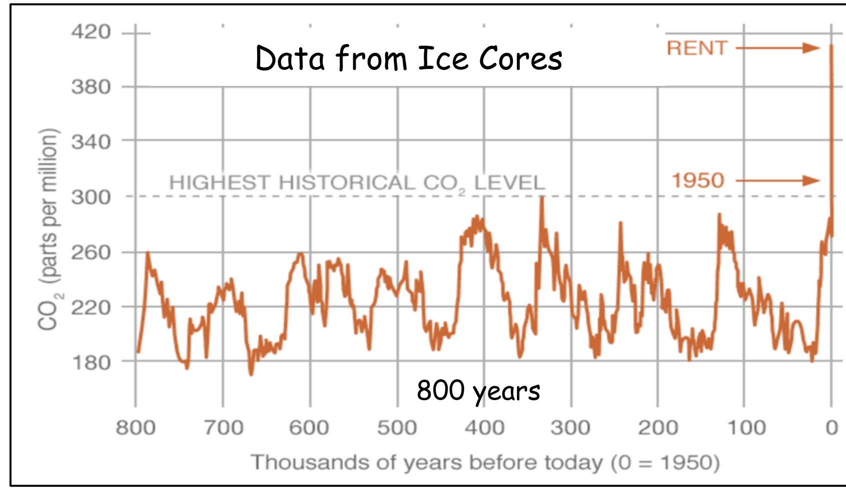
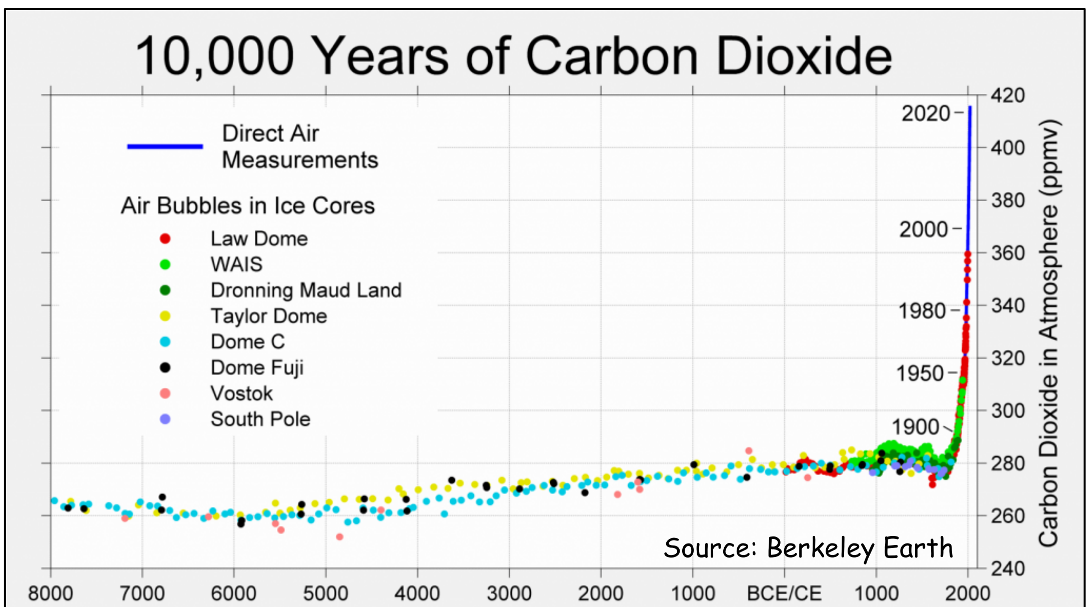
CO2 Emissions



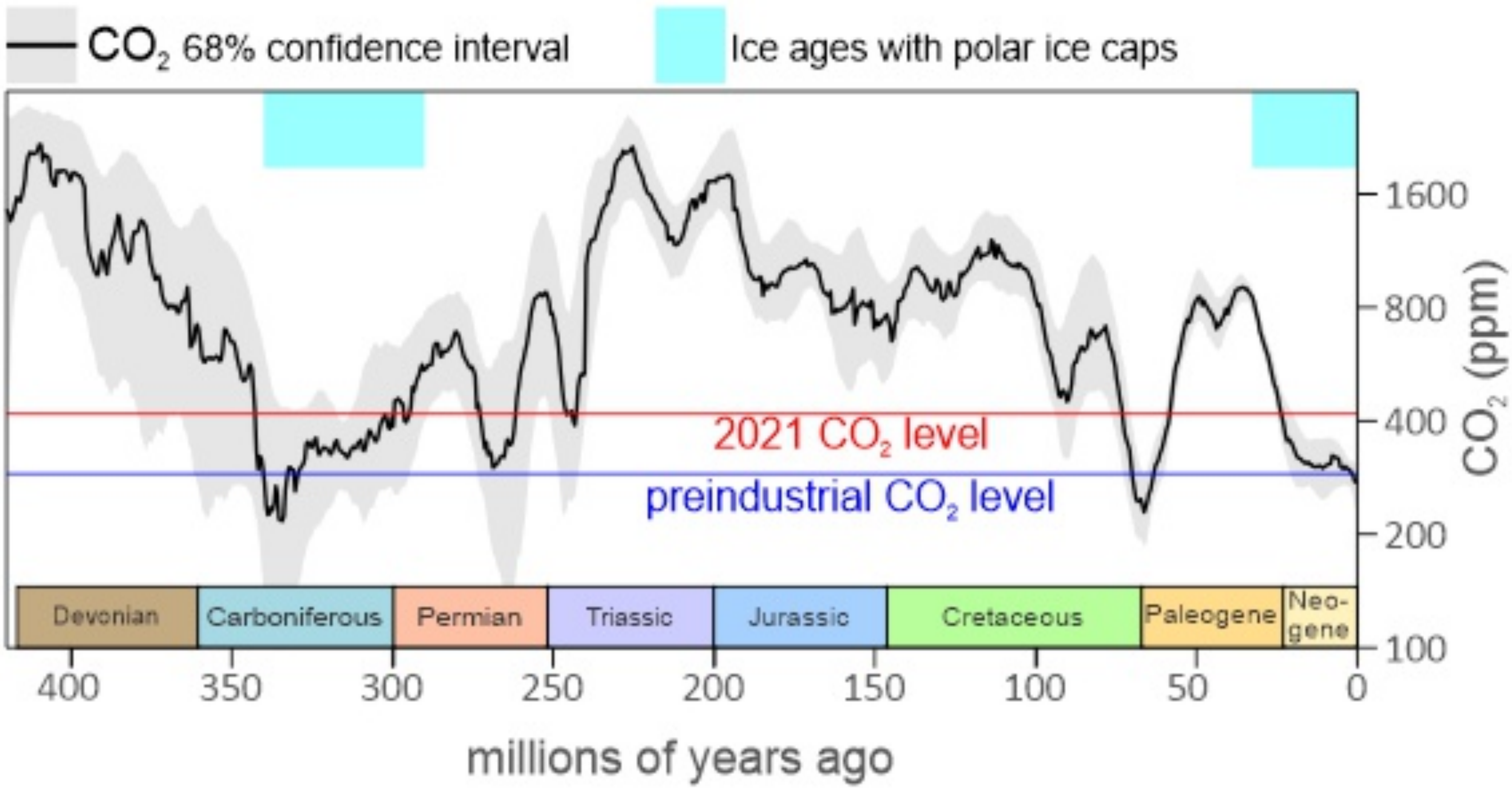


Source: National Oceanic and Atmospheric Administration (NOAA)



- CO2 in the atmosphere warms the planet causing climate change
- Human activities have raised levels by 50% in the last 200 years and they continue to rise
- Most CO2 is from the burning of fossil fuels

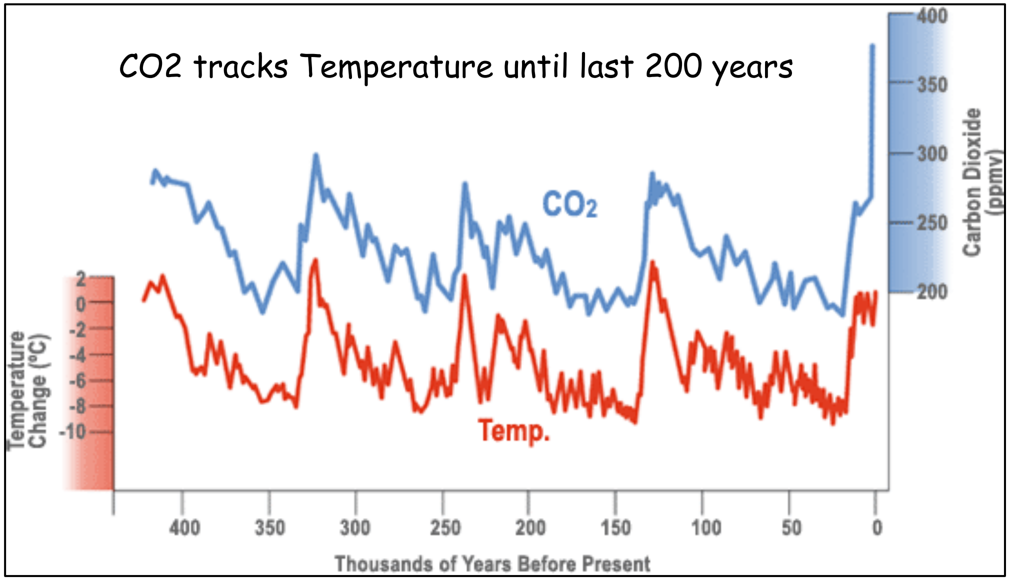
Global Temperature and Atmospheric CO2 over Geologic Time



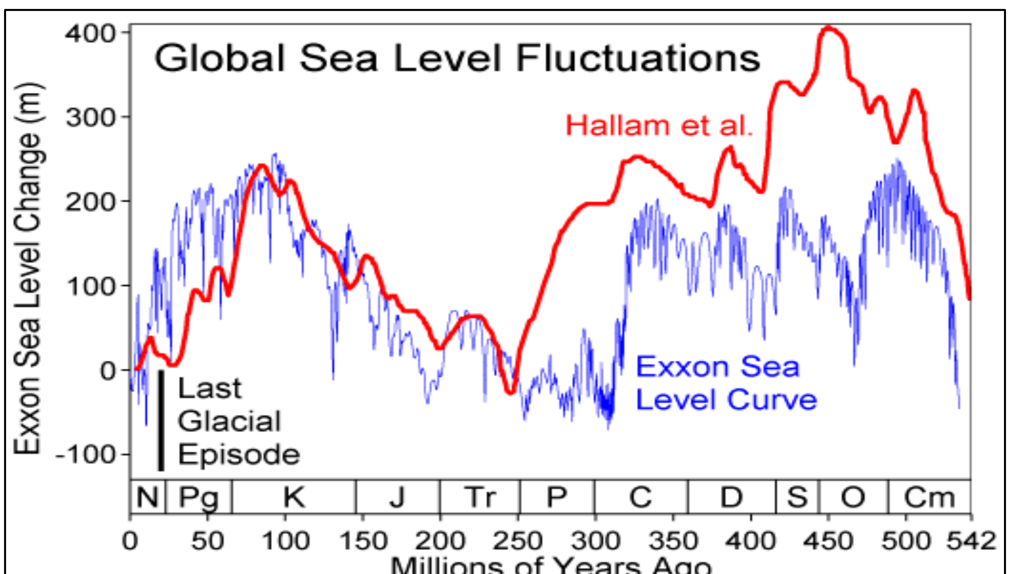
Even more extreme in the distant past

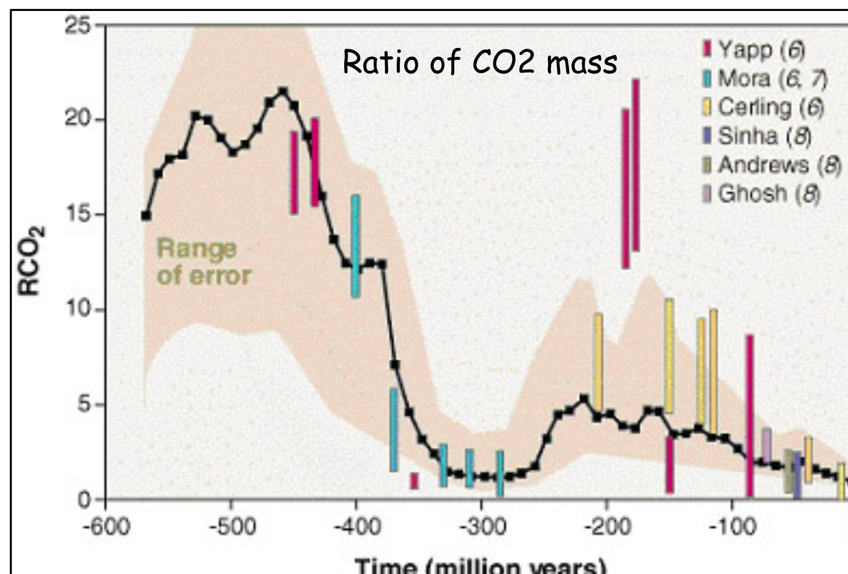
- 7000ppm (x18) in Cambrian
- 4400ppm (x12) in Late Ordovician (also an ice age)

Climate Change



- Huge decrease in CO2 levels during geologic time due to plants
- Huge increase in CO2 since 1800 from 270 to 419ppm
- Plant growth strongly affected below 200ppm
- If all sea ice melts oceans will rise by about 120m – not seen since the Eocene





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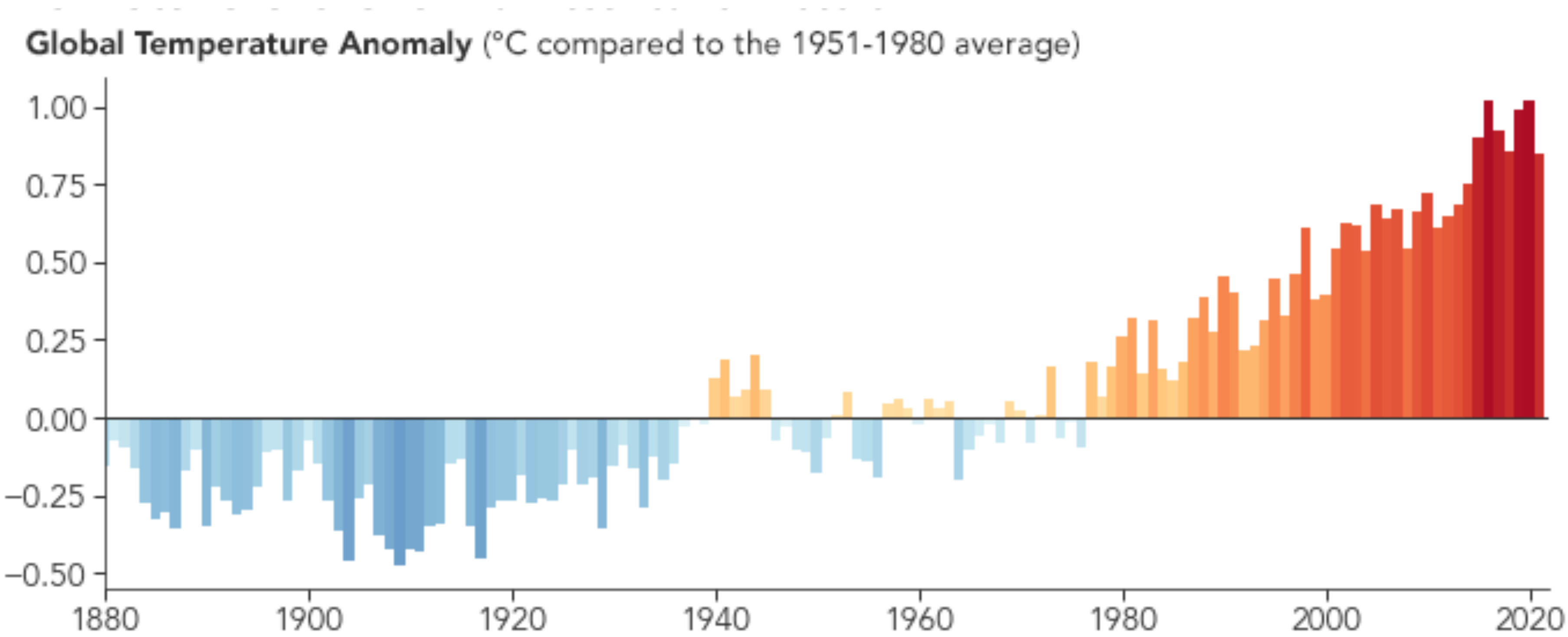
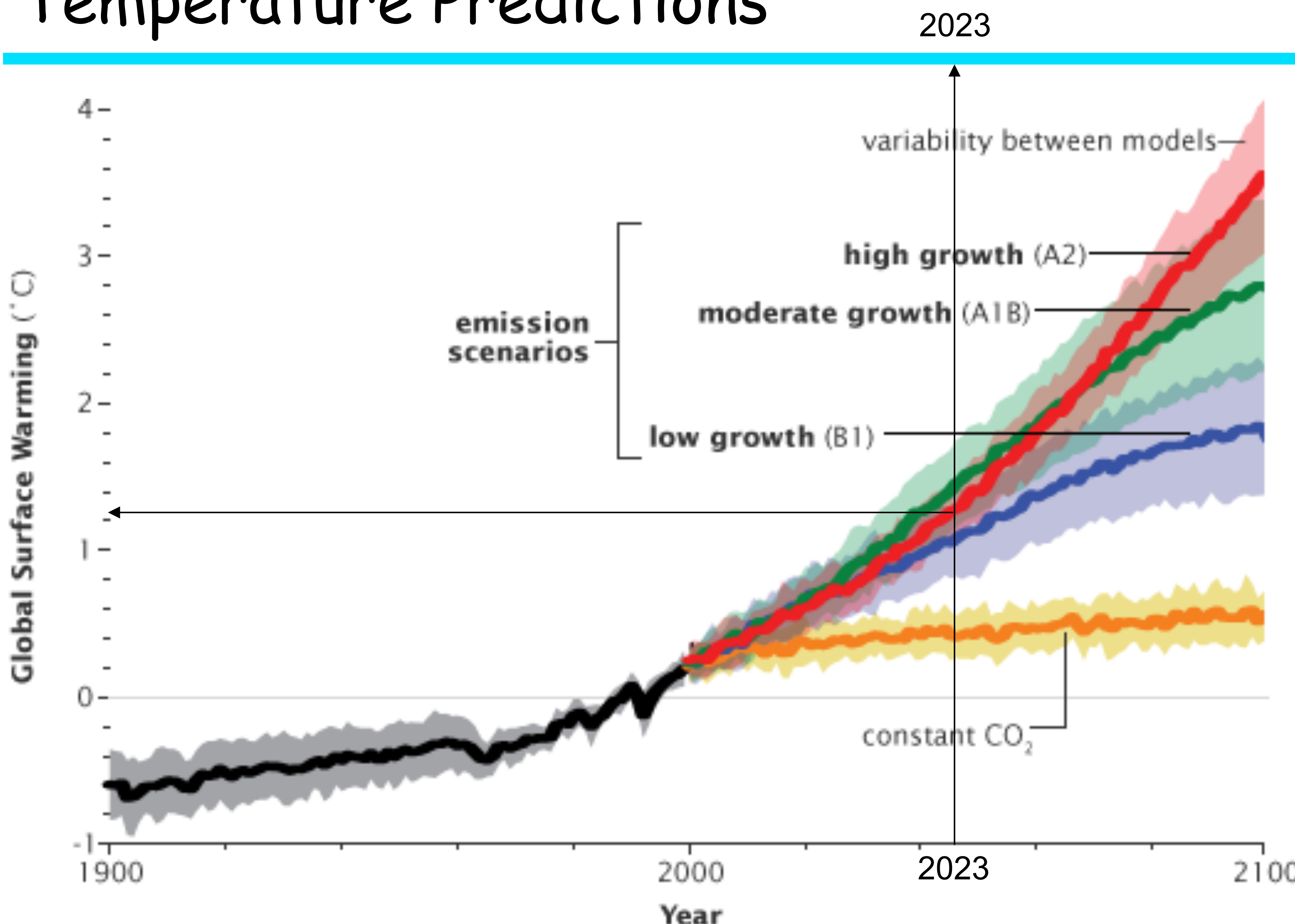
Global Temperature Changes



Earth in 2021 was about 1.1°C (1.9°F) warmer than it was in the late 19th century,

Source: NASA Earth Observatory

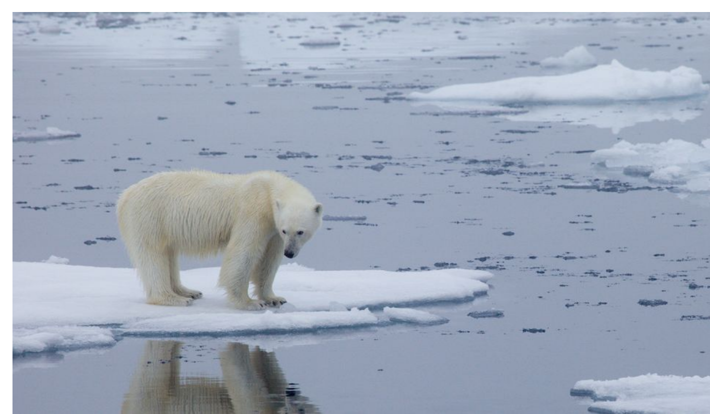
Temperature Predictions



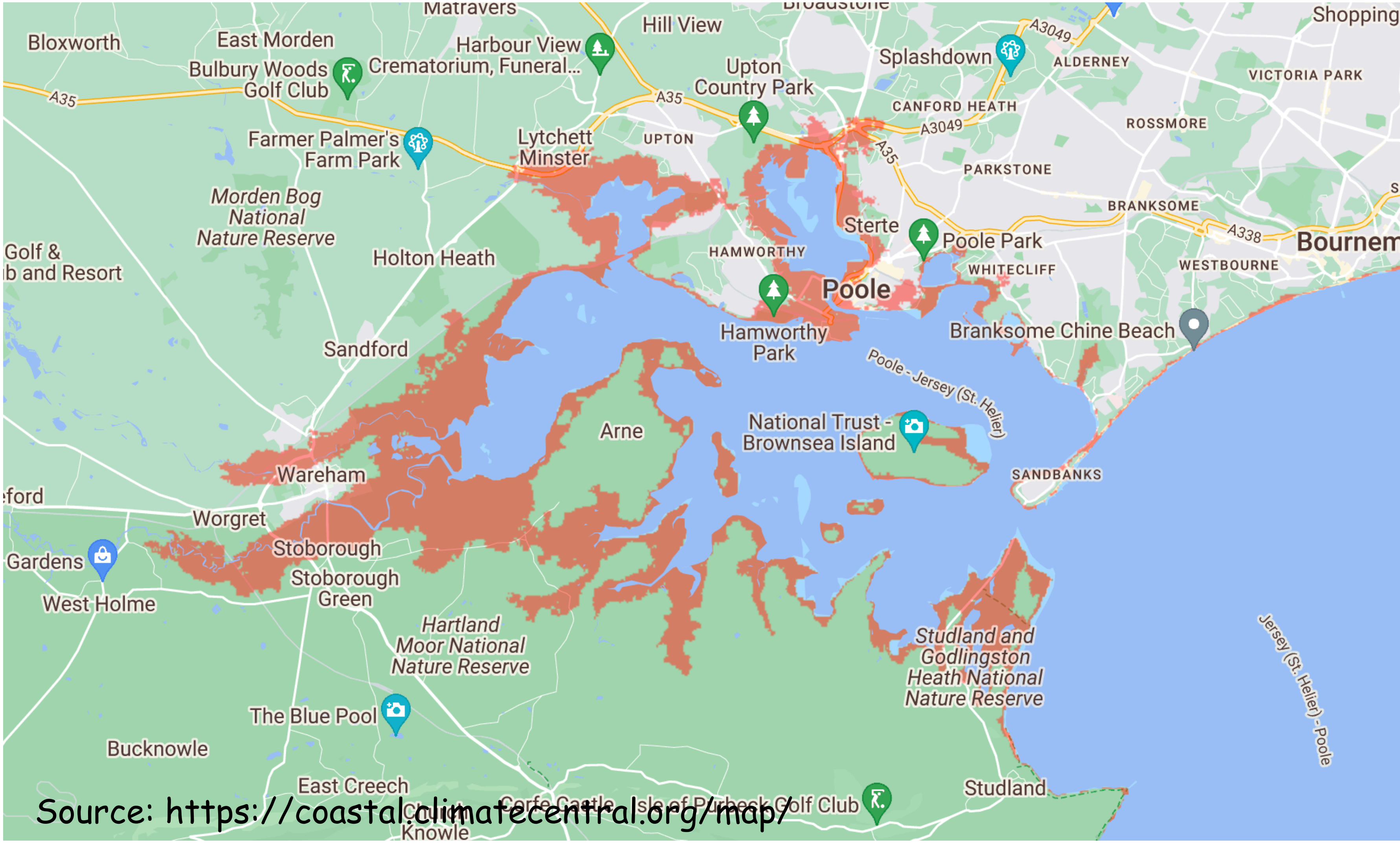
Source: IPCC (2007)

Consequences of Global Warming

- Warming Atmosphere
  - Dangerous weather events more common and more intense
  - More frequent and intense drought
  - Violent Storms, 1-in-1000 year wave heights
  - Heat waves
- Warming Land and Seas
  - Warming oceans
  - Rising sea levels
  - Melting glaciers, loss of ice
- Destruction of habitats
  - Bleaching of sea corals
  - Direct harm to animals
- Impact on People
  - Wreak havoc on people's livelihoods and communities.
  - Access to Water
  - Loss of Ocean Atolls
  - Eco Fairness



Land Projected to be Below Annual Flood Level in 2050



Source: https://coastal.climatecentral.org/map/

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International Agreements

- Kyoto 1997 (in force in 2005, 1st period began 2008)
  - The Protocol applies to 6 greenhouse gasses including CO_2 and Methane.
  - Countries required to prepare legally binding policies and measures for GHG reduction
  - Puts the main obligation on developed countries first
  - 37 countries have binding targets, 4 ratified (Canada withdrew, US not included

- Paris Agreement 2015:
  - Commitment: global temperatures below 2.0C (above pre-industry) and try to limit them below 1.5C
  - Net zero emissions from 2050 became law for UK in 2019
  - Implications: Implies at or after peak oil and half of all discovered oil may need to remain in the ground

- Glasgow COP26 2021:
  - The main objectives: commit to more ambitious targets to reduce emissions by 2030 and introduce measures for adaptation
  - Global pledge to cut Methane and reduce deforestation

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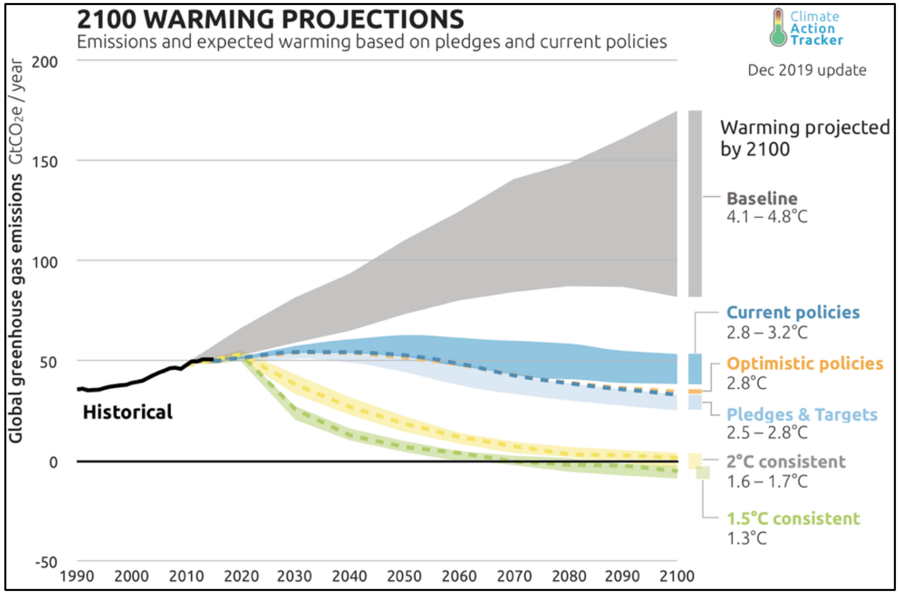
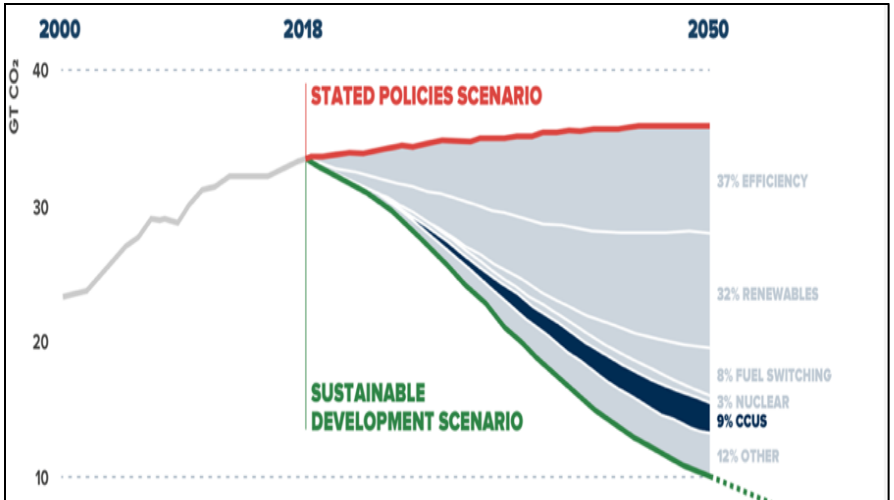
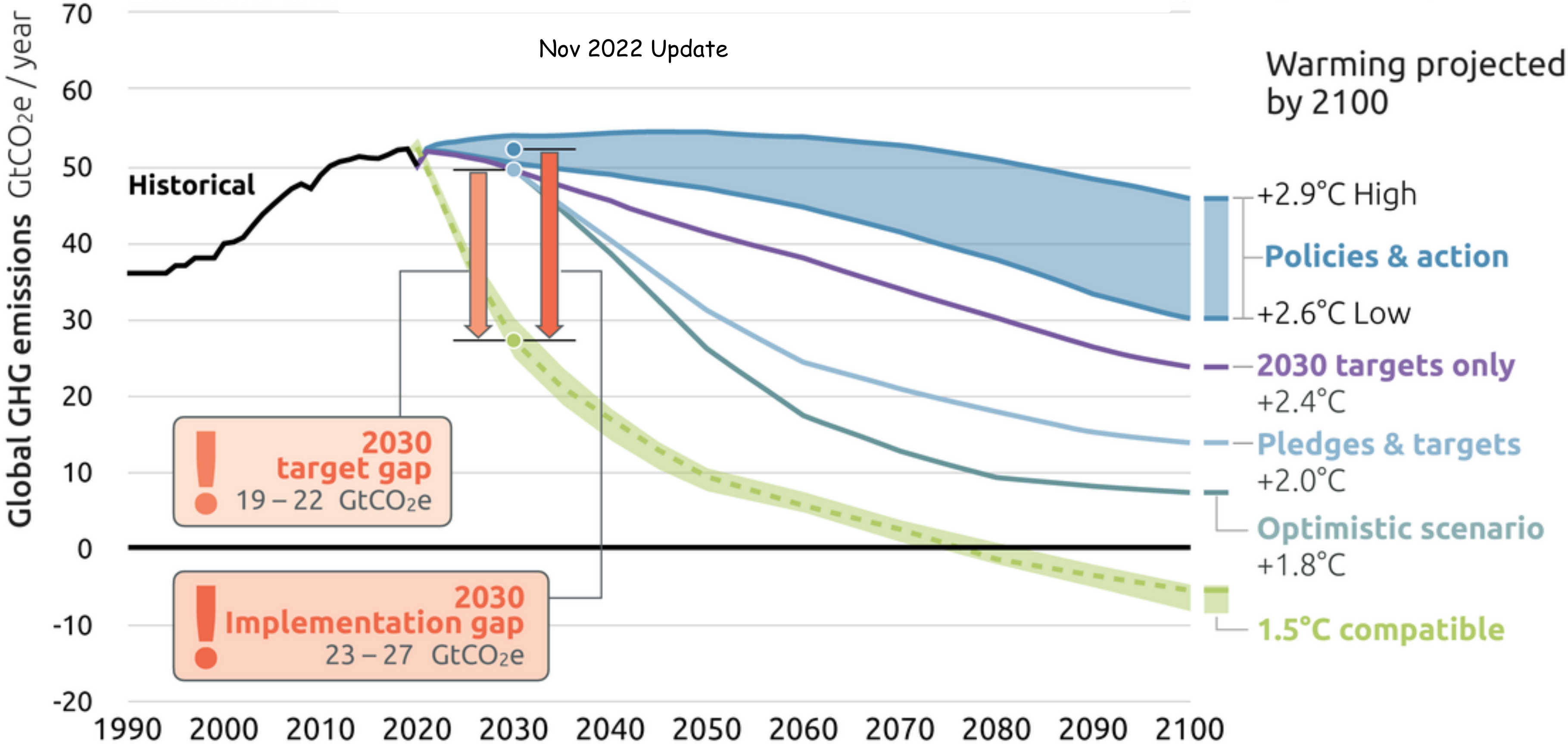




Emission reductions SDS (From Global CCS Institute, 2019)

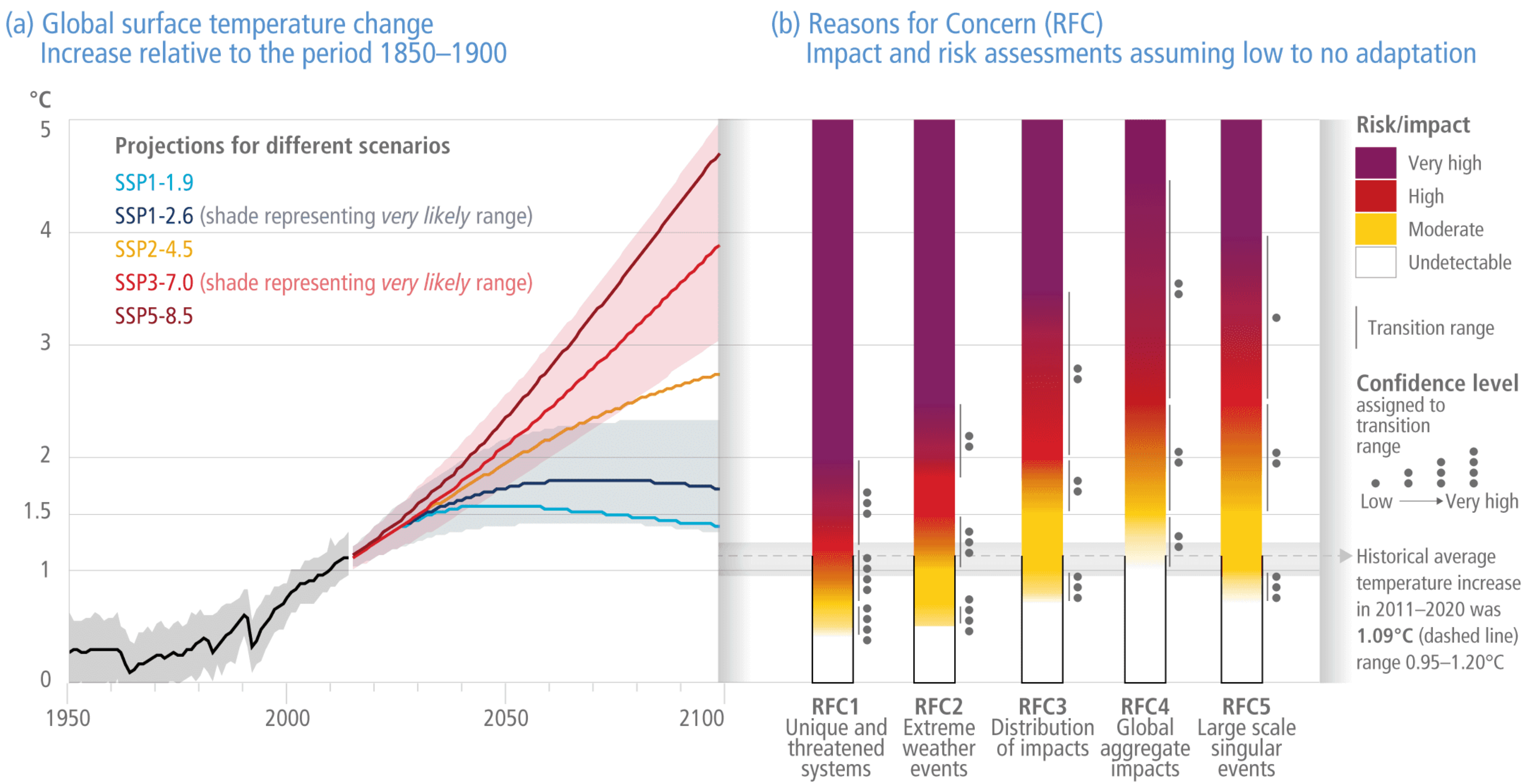
2100 Warming Projections (Nov 2022 Update)



Conclusion: We will almost certainly need "Adaptation"

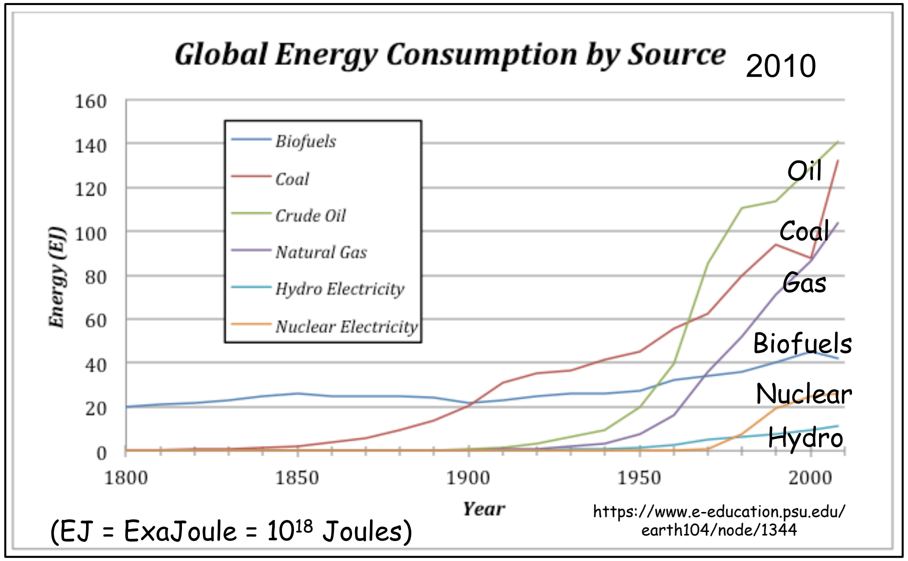
Source: Carbon Tracker (Based in IPCC)

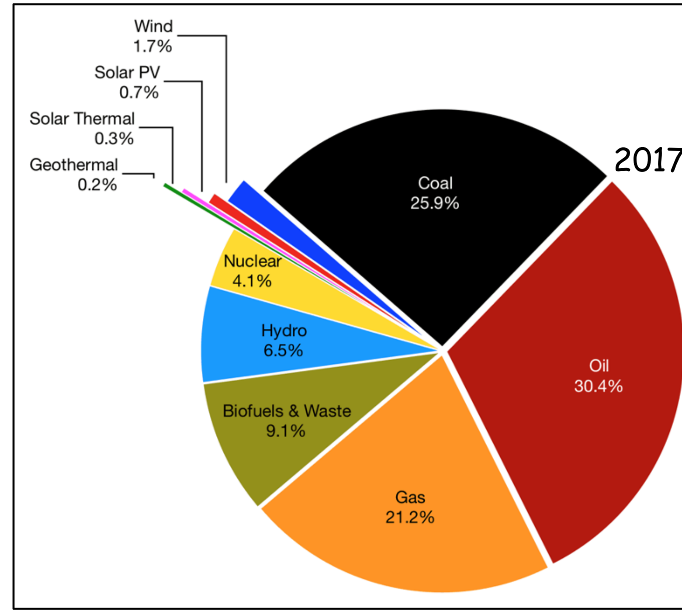
Global and Regional Risks for Increasing Levels of Global Warming

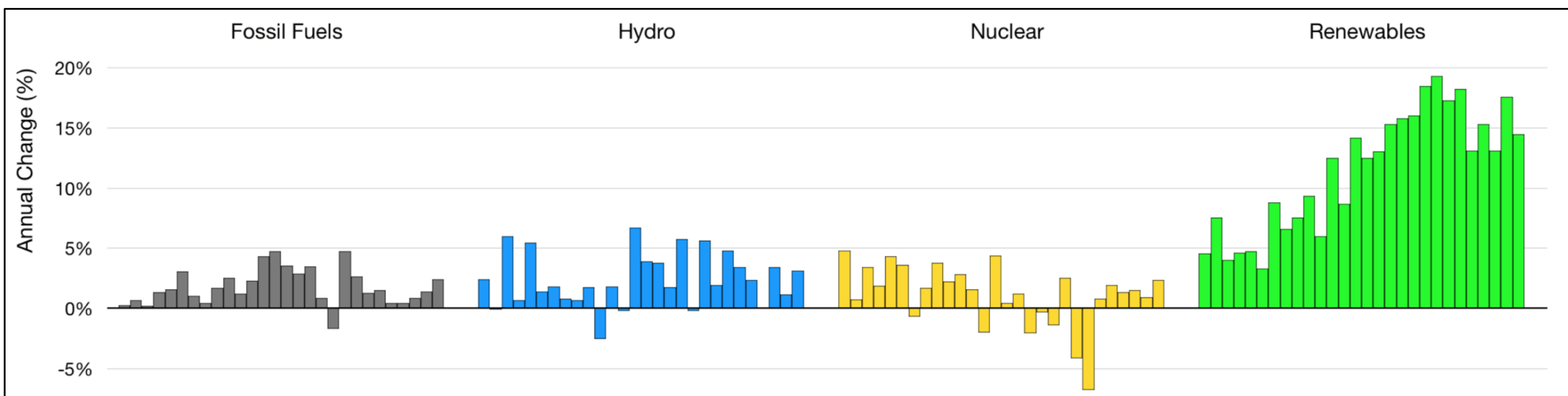


Source: IPCC 2022

Global Energy Supply

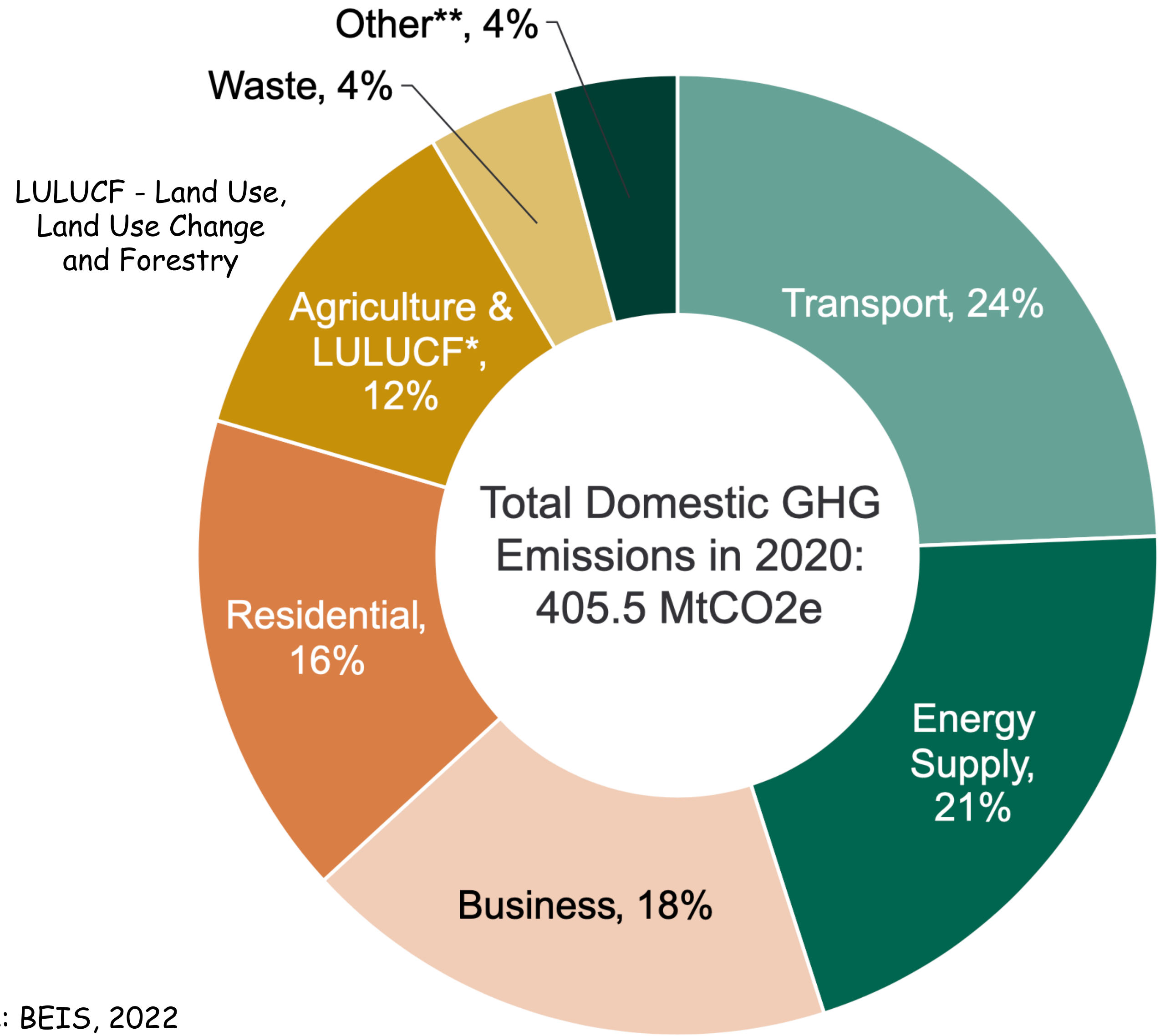






% change of energy supplied by year compared to previous year 1990-2018 (from BP review, 2019)

UK Emissions by Sector



Source: BEIS, 2022

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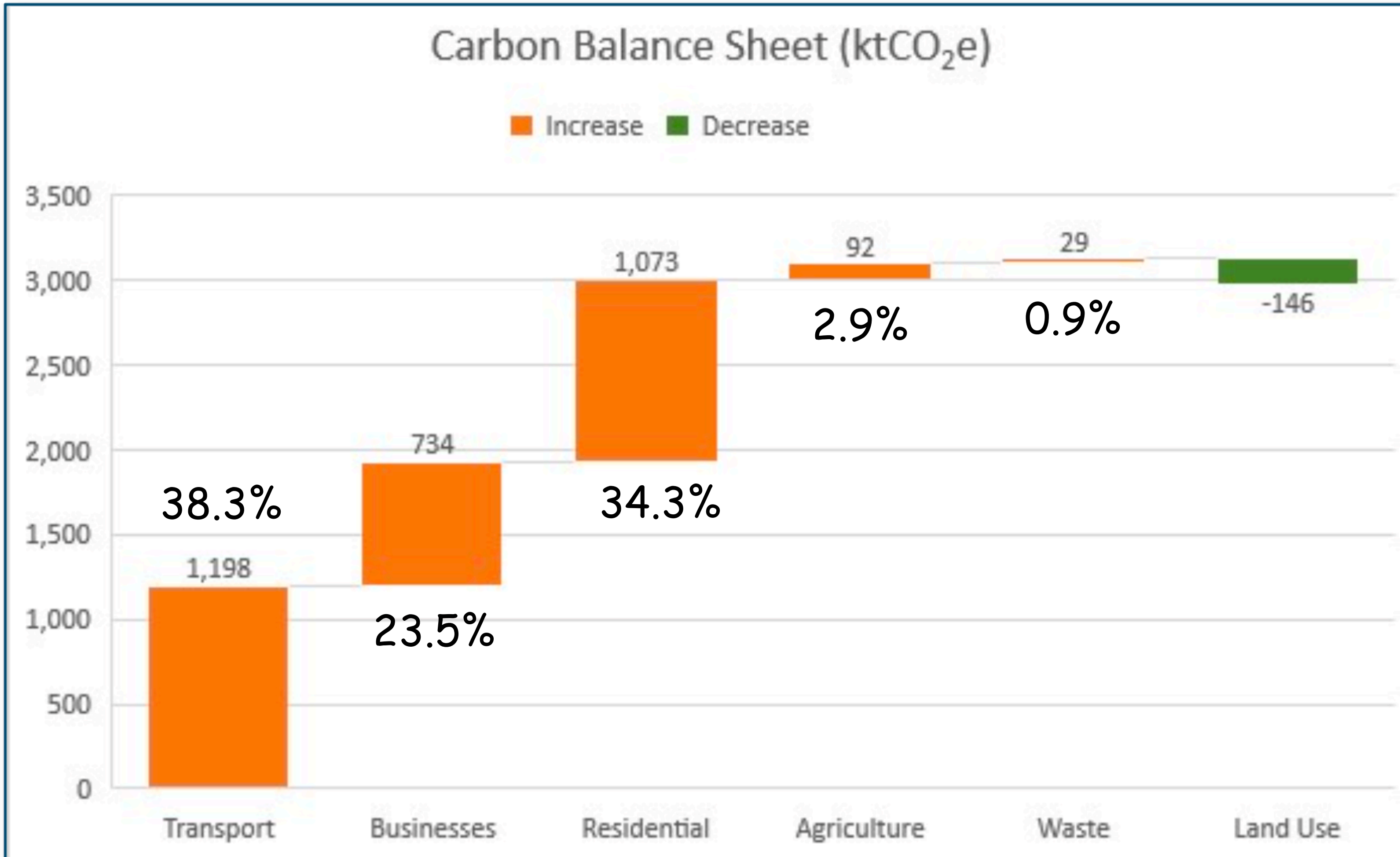
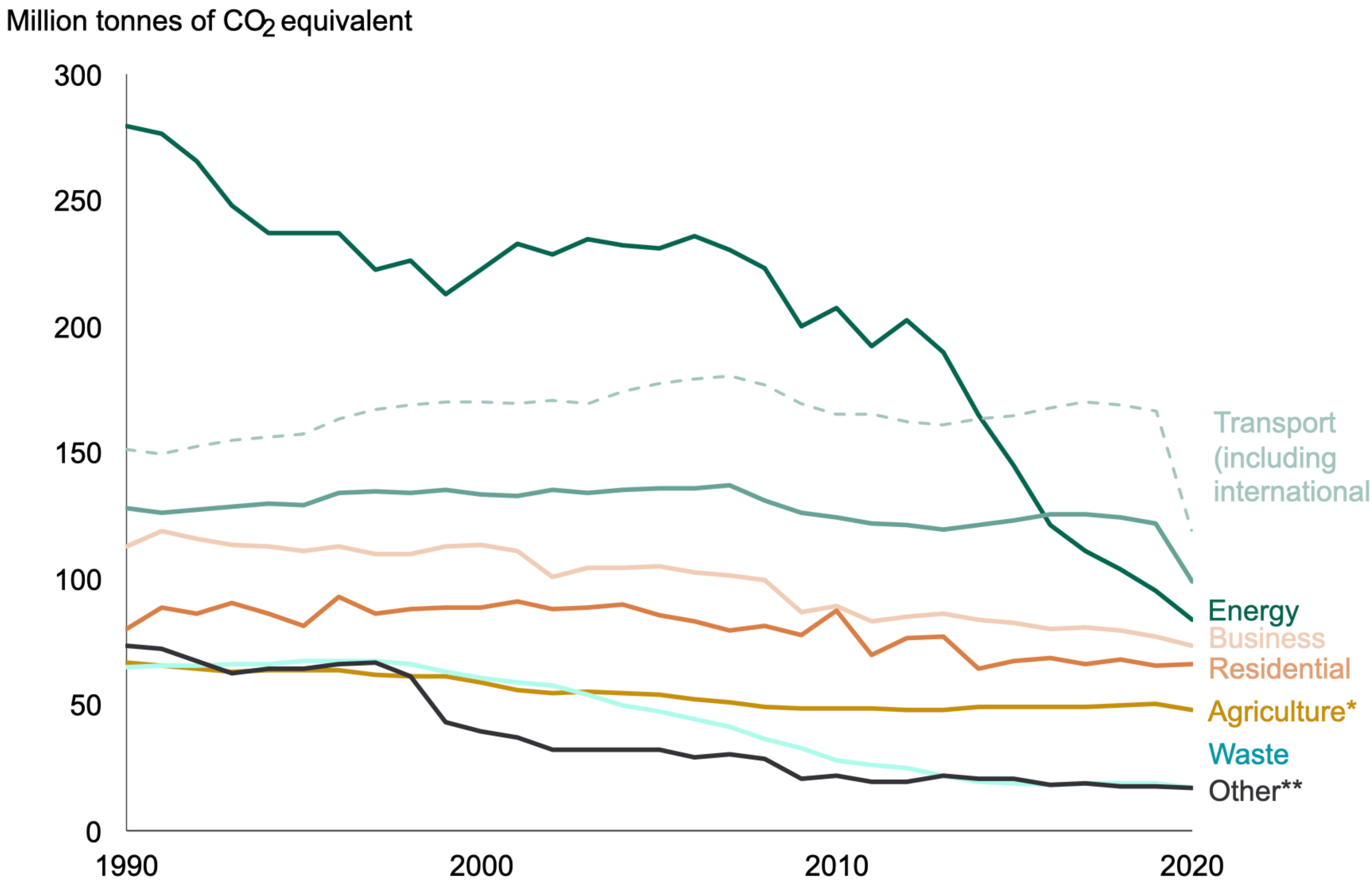
Dorset's Yearly Emissions: 3.1mtco$_2$/year



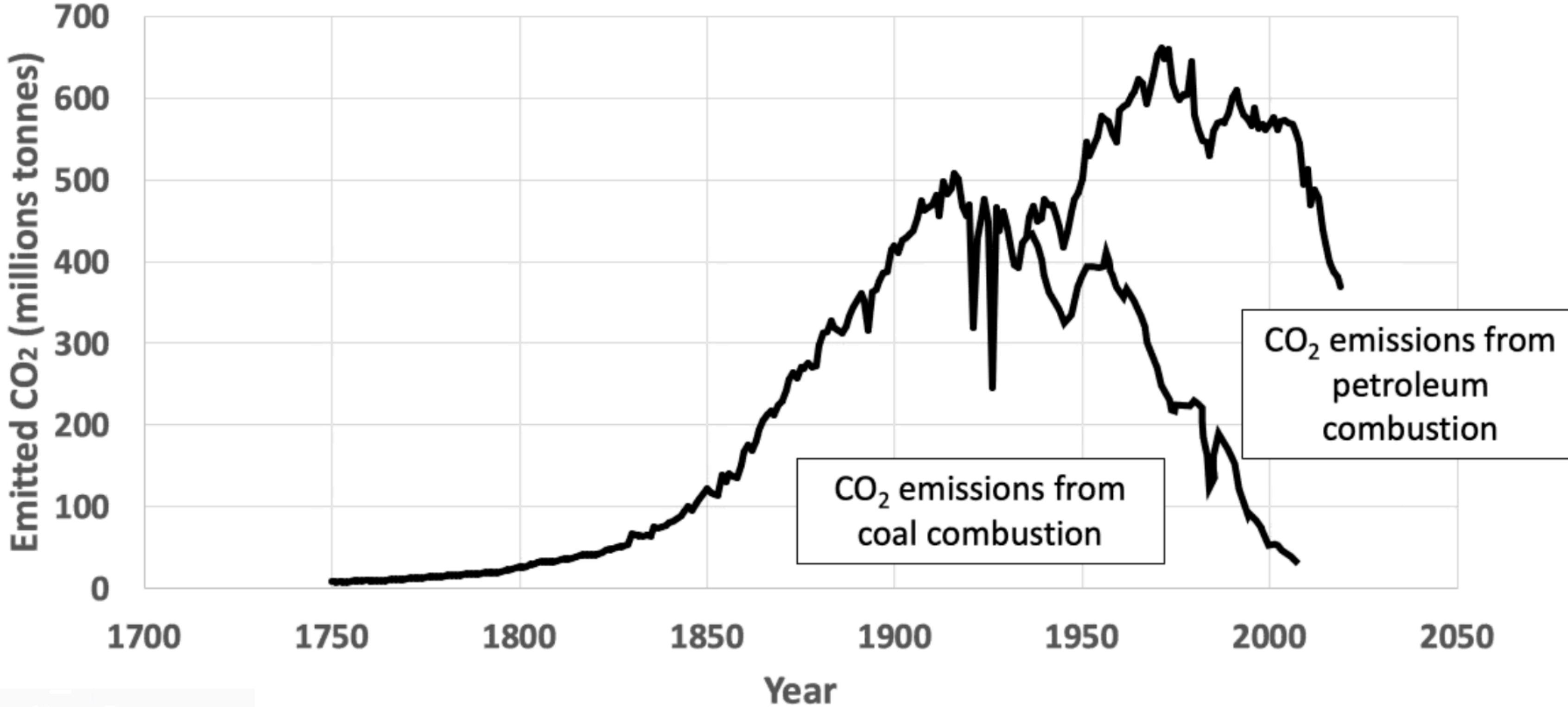
Greenhouse gas emissions by sector 2020 (BEIS, 2022)



Source: BEIS, 2022

UK CO2 Emissions

Decarbonisation of the UK Economy
Jon Gluyas. Durham Energy Institute
EAGE CO2 Underground Storage Workshop May 2021,



Durham University
Durham Energy Institute

The UK's Declining CO2 Emissions

Decarbonisation of the UK Economy
Jon Gluyas. Durham Energy Institute
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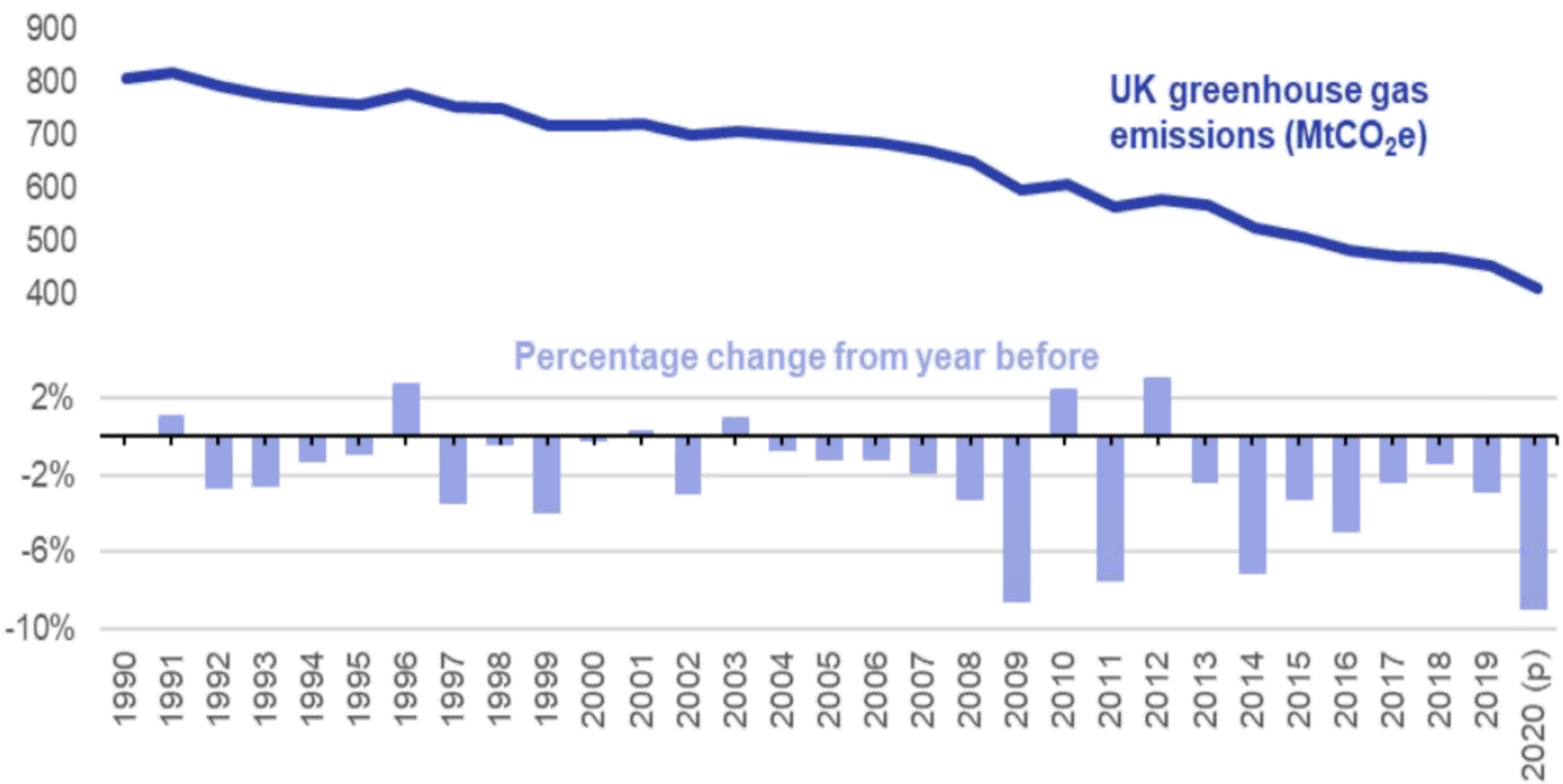

Durham University
Durham Energy Institute

Data source
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/972583/202

Two Ways to Reduce Greenhouse Gasses

- Reduce Emissions
  - Generate much more renewable energy
  - More active travel, electrify transport
  - Convert industry to hydrogen
  - Retrofit households, convert to heatpumps
  - Eat less meat and dairy

- Remove CO2 from Atmosphere
  - Nature-based solutions
  - Chemical based solutions (BECCS, DACCS)

About CCS


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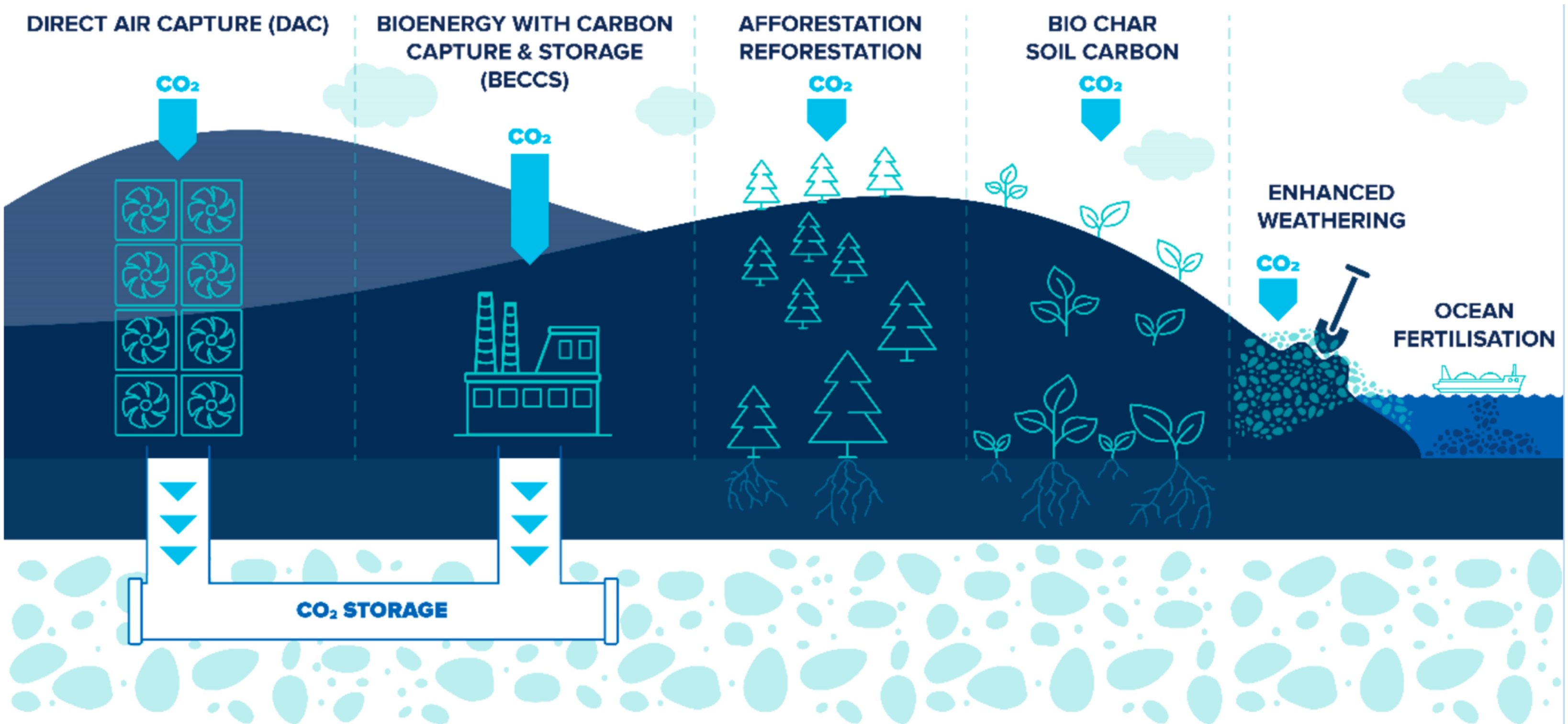
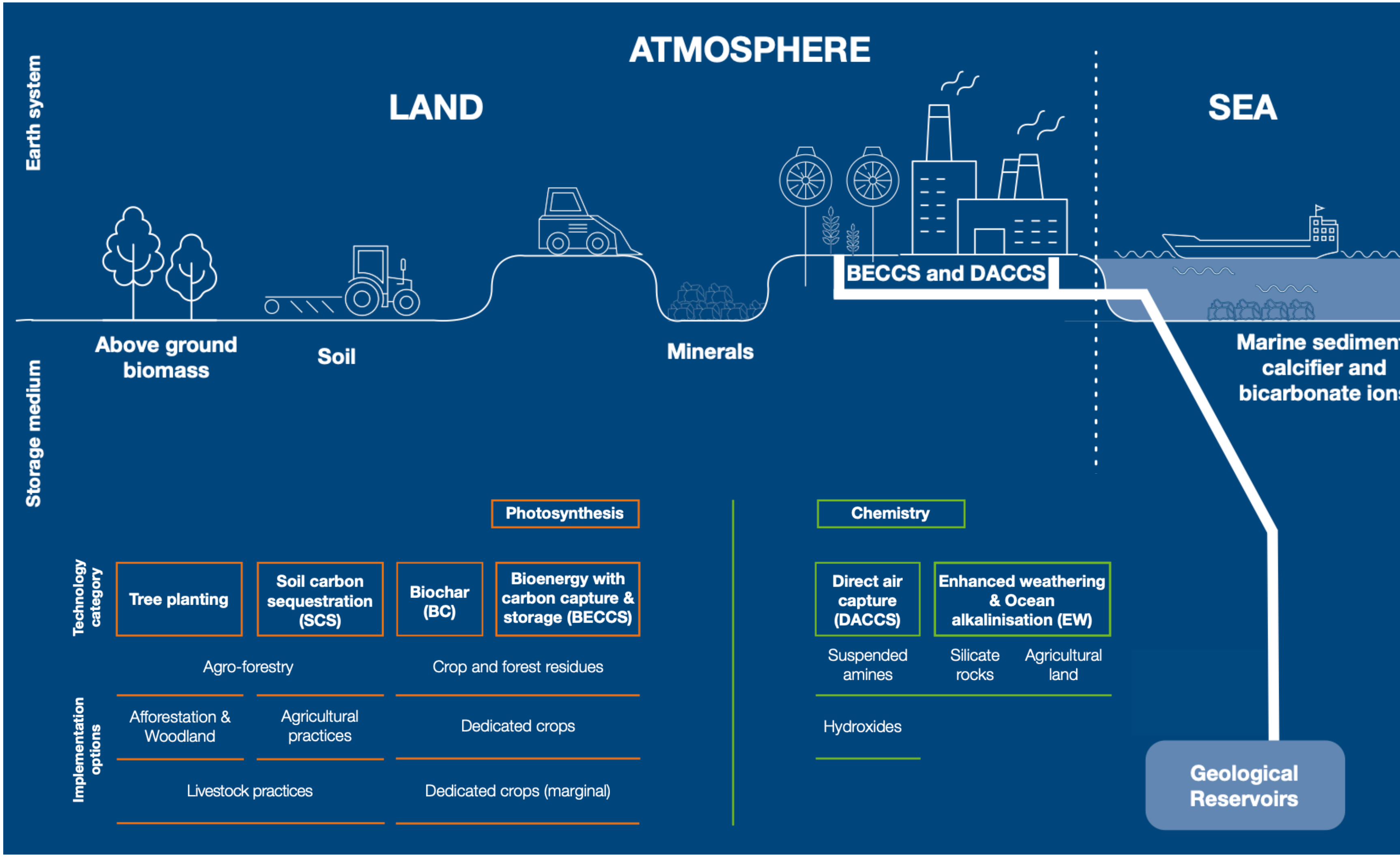
Carbon Removal Approaches



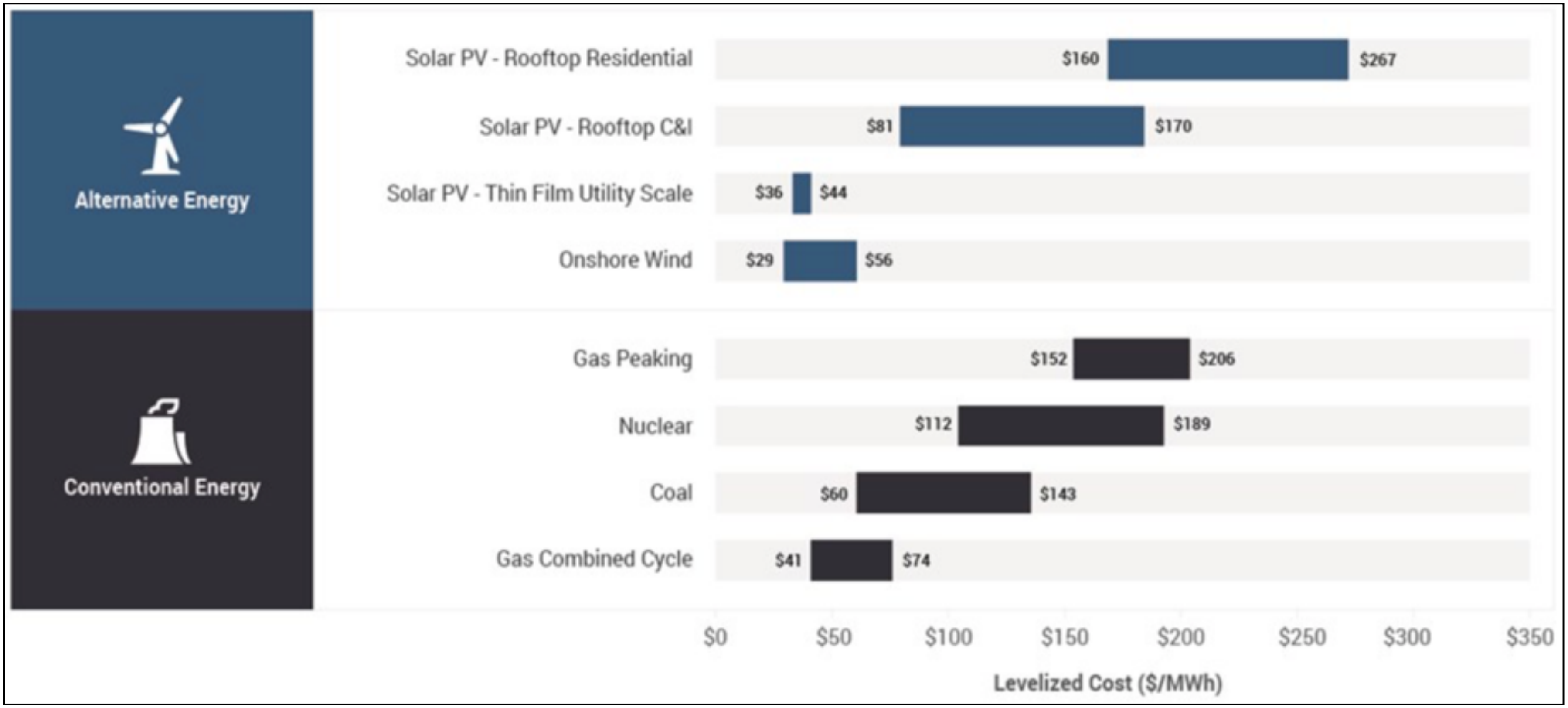
- Land based (Photosynthesis) or Industrial based (Chemical)
- of All carbon removal approaches have different limitations and challenges of Scalability, permanence, cost, impact on land use change and/or biodiversity, or other aspects.
- No single approach will meet the rates of carbon reduction required (Fuss et al., 2018).

Source: Carbon removal with CCS technologies, Eve Tamme, International Climate Change Policy

Greenhouse Gas Removal (GGR)



Levelised, Unsubsidised cost of energy



(Lazard 2018)

Oil Companies Response

Driving down Emissions (Scope 1, 2 & 3)

- Lowering emissions of pollutants (flaring, Methane, Nitrous oxides etc,.)
- Some majors have now set ambitious targets to be carbon neutral in 25-30 years

Diversifying and Rebranding

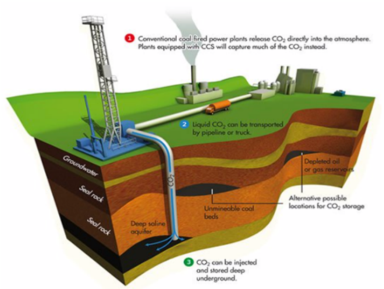
- Diversify into solar, wind and hydro and rebranding as "Energy Companies"
- People, skills & experience in engineering - want to be part of the energy transition

Gas as a transitional fuel

- Refocus towards gas as low-carbon "transitional" fuel – lower footprint

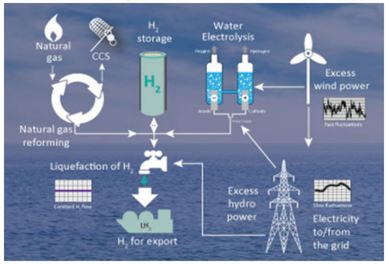
Carbon Capture and Storage

- Burn fossil fuels and bury the carbon
- Scaleable and likely to play a key future role but not carbon free
- Additional cost ~$20-40/barrel. Green community not convinced

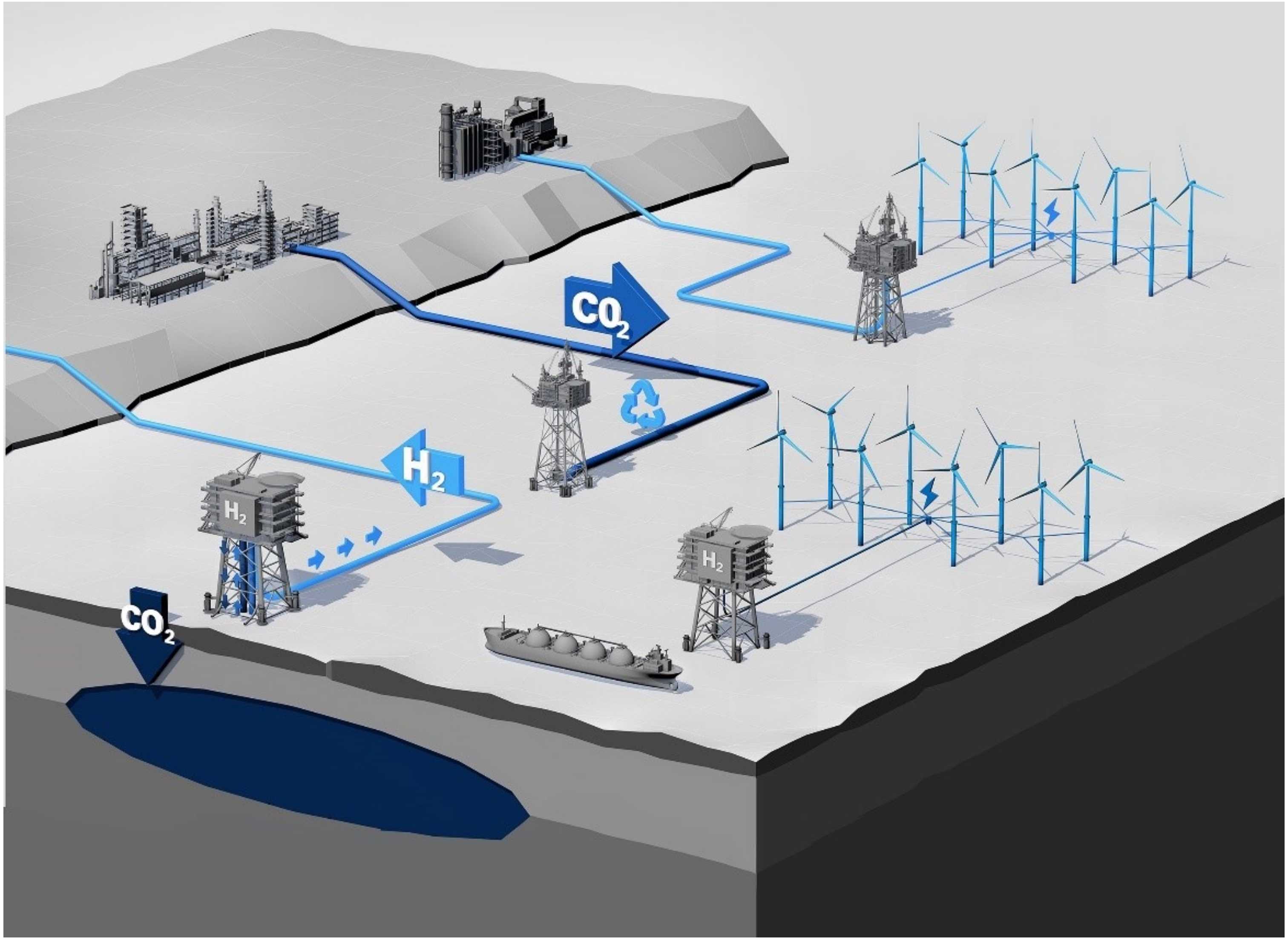


The Hydrogen Economy

- High-energy, very light alternative with zero emissions
- Use in long-distance freight, trains, aeroplanes/drones, heating
- Green vs Blue hydrogen

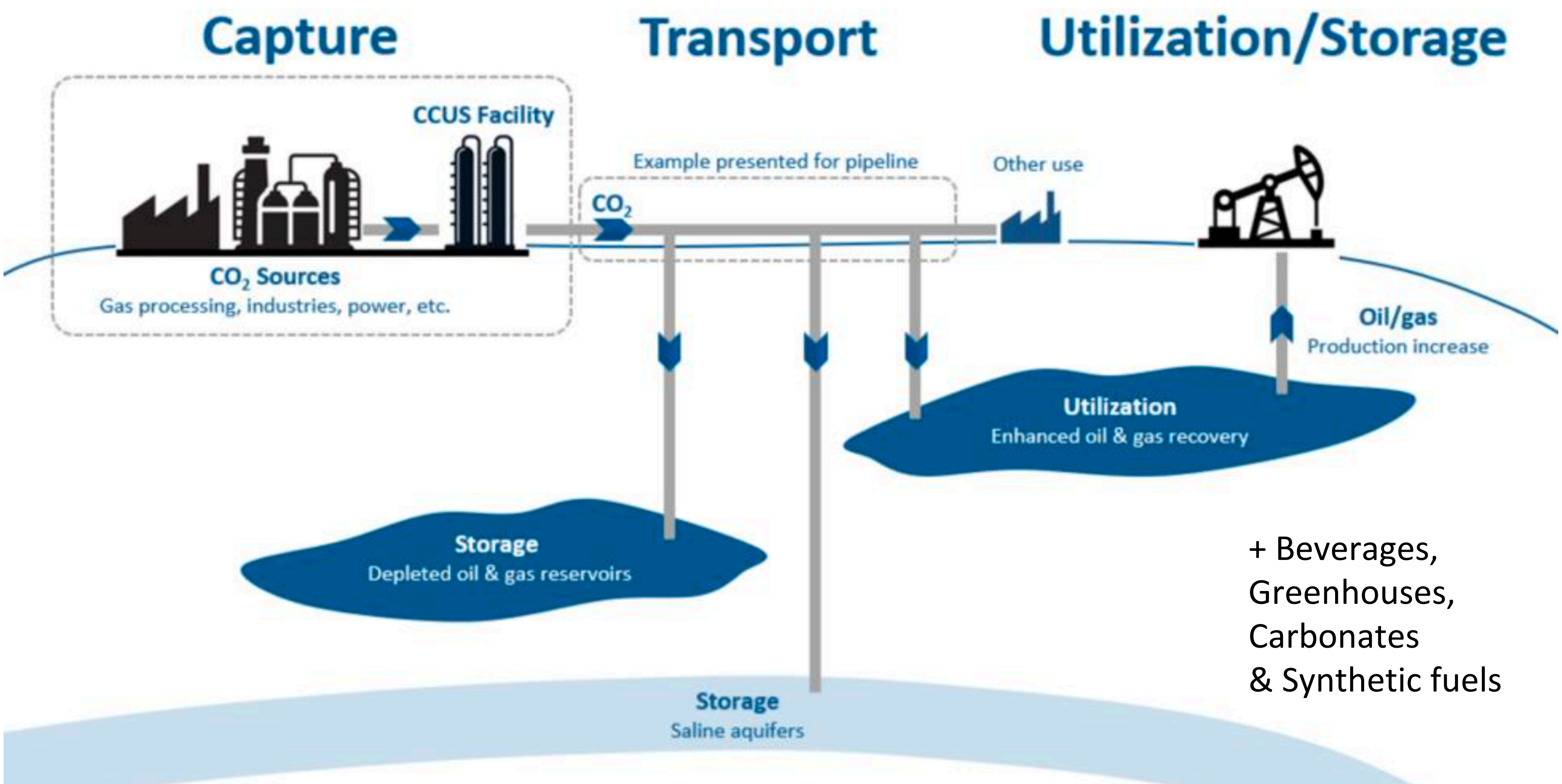


What is CCS ?



Source: NSRA Web Site

What is Carbon Capture, Utilisation and Storage (CCUS) ?



+ Beverages,
Greenhouses,
Carbonates
& Synthetic fuels

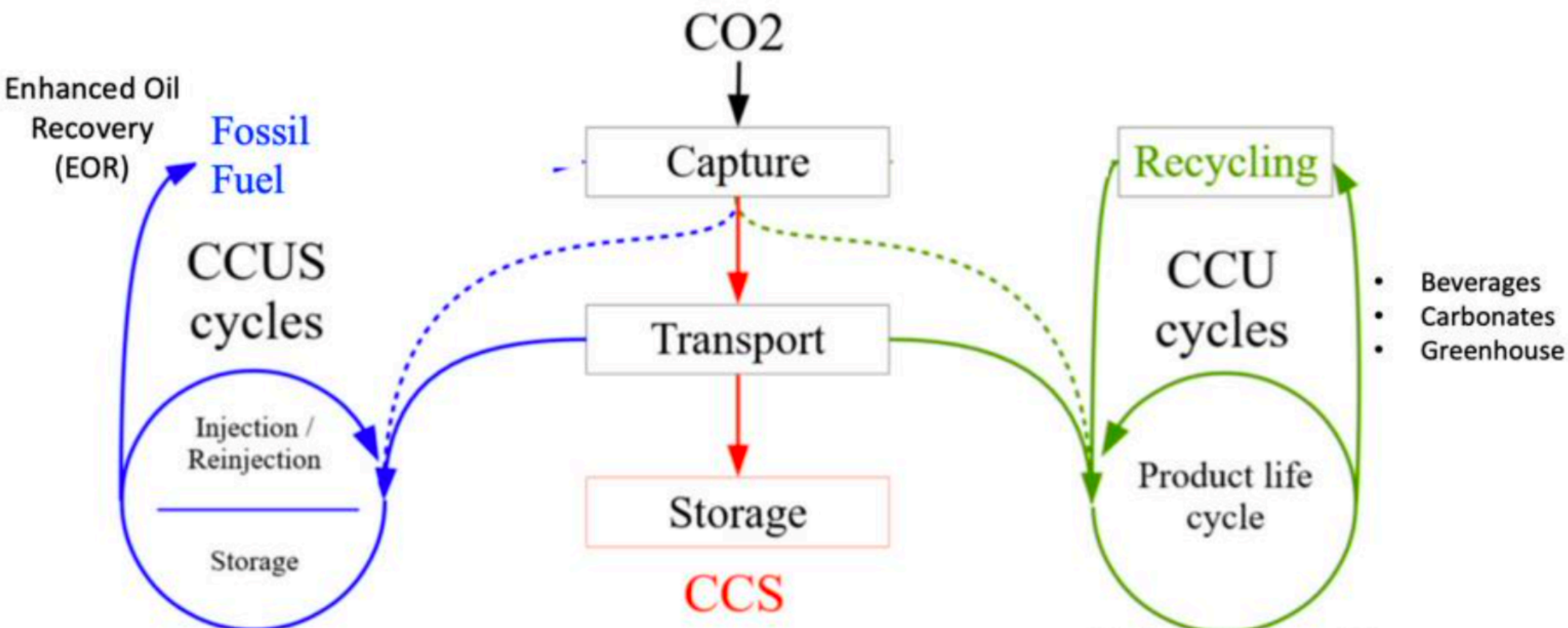
Source: IEEFA, Carbon Capture in the Southeast Asian Market Context. 2022.

What is CCS ?

- CCS refers to a variety of processes which capture and store carbon dioxide emissions, generally from industrial processes. The carbon dioxide can then be transported (pipelines or shipping), and stored, for example within rock formations in the UKCS, including depleted oil and gas reservoirs.

- Carbon Capture and Storage (CCS) is critical to the UK achieving net zero – government aims to capture and store 20-30 million tonnes of CO_2 per year by 2030 and over 50 million tonnes/yr by 2035.

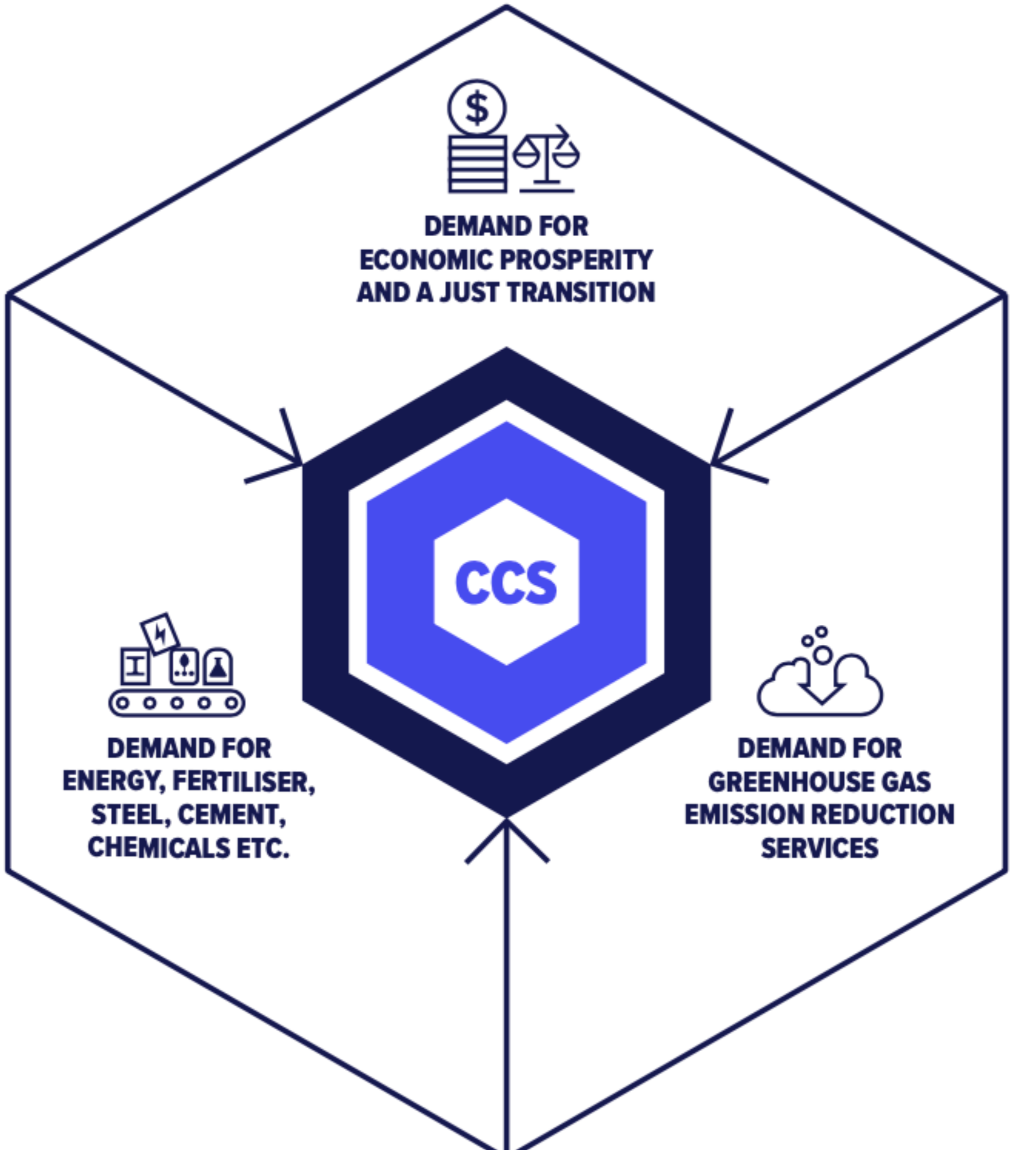
Conceptualisation of CCUS vs CCS vs CCU



Carbon Capture, Utilisation & Storage (CCUS)	Carbon Capture & Storage (CCS)	Carbon Capture & Utilisation (CCU)
≈73% of the total capacity	≈27% of the total capacity	<1% of the total capacity

Source: Sustainability Journal, MDPI, 2019.

A Solution to the Energy Trilemma



Dual Role for CCS in Climate Change

- Reducing Emissions
  - Decarbonising Heavy Industry (Cement, Steel, Chemicals)
  - Clean Hydrogen Production (Blue Hydrogen)
  - Reducing Emissions from recent Power Plants - especially Coal and gas in Asia (Blue Power)

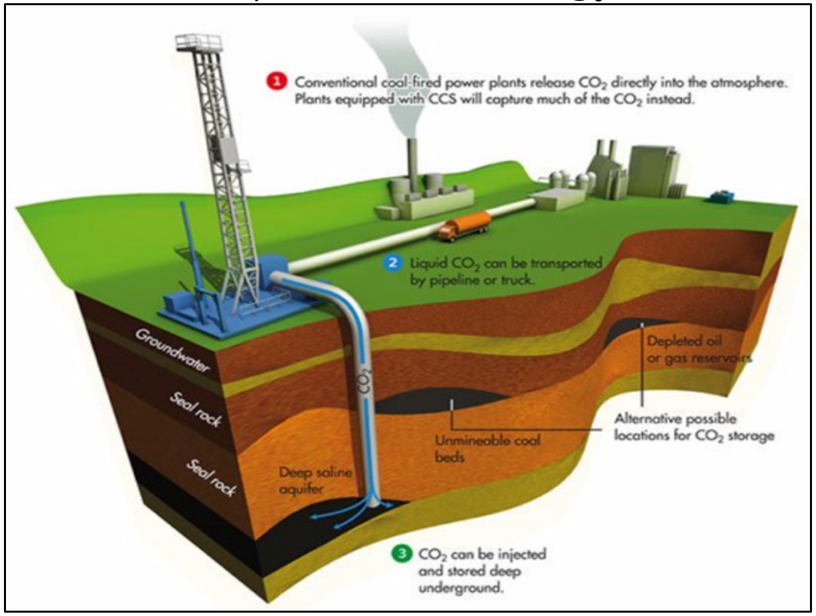
- Carbon Removal
  - BECCS (Biochar & bioenergy + CCS). (Including waste to Energy +CCS)
  - DACCS (Direct Air Capture + CCS)

Carbon Capture and Storage
CCS and CCUS

Pros

- Store CO2 permanently in underground storage sites, e.g. saline aquifers or disused O&G field.
- Decarbonize industry and power at scale
- CCS is a proven and well understood.
- Likely to play key role in climate change targets
- In 2019, 19 active projects storing 25 Mtpa CO2.

Carbon Capture (CCS) Bundogji, 2015.



Cons

- Additional cost ~$20-40/barrel - more expensive than some renewables
- Not "Zero Carbon"
- However, future projects need to grow CCS by 20% per year to reach the target of 2800 Mtpa by 2050: a 70-fold increase.
- Lacks a viable mechanism for cost sharing
- Oil companies see a solution, many green activists do not agree

The Carbon Capture Crux- Lessons Learned

- Failed/underperforming projects considerably outnumbered successful
- experiences.
- Successful CCUS exceptions mainly existed in the natural gas processing sector serving the fossil fuel industry, leading to further emissions.
- The elephant in the room of the application of CCS/CCUS in the natural gas processing sector: Scope 3 emissions are still not being accounted for.
- Captured carbon has mostly been used for enhanced oil recovery (EOR): enhancing oil production is not a climate solution.
- Using carbon capture as a greenlight to extend the life of fossil fuels power plants is a significant financial and technical risk: history confirms this.
- Some applications of CCS in industries where emissions are hard to abate (such as cement) could be studied as an interim partial solution with careful consideration.

ute for Energy Economics and Financial Analysis, The Carbon Capture Crux: Lessons Learned. 2022.

Supporters of CCS

- UN Intergovernmental Panel on Climate Change (IPCC) identified CCUS as a "Critical "critical decarbonisation strategy in most mitigation pathways", which will need to be deployed alongside drastic emissions cuts to keep global temperature rise between 1.5°C and 2°C.

- The UK Climate Change Committee (CCC) said that CCUS is a "necessity not an option".

- International Energy Agency said that reaching net zero will be "virtually impossible" without CCUS and is "the most cost-effective approach" to curbing emissions from heavy industries such as iron, steel and chemicals.

- The Carbon Capture and Storage Association (CCSA) found that CCUS could remove 70 million tonnes of carbon dioxide emissions every year by 2035.

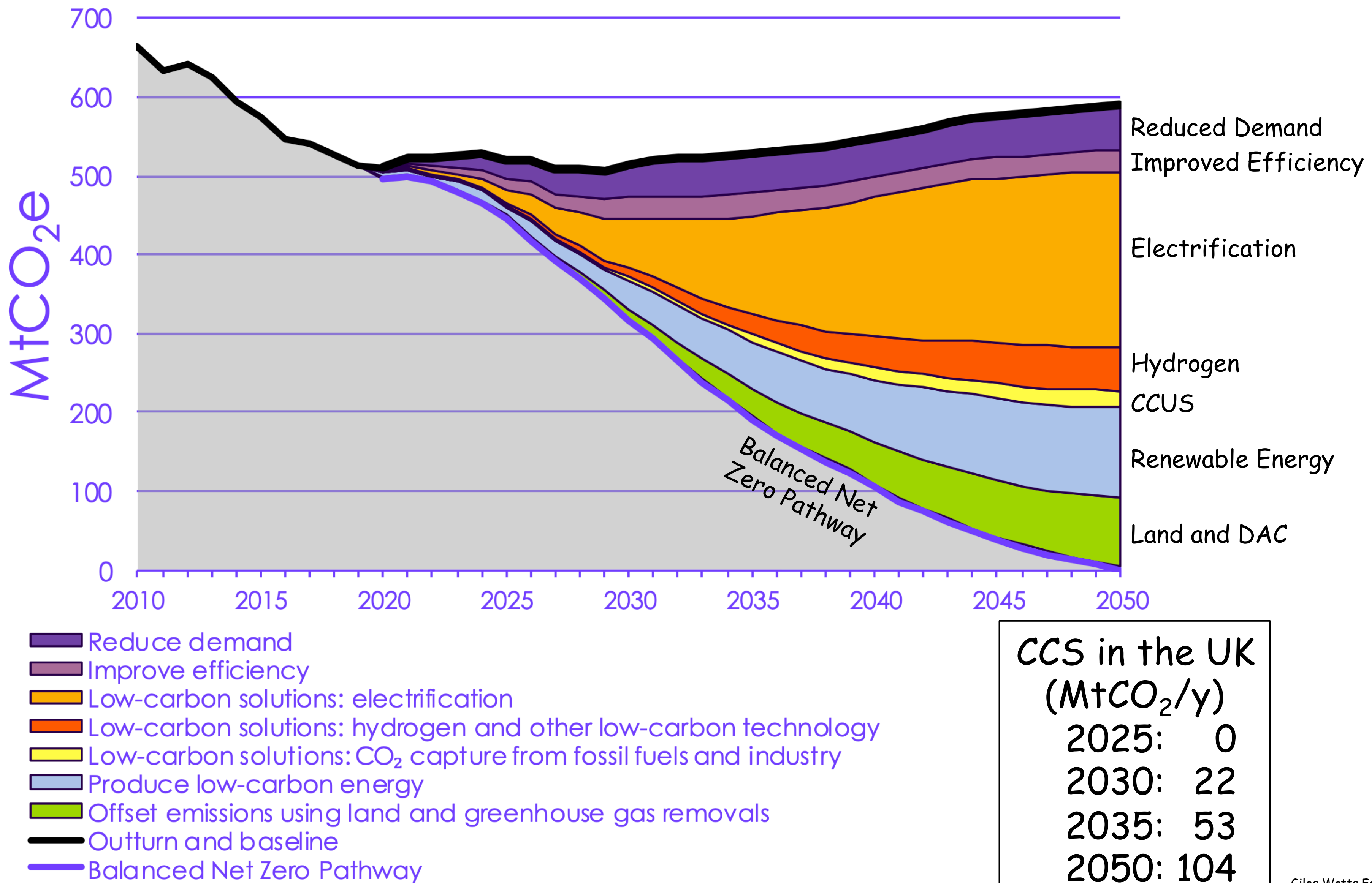
Concerns

- Should use natural sequestration and CCUS should be reserved for only the “hardest-to-abate” emissions
- Does it work ? Disappointing results at some carbon capture projects (e.g. Gorgon, Australia)
- Will we be able to scaling up CCS in time ?
- What is the real risk of leakage can they be properly mitigated
- Most CCS projects to date are CO2-EOR projects and so have been supporting more hydrocarbon production !
- CCS could be used to delay action on emissions reduction and water down the ambition
- CCS may just encouraging oil companies rather than persuading them to keep hydrocarbons in the ground
- CCS is low Carbon not zero carbon. Release of methane removes further the benefits of CCS

Those less enthusiastic about CCS

- The financial climate think tank Carbon Tracker has argued that CCUS should be reserved for the "hardest-to-abate" emissions
- Environmental campaign group Friends of the Earth Scotland has previously said carbon capture "cannot deliver the urgent action we need to cut emissions this decade".
- Groups point to the disappointing results at some carbon capture projects (e.g. Gorgon, Australia)
- Some point out the difficulties of scaling up the technology so that it
- Some are not convinced that the risk of leakage can be properly mitigated
- Some point out that most CCS projects to date have been CO2-EOR projects and so have been supporting more hydrocarbon production – hardly solving the problem !

CCC: Types of abatement in the Balanced Net Zero Pathway – with the most rapid reductions in 2025-2035



CCS in the UK ($MtCO_2/y$)

2025: 0
2030: 22
2035: 53
2050: 104

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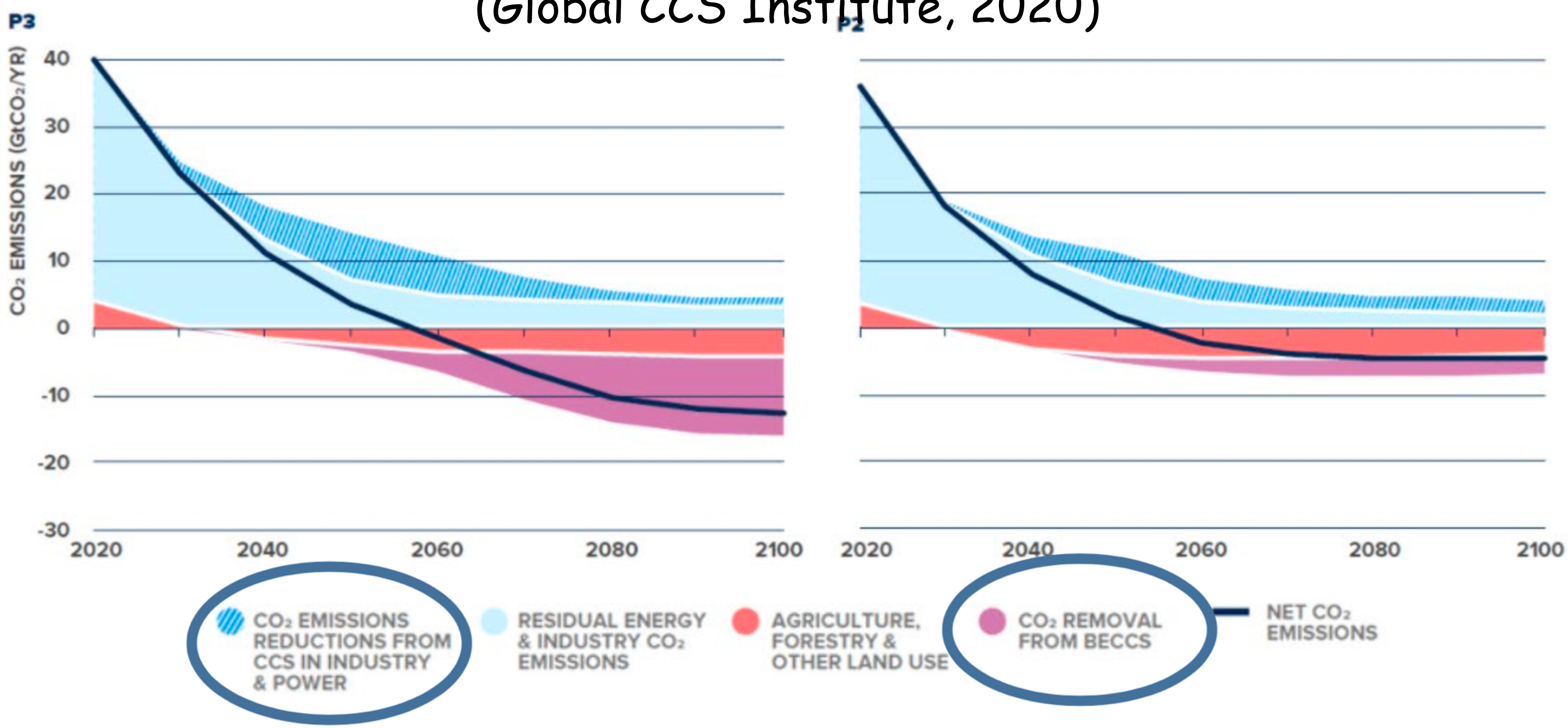
Pathways to Net Zero

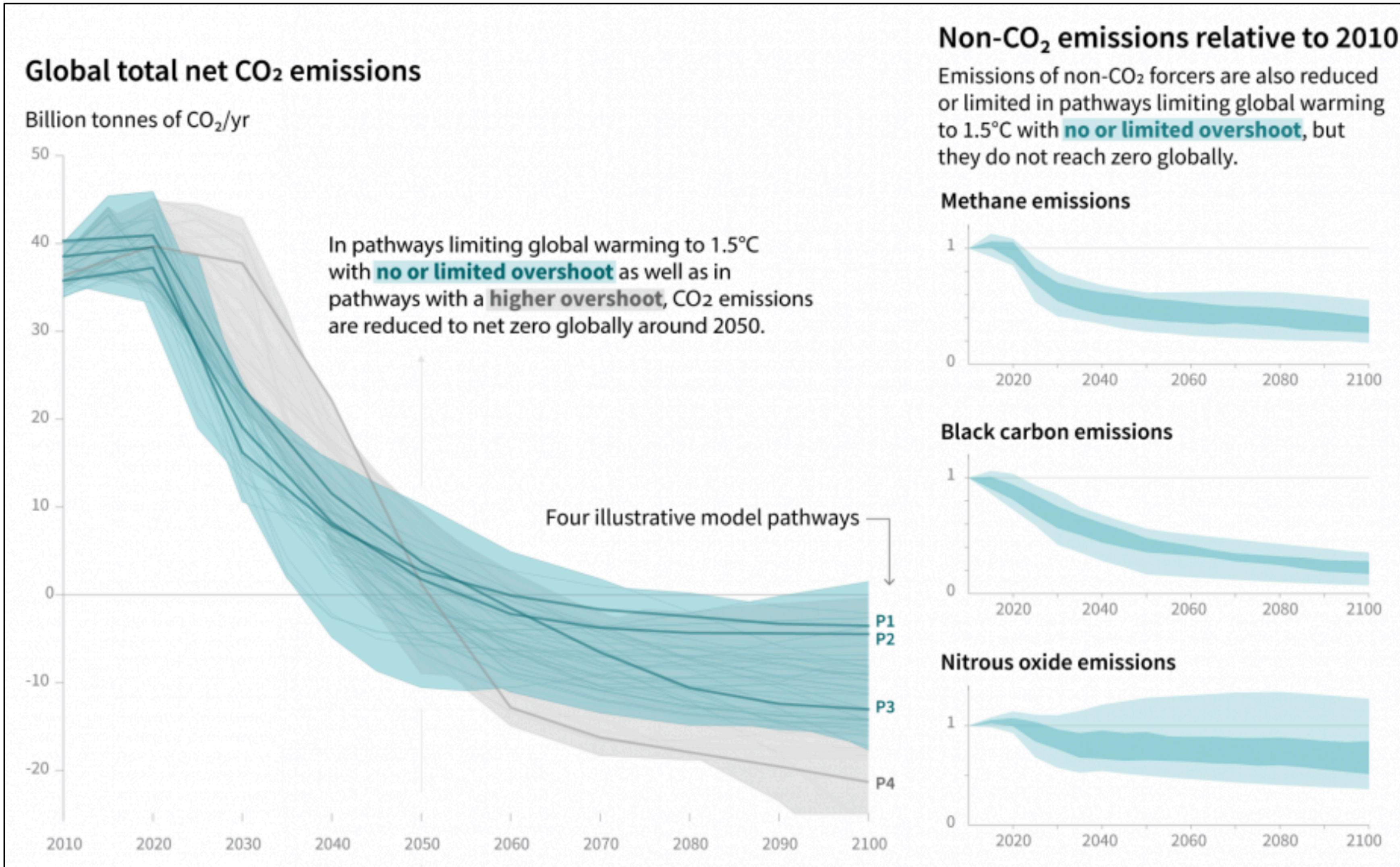
Illustrative mitigation pathways P3 and P2 in the IPCC 1.5 degree report (Global CCS Institute, 2020)



- 1.5 degrees global warming requires emission reductions and carbon removal from the atmosphere
- Carbon removal needs to be 100–1000 GT CO2 over the 21st century (IPCC, 2018).
- Emphasis is emission reduction in 1st half of century and carbon removal in 2nd

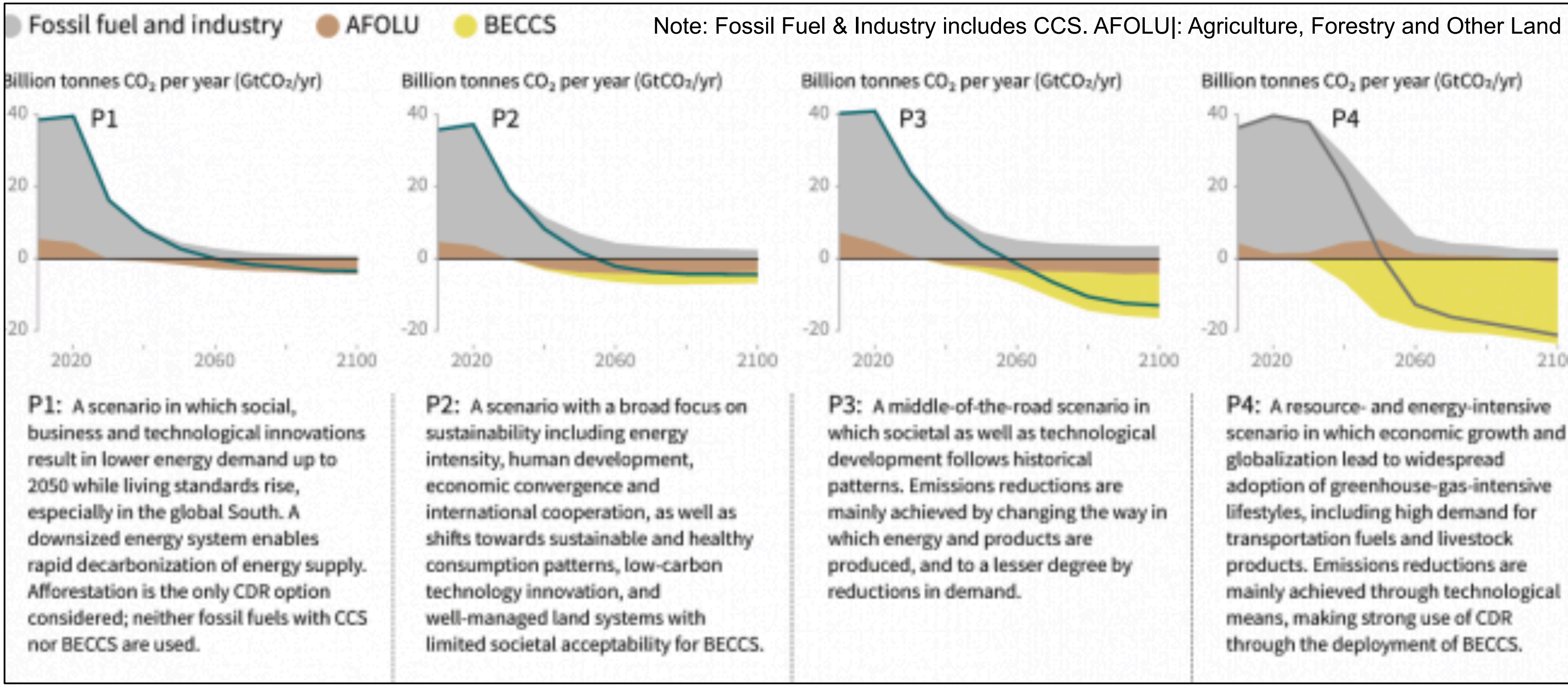
Source: Carbon removal with CCS technologies, Eve Tamme, International Climate Change Policy

Global Net CO2 emissions - Scenarios



Source: IPCC, 2018

Breakdown of contributions to global net CO_2 emissions in four illustrative model pathways



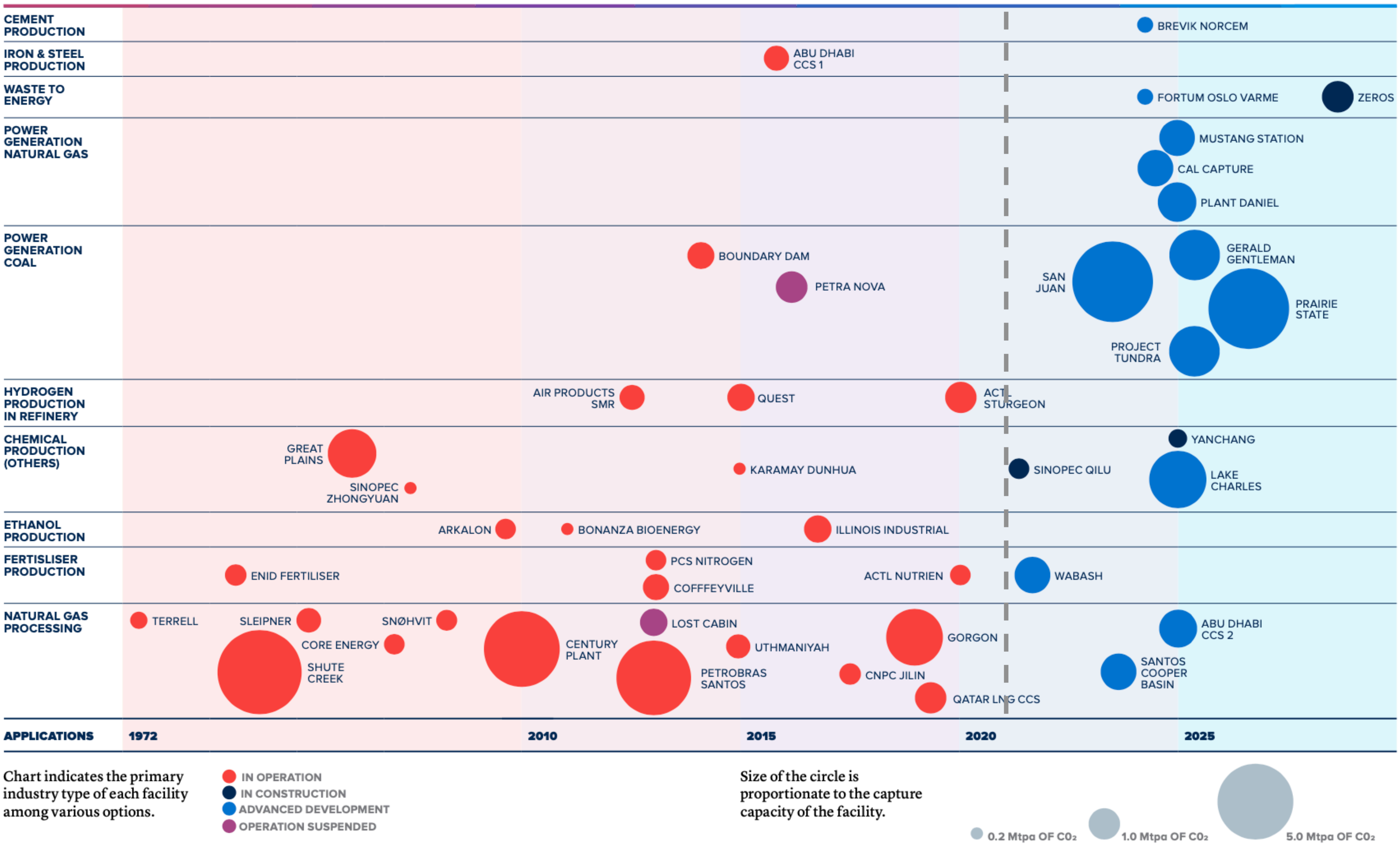
P1: ”Ideal:” option with lower energy demand to 2050. Afforestation is only CO2 removal option
P2: “Sustainable” option with everyone co-operating. Limited use of BECCS
P3: :”Middle” option with society and technology following historical patters. Large BECCS
P4: “High consumption, high growth” option. Emissions reduction through technology not behaviou

Source: IPCC, 2018

About CCS Projects

Worldwide Commercial CCS Facilities

Note the area of circles is proportional; to the current CCS capacities.



Source: Global CCS Institute. Global Status of CCS Report, 2020

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Worldwide Commercial CCS Facilities

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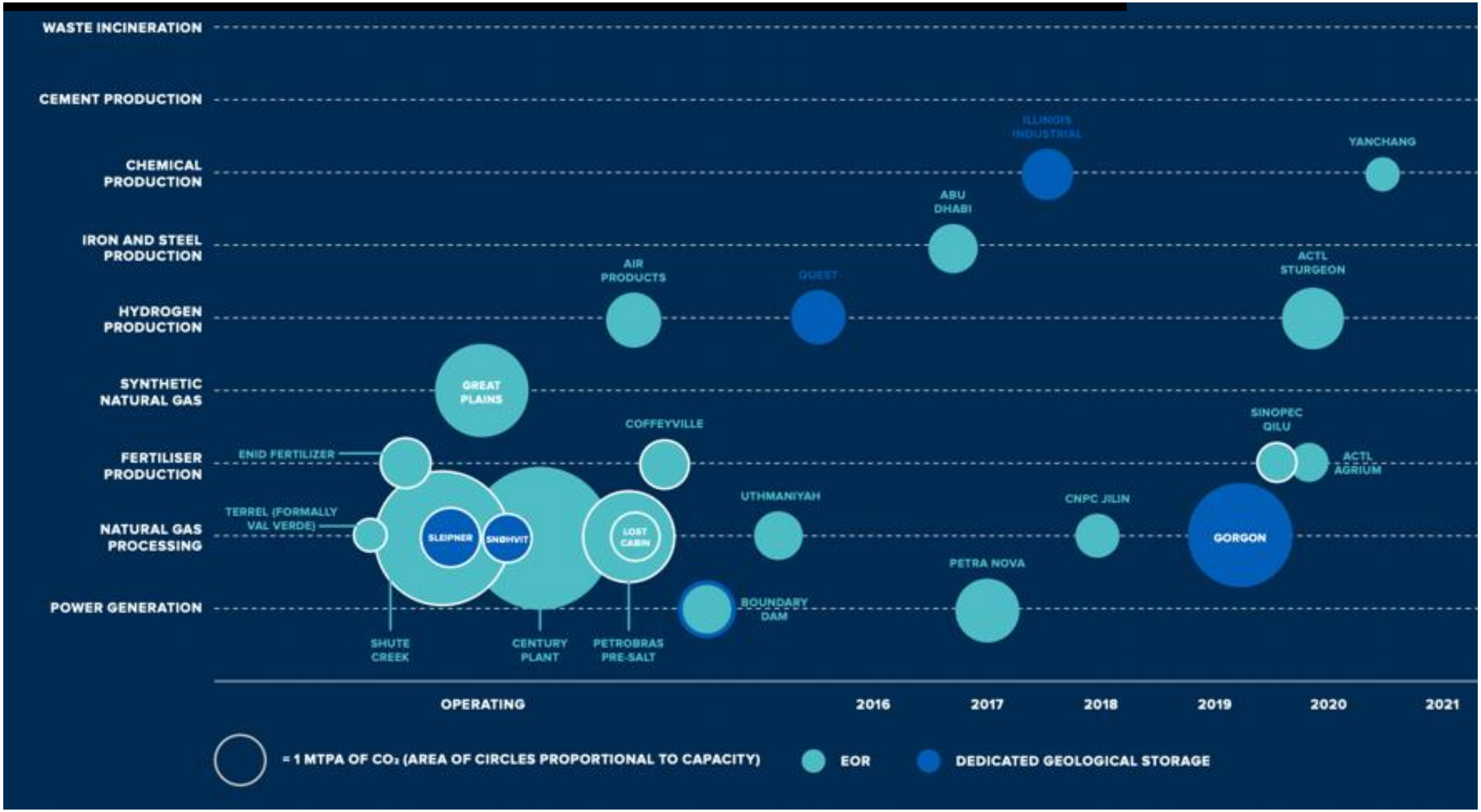
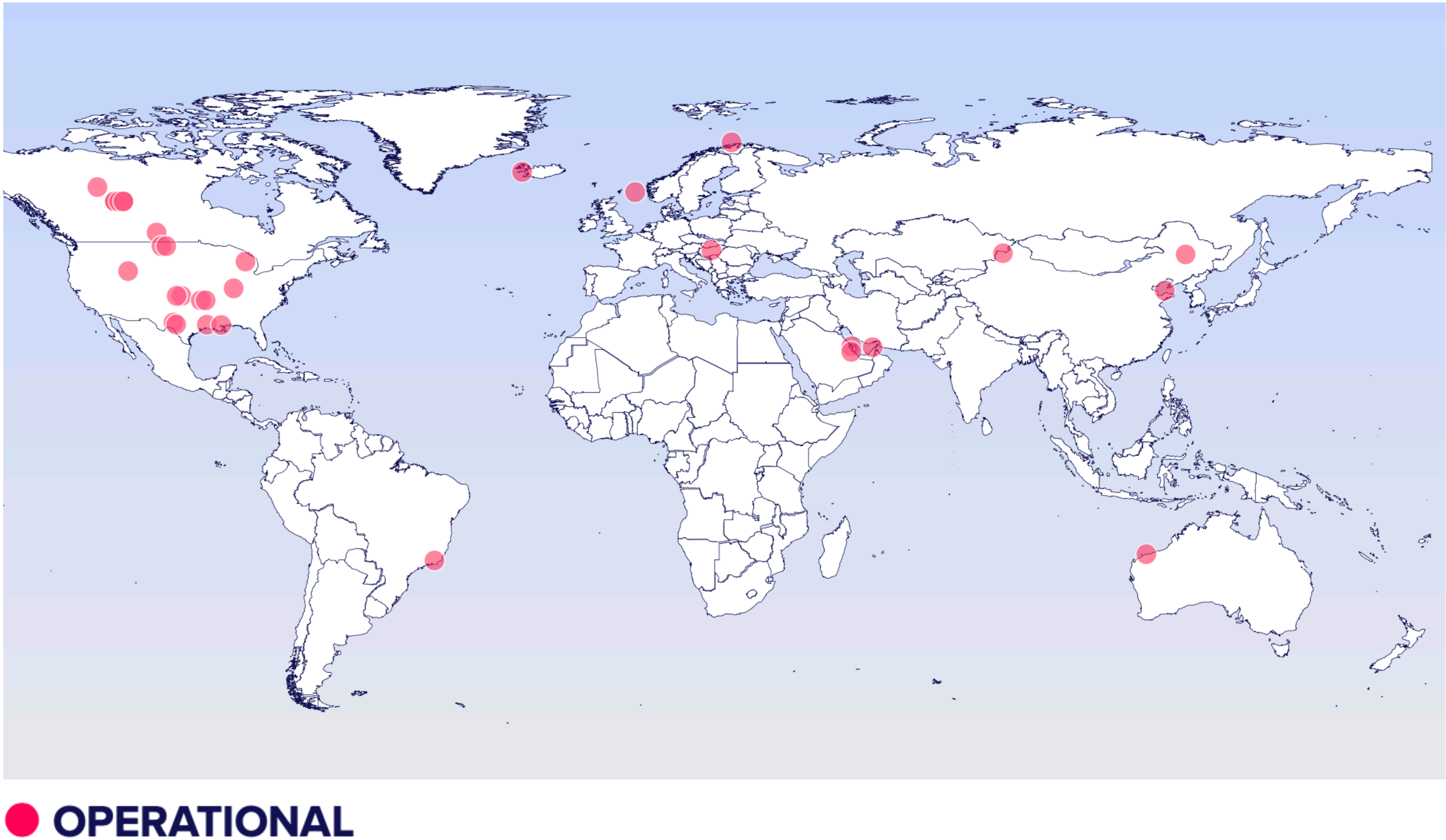


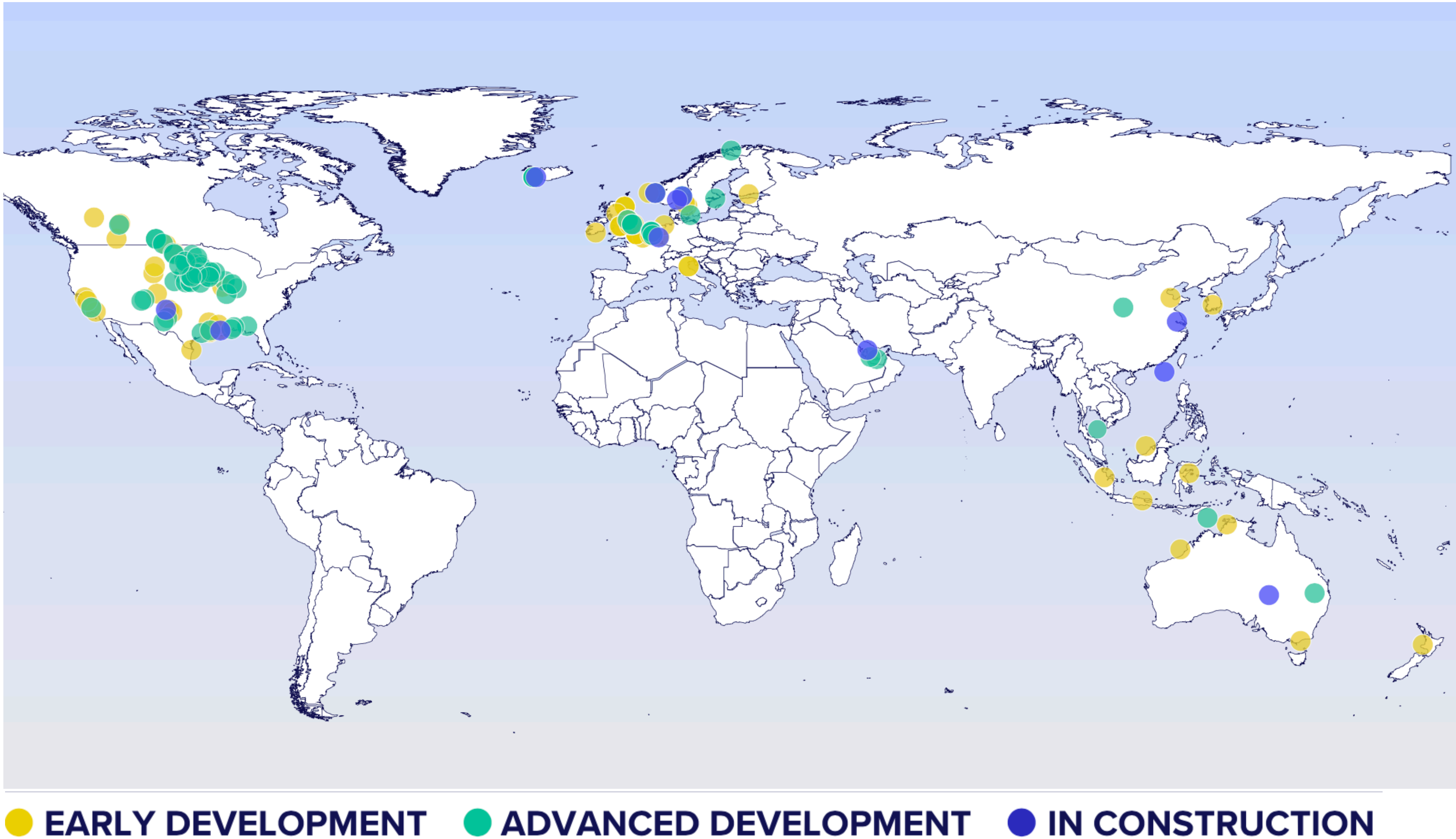
Source: Global CCS Institute. Global Status of CCS Report, 2018

Operational CCS Projects 2022



Source: Global CCS Institute. Global Status of CCS Report, 2022

Developing CCS Projects 2022



Source: Global CCS Institute. Global Status of CCS Report, 2022

CCS in 2022

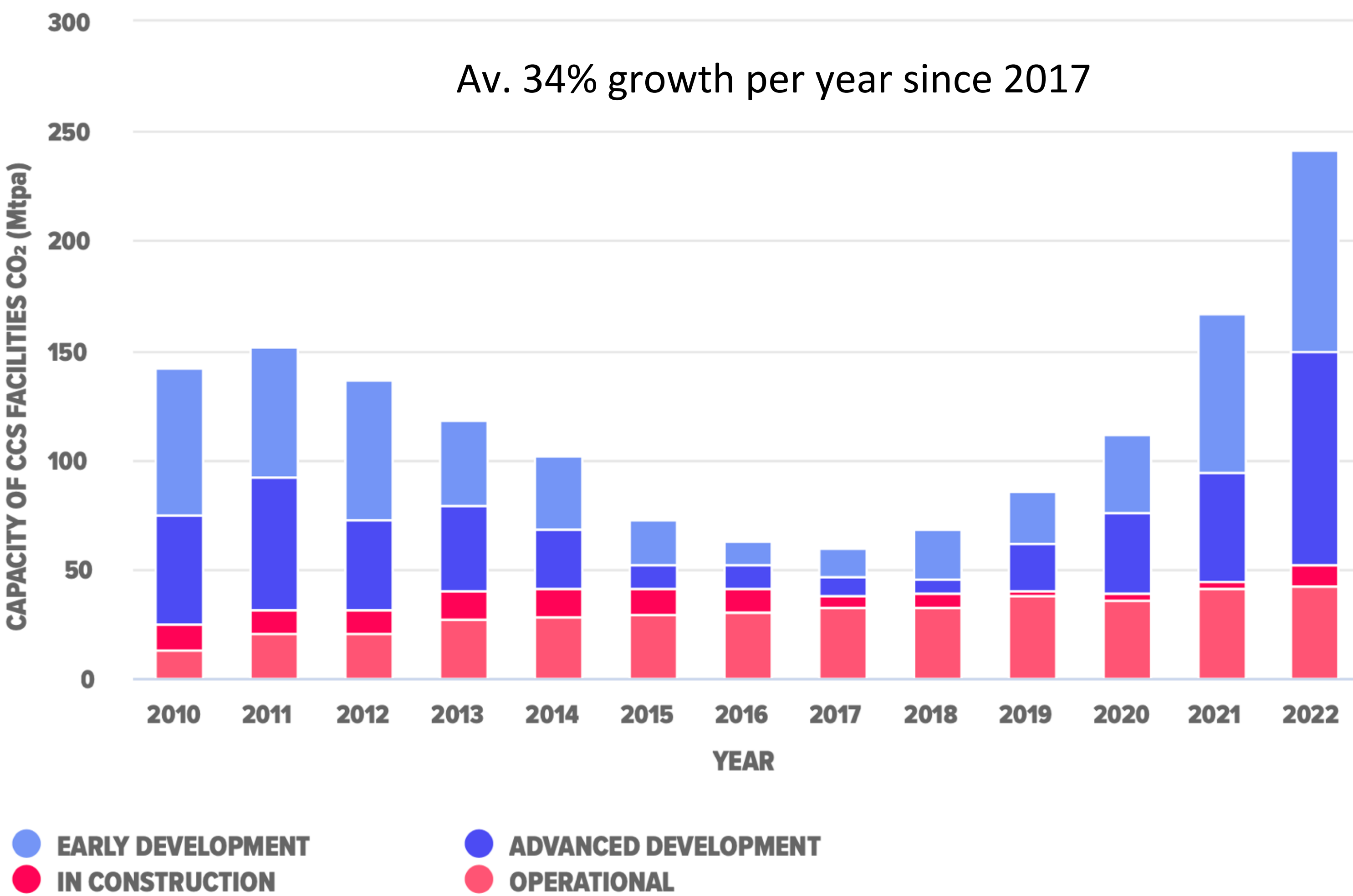
- Since 2017, capture capacity has grown at a compound rate of over 34 per cent per annum
- By facility count growth, the US continues to lead the way globally, with 34 new projects since 2021. Other leading countries in the past year include Canada (19 new projects), the UK (13), Norway (8), and Australia, the Netherlands and Iceland (6 each).
- New CCS projects have been announced each month in 2022. As of September 2022, there are 196 (including two suspended) projects in the CCS facilities pipeline.1 This is an impressive growth of 44 per cent in the number of CCS facilities since the Global Status of CCS 2021 report and continues the upward momentum in CCS projects in development since 2017.

	OPERATIONAL	CONSTRUCTION	ADV DEVELOPMENT	EARLY DEVELOPMENT	OPS SUSPENDED	TOTAL
NUMBER OF FACILITIES	30	11	78	75	2	196
CAPTURE CAPACITY (Mtpa)	42.5	9.6	97.6	91.8	2.3	243.9

Notable New Projects in 2021-2022

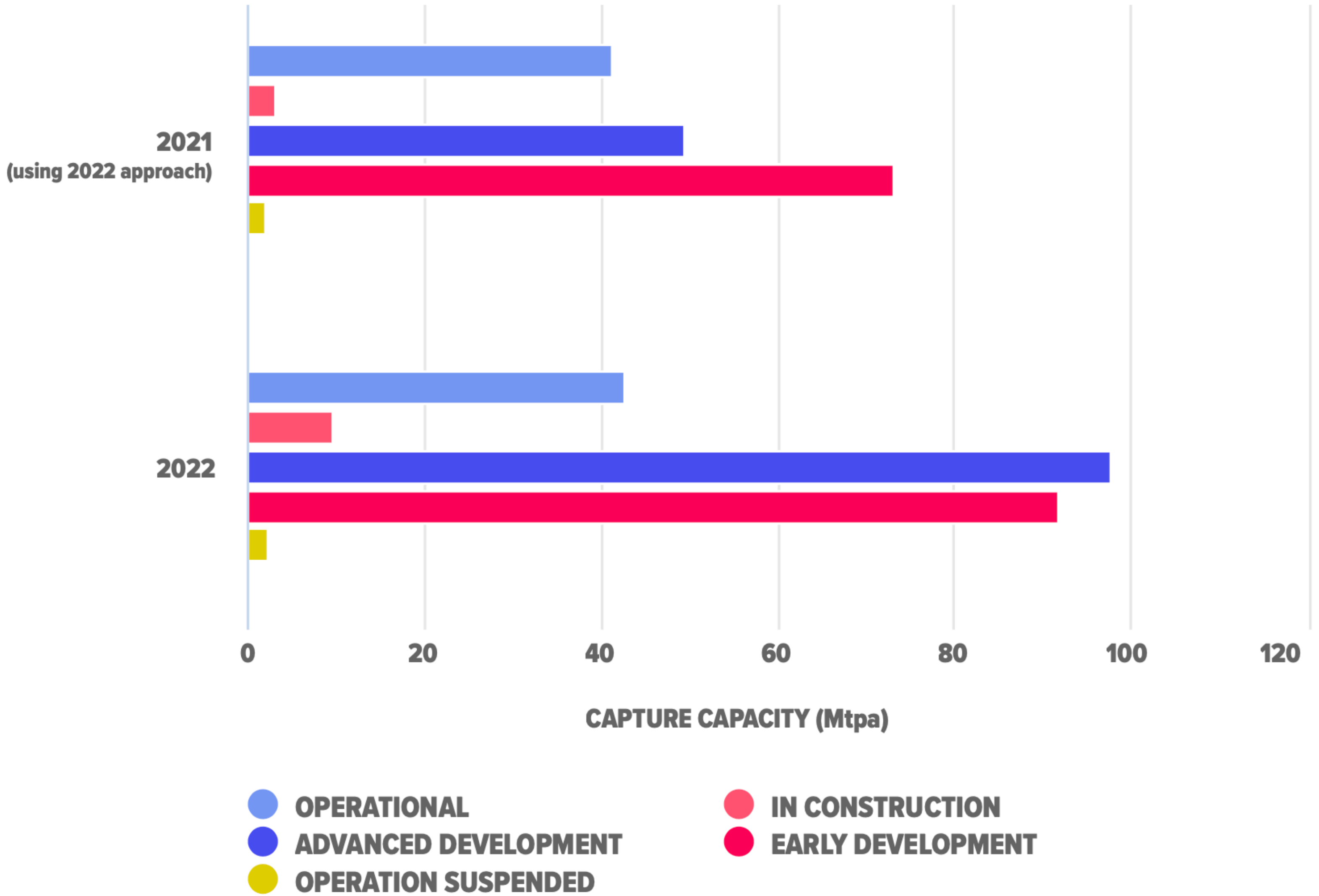
- Drax Power Station (UK) world's single largest bioenergy with CCS (BECCS) project, with a capacity of 8.0 Mtpa
- The Klemetsrud Waste-to-Energy CCS project (Norway) moved to In Construction, having secured funding. This is the first commercial-scale CCS project applied to a waste-to-energy facility.
- Glacier CCS Project (Alberta, Canada) is a CO2 capture facility on a natural gas-fired power station, the first of its kind at commercial scale from natural gas combustion streams worldwide.
- Air Products announced its blue hydrogen project (Louisiana, USA) incorporating natural gas gasification technology.
- ORCA, the world's first commercial direct air capture with carbon storage (DACCS) facility, was commissioned in Iceland. Its follow-up, the MAMMOTH project, was then announced.
- Bayu-Undan project by Santos (Australia) has moved into FEED. This project will capture CO2 from LNG production in Darwin and transport it via a repurposed pipeline for storage offshore.
- Occidental, in partnership with DACCS technology company Carbon Engineering, announced the construction of a 500 ktpa direct air capture CCS project (DACCS) in the

Pipeline of Commercial Facilities



Source: Global CCS Institute. GLOBAL STATUS OF CCS 2022

Capacity of CCS Facilities in Development



Source: Global CCS Institute. GLOBAL STATUS OF CCS 2022

Sleipner

Key Parameters:

Location:	NOCS, Offshore
Partners:	Equinor, ExxonMobil, Total
Start Date:	Oct 1996 -> Today
CO_2 Source:	Natural Gas Production
CO_2 stored:	24 MT
Pipeline:	4km
Storage type:	Saline aquifer
CO_2 Phase:	Dense

Main Issues:

- Initial Injectivity due to Sand Influx
- MMV requirements for first of its kind project

Sleipner – Lessons Learned

Successful CO_2 be injected.

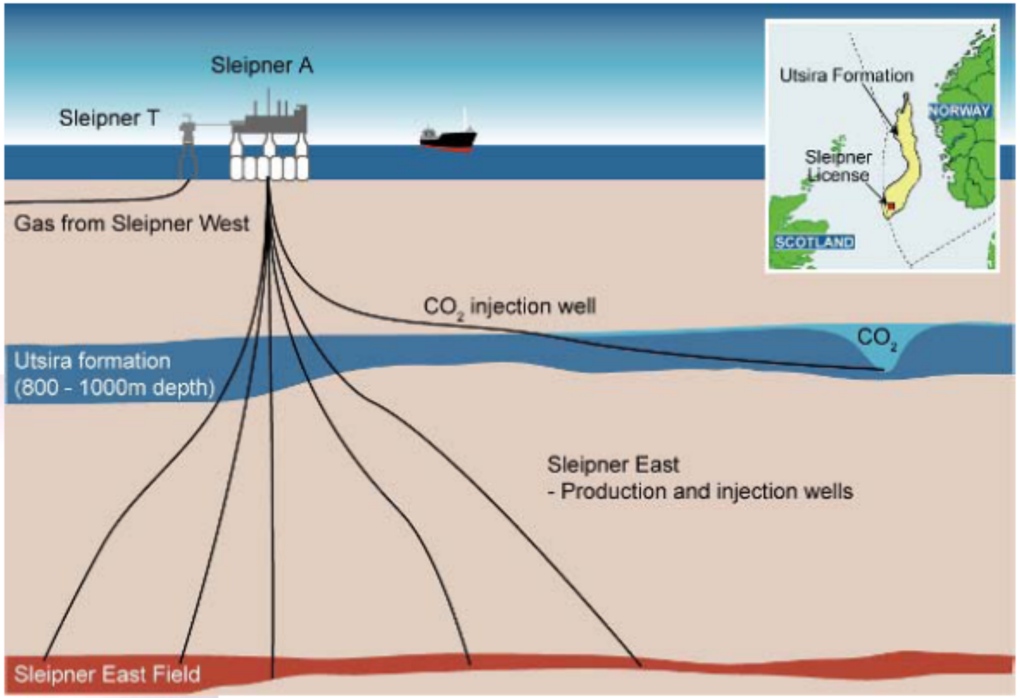
- CO_2 stays safely in the storage unit
- The project only went ahead due to incentive of avoiding Norwegian CO_2 tax.
- Downhole pressure and temperature gauges are needed for obtaining good control of the injection in-situ conditions and should be implemented for future CO_2 injection projects.
- Repeated seismic surveys have been crucial for ensuring both containment and conformance monitoring. Currently no good technology alternative exists.
- By acquiring both gravimetric and seismic monitoring, it is possible to combine the free CO_2 mass change and plume geometry data, and make an estimate of dissolution in formation water. This is important for longer term predictions. Together the datasets give much richer information than when handled separately.

Challenges

- Within the first year of injection there were considerable challenges due to sand influx.
  - In Sleipner the injection rates in the first period were 200m¬3/day/bar, 10% of the design rates.
  - As Sleipner utilises long horizontal wells, gravel packing was and still is the most effective technique.
  - gravel pack workover injectivity (2400m¬3/day/bar) was 20% higher than the expected injectivity (2000m¬3/day/bar).
- Challenges are to be expected in first of kind projects thus good standards of MMV is important to find and react to problems quickly – Due to success of the project (lack of interventions required) monitoring has been the focus of research and development since first gas

Sleipner Project

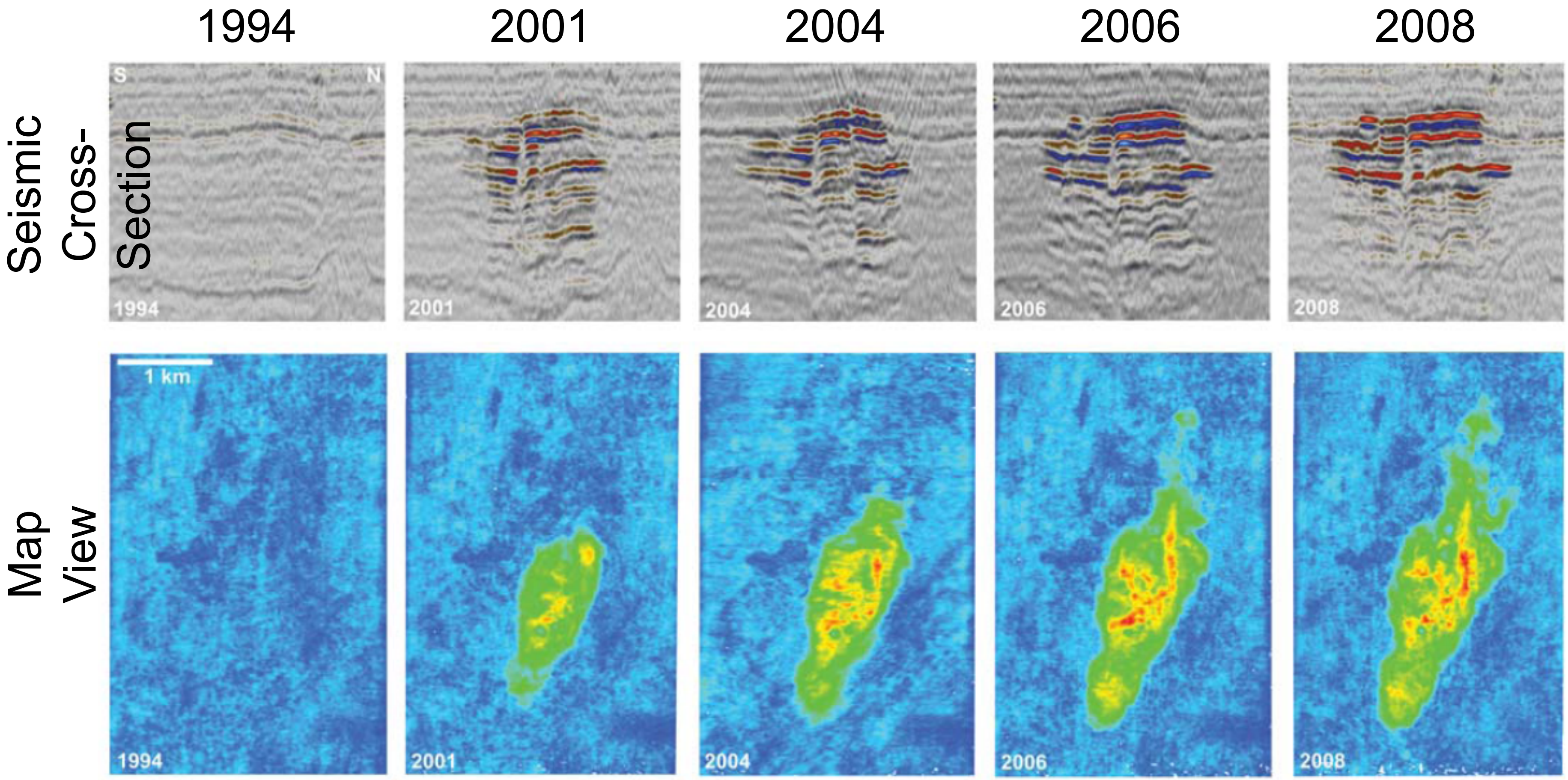
- 1996 to present
- 1 Mt CO_2 injection/yr
- Seismic monitoring



Natural Gas field with CO2:
- CO_2 stored to date 24Mt
- Saline aquifer
- CO_2 stored in dense

Main Issues:
- Initial Injectivity issues due to Sand Influx
- Monitoring requirements for first of its kind project

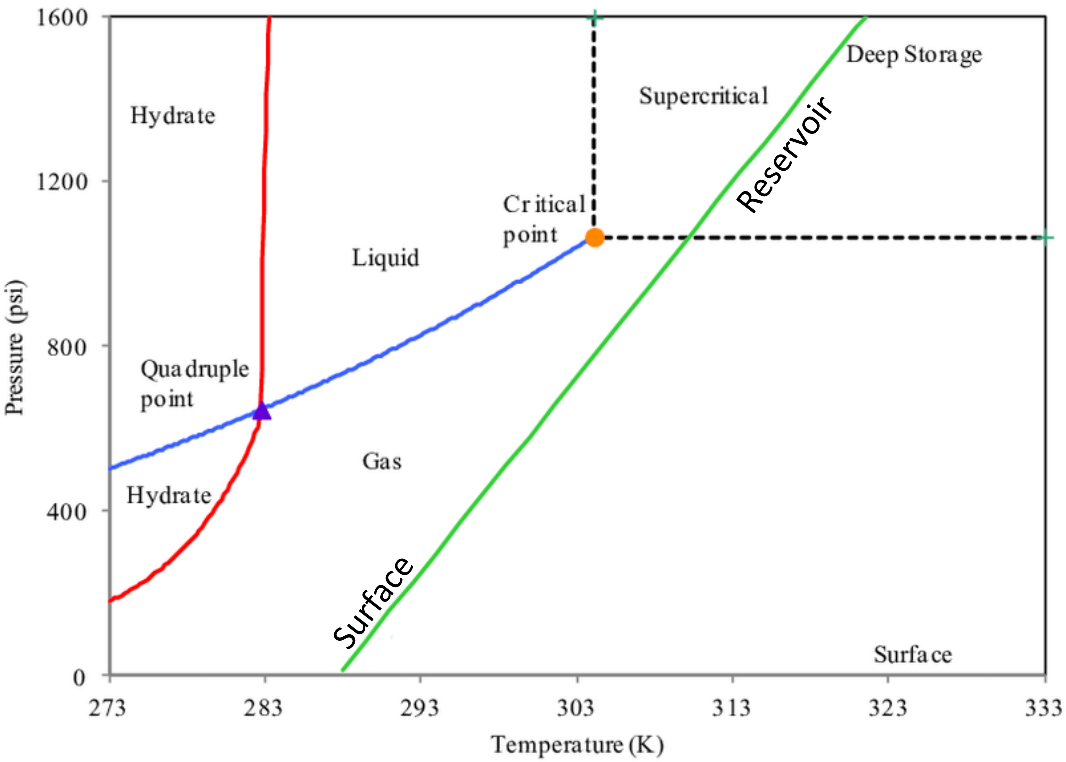
Sleipner Project

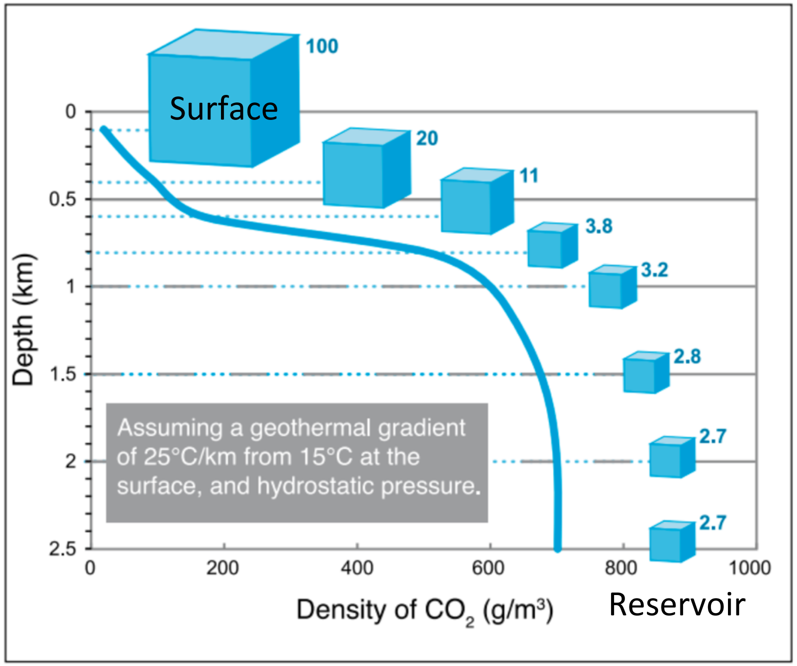


What's going on underground ?

Phase Diagram for CO_2

- Down to 800m, CO_2 density increases rapidly until it reaches a supercritical state.
- At depths below 1.5 km, the density and specific volume become nearly constant.
- A sudden leak will cause the fluid to cool quickly forming hydrates, the fast density change makes it explosive.



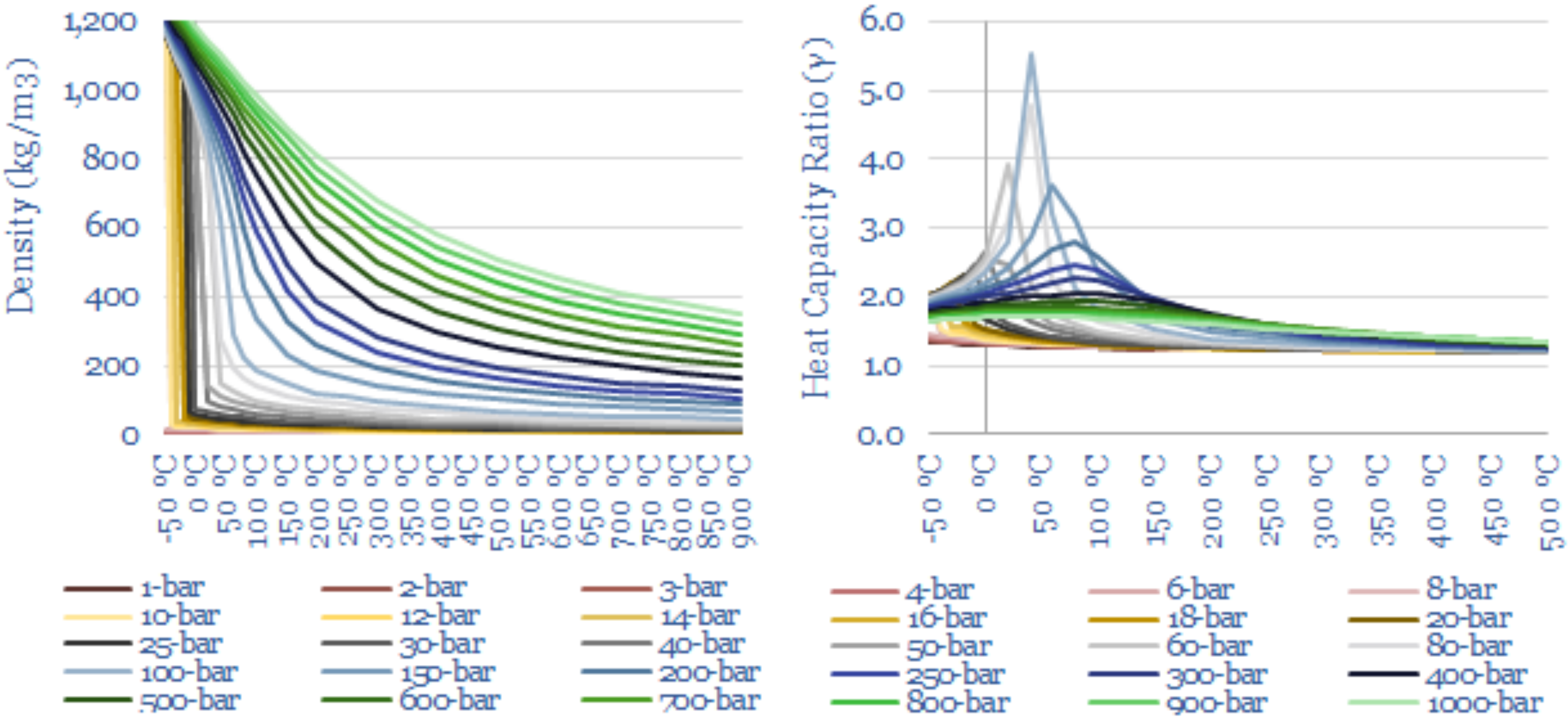


- Reservoirs need to be at >800m depth so CO_2 is stored as a dense fluid
- Be very careful of sudden leaks !

Molecule of CO_2

- Picture of CO_2 and H_2O and N_2
- Greenhouse gasses – rotational modes
- Packing for unusual properties

Strange Properties of CO2



Satartia, Mississippi Feb 2020

The spot where a carbon dioxide pipeline ruptured in Satartia, in February 2020, leading to the evacuation of 200 residents and the hospitalization of 45 others. No one was killed

Controlled test at Spadeadam, 2013

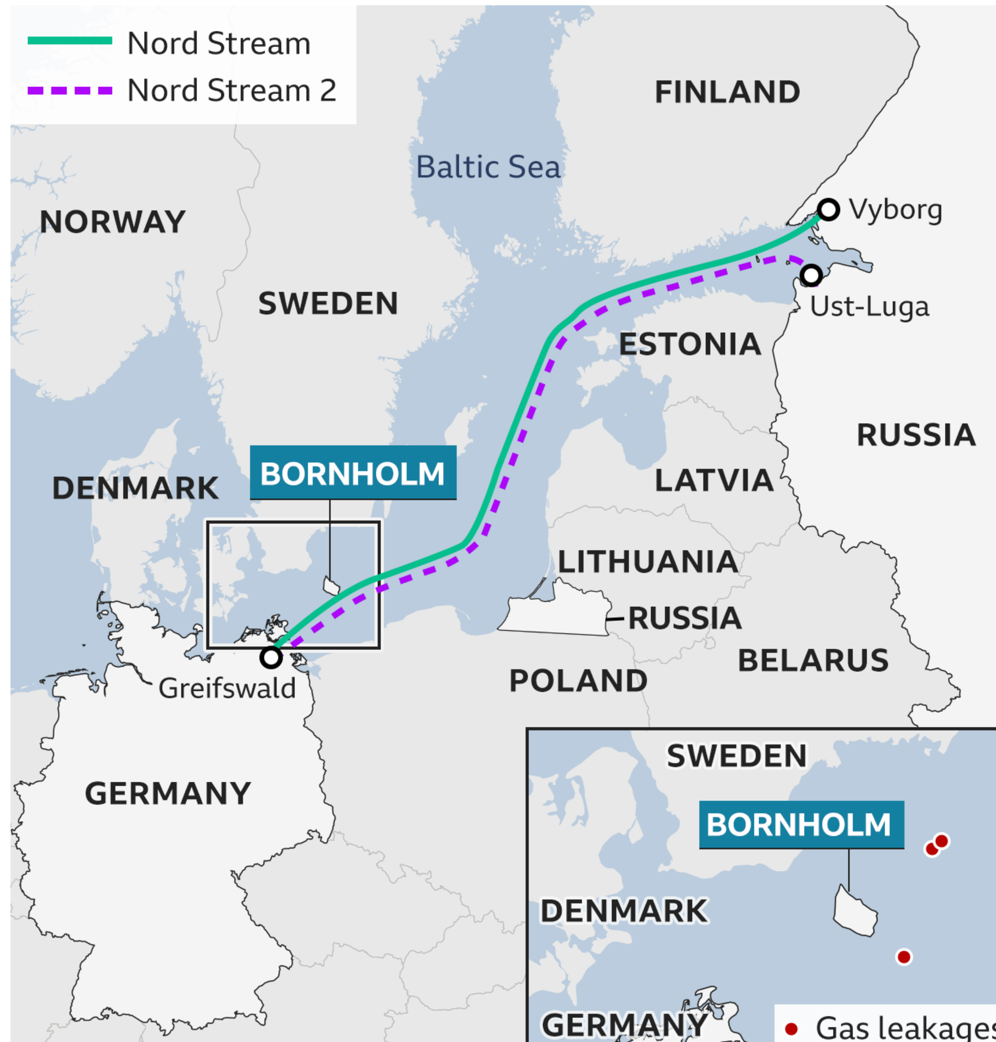
- Controlled test in a safe and secure environment at DNV Spadeadam Research & Testing centre.
- The test opened up vital access to data and observations for vital safety improvements.
- Provided insight on the consequences of such ruptures in terms of mass outflow, crater formation and dense gas dispersion.
- The test was carried out in summer 2013 and sponsors were National Grid, ENI, Statoil (now Equinor), Total, Petrobras and Gassco.

Nordstream Rupture (Methane) Sep 22, 2022

Gas Leak from Nord Stream1

Nord Stream pipelines from Russia

Leaks detected on both pipelines near Bornholm

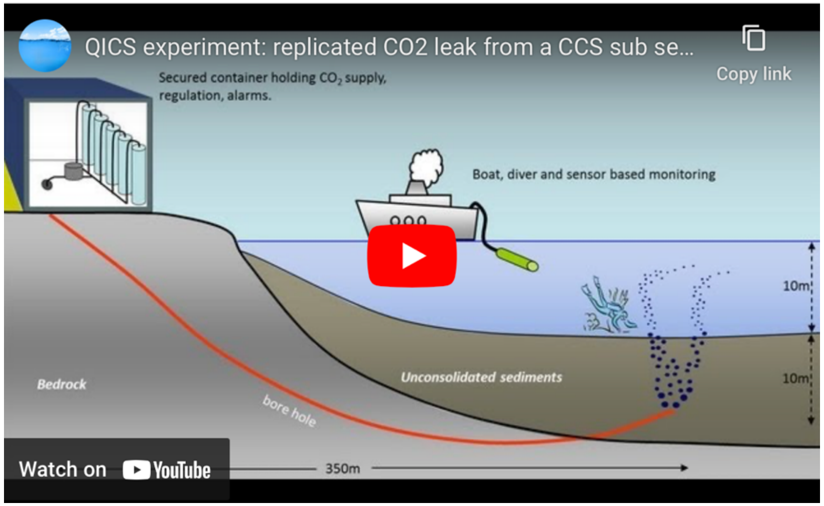


Source: Gazprom, Danish Maritime Authority

BBC

- Two subsea pipelines connecting Russia to Germany
- Possibly the single largest release of methane in history
- Many suspect it was the result of "gross sabotage."
- The Kremlin has dismissed claims it destroyed the pipelines claiming that it is the U.S. that had the most to gain.

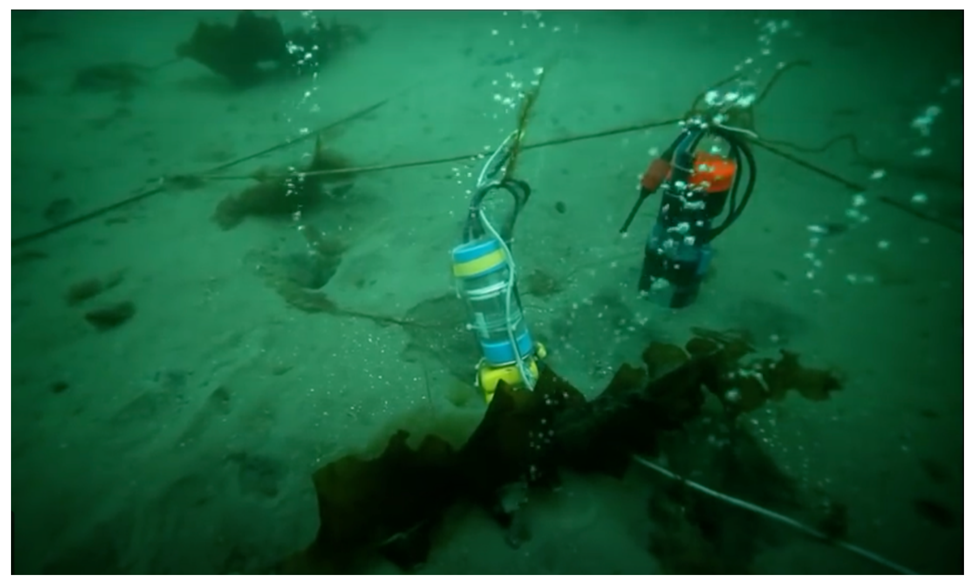
World's first CCS leak experiment completed in sea off Scotland - Jun 2012



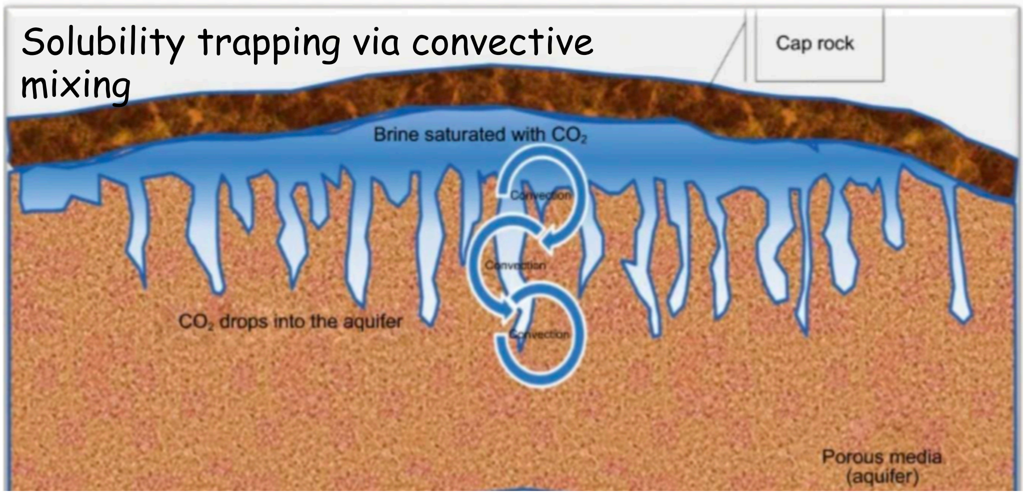
https://youtu.be/N_CUdiI5_r4

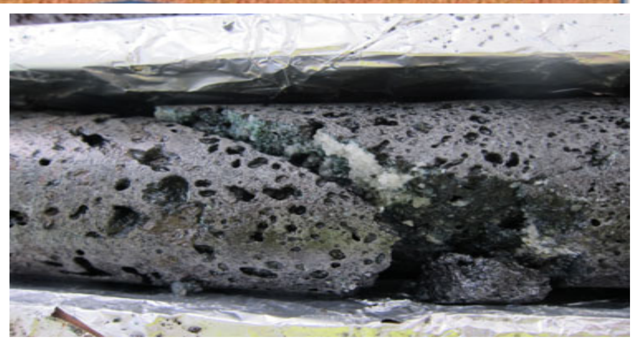
- The world's first experiment to investigate the impact of CO2 on the marine ecosystem
- Ardmucknish Bay, near Oban
- Experiment led by the Plymouth Marine Laboratory
- 4.5 tonnes of CO2 pumped into the seabed.
- Simulate a gas leak 350m from shore and 12m below seabed
- For 30 days, CO2 was supplied from a "pop-up" lab and through a borehole to the release site.

- Initial results show localised impacts that have affected some sea creatures.
- Clear but localised drop of the pH in the sediments and overlying in the bubble zone
- Some animals, such as sea-urchins, react negatively to the increase in CO2 whereas others, such as crabs, seem unaffected.
- Ongoing monitoring and analysis will further our understanding of how leaked CO2 affects the marine ecosystems.



CO_2 in the Subsurface





CO_2 precipitates as carbonate when injected into Basalts

In a hydrocarbon reservoir:

- CO_2 is probably miscible in hydrocarbon reservoirs
- CO_2 is probably neutrally buoyant in an oil reservoir but may sink in a gas reservoir where it is denser than methane
- CO_2 is used to enhance oil recovery (EOR)

In a saline acquifer:

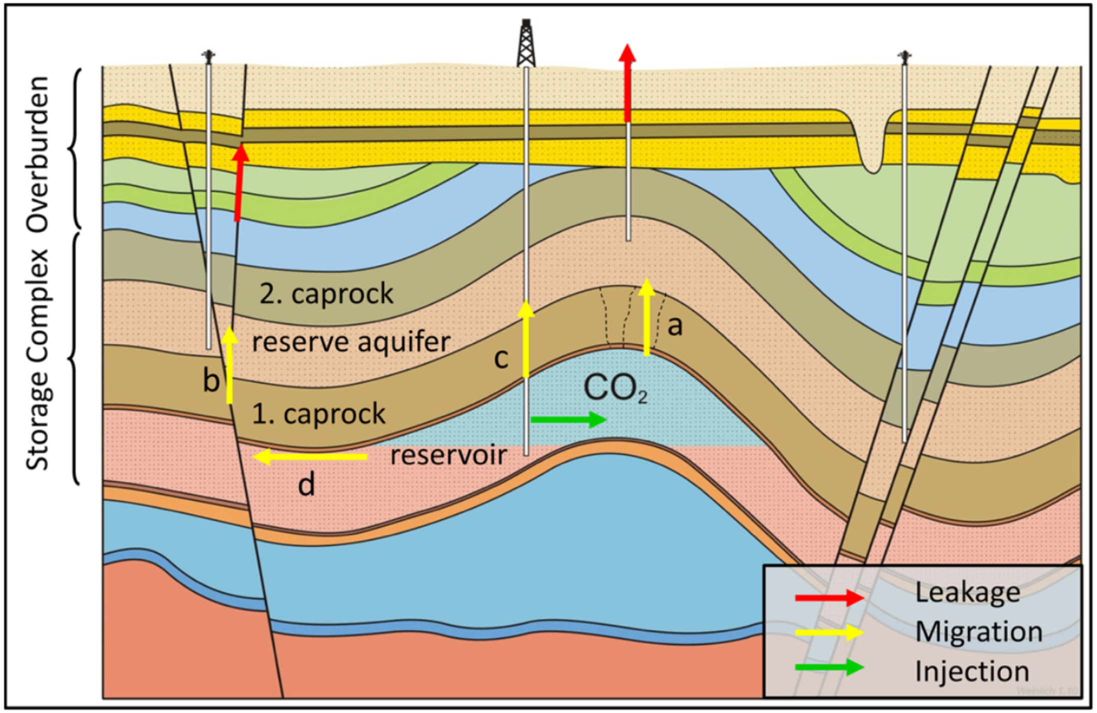
- CO_2 is immiscible and lighter than water so will rise
- CO_2 is very mobile and will rise
- CO_2 displaces water to saturation of 30-60%
- CO_2 may dissolve limestone rock or cement
- The ph is critical and CO_2 can dissolve the rock

Long term, CO_2 may:

- Remain in a supercritical or gas phase
- Dissolve in the formation waters
- Precipitate as a carbonate

Key Monitoring Requirements

- ESG Assurance for governments and stakeholders
- Provide assurance of containment
- Identify any breaches
- Track the plume
- Provide evidence of dissolution
- Available away from the wells
- Low cost

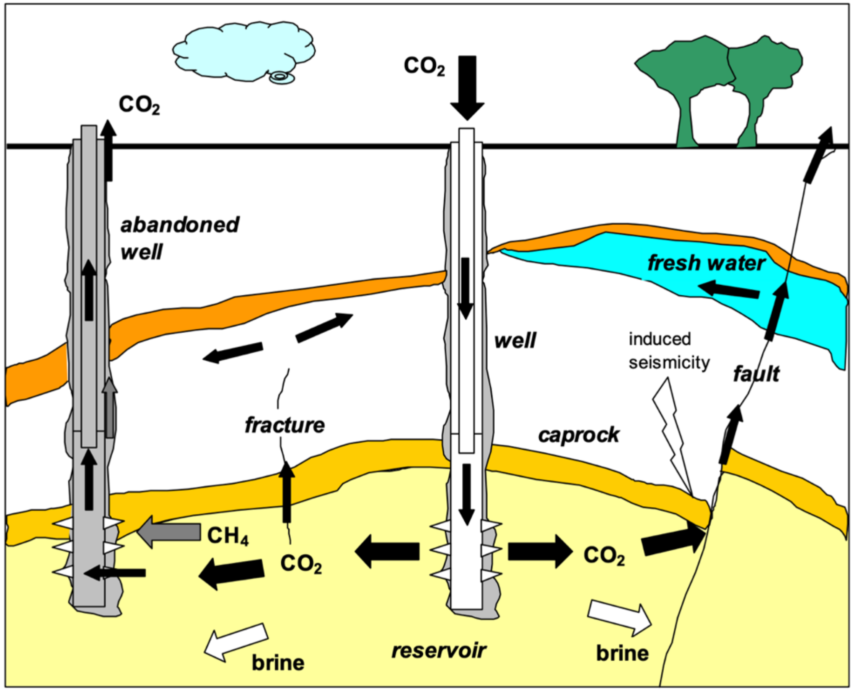


Risks of CO_2 Storage

From "Health, safety and environmental risks of underground CO2 sequestration. Overview of mechanisms and current knowledge" by Kay Damen, André Faaij and Wim Turkenburg. Utrecht University. 2003.

The risks of CO_2 sequestration in a geological reservoir can be divided into 5 categories:

- **CO_2 leakage:** CO_2 migration out of the reservoir through the subsurface and finally into the atmosphere
- **CH_4 leakage:** CO_2 injection might cause CH4 present in the reservoir to migrate out of the reservoir, through the subsurface and finally into the atmosphere
- **Ground movement:** Subsidence or uplift of the earth surface as a consequence of pressure changes induced by CO_2 injection
- **Seismicity:** The occurrence of (micro) earth tremors caused by CO_2 injection
- **Displacement of brine:** Flow of brine to other formations (possibly sweet water formations) caused by injection of CO_2 in open aquifers

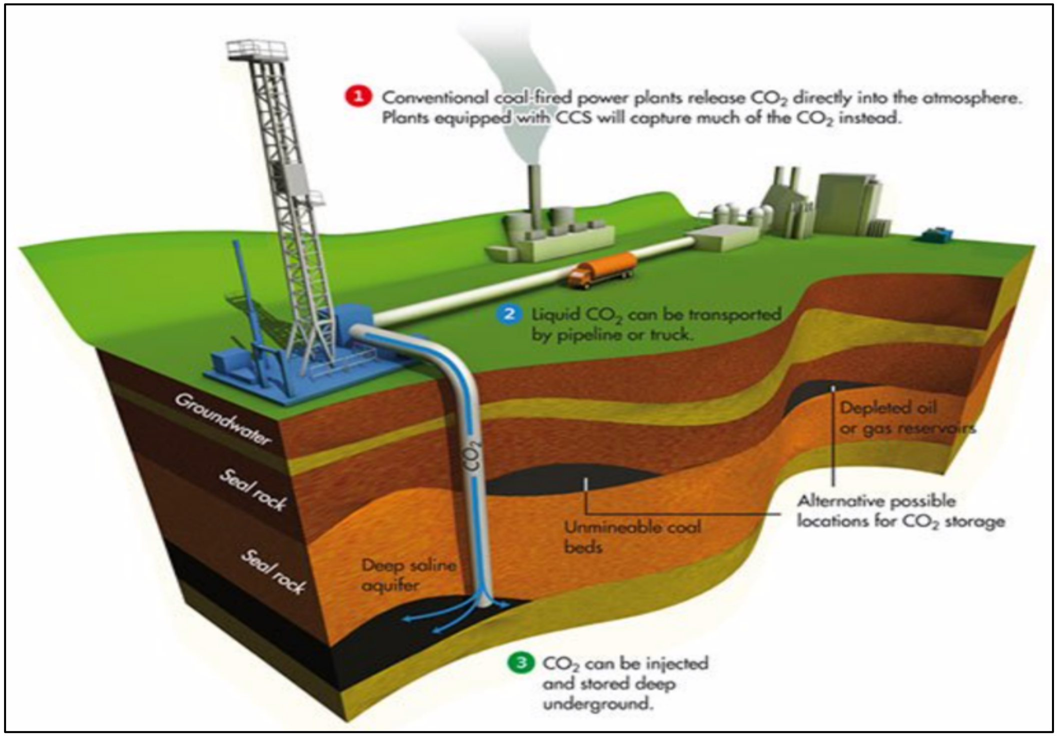


Risks of underground CO_2 sequestration. Black and grey arrows represent CO_2 and CH_4 flows (along abandoned wells, fractures and faults). White arrows represent brine displacement as a consequence of CO_2 injection.

Carbon Capture and Storage

- Use to decarbonize industries where CO2 emissions are inevitable
- Scaleable
- Likely to play a key role in meeting climate change targets
- Costs an additional ~$20-40/barrel - more expensive than some forms of renewable energy
- Not "Zero Carbon"
- Lacks a viable mechanism for cost sharing
- Oil companies see a solution, many green activists do not agree

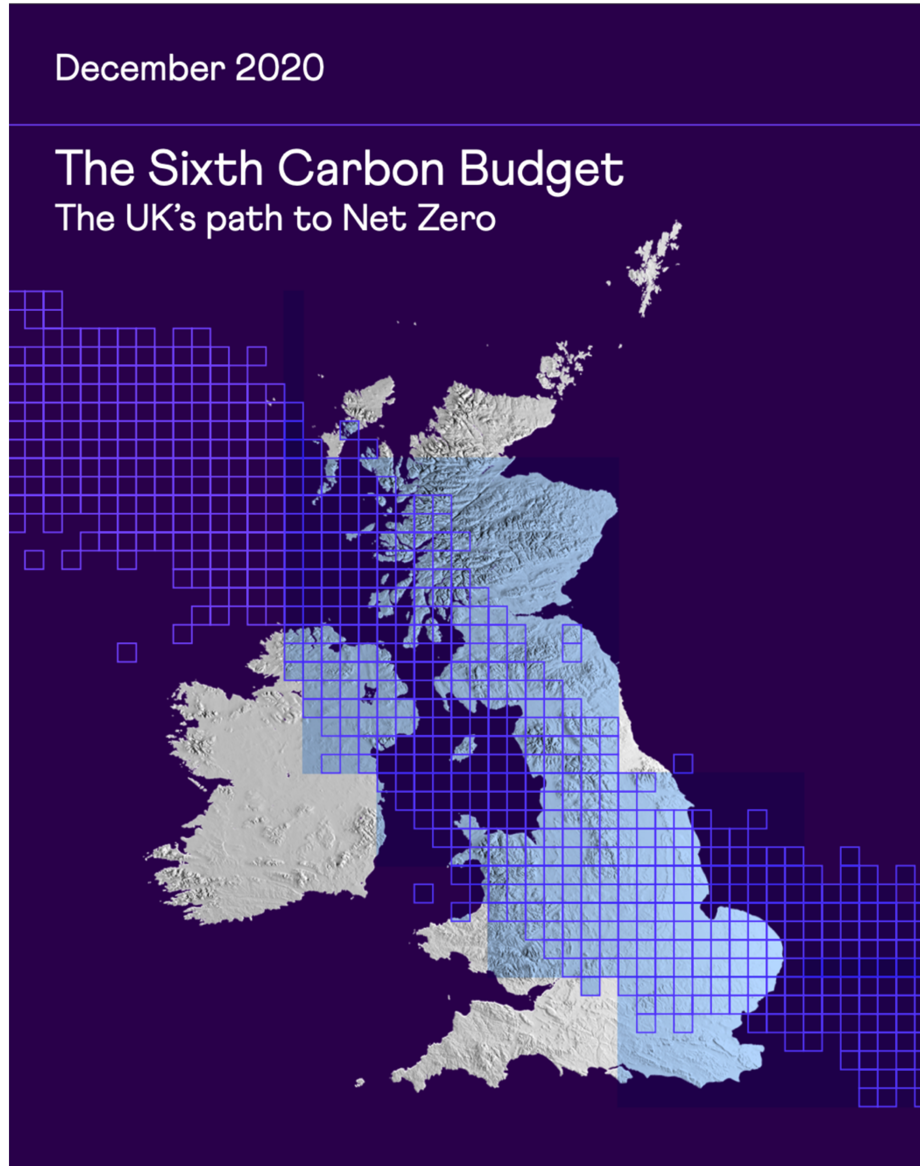
Cartoon showing a simple form of Carbon Capture (CCS) Bundogji, 2015.



What's Happening in the UK ?

CCC 6th Carbon Budget 2020

- Committee for Climate Change (CCC) is an independent body, that advises the UK government on targets and tracks progress.
- UK's Sixth Carbon Budget runs 2033 to 2037.
- Report describes the path to Net Zero and details the steps required.
- It is a blueprint for a fully decarbonised UK by 2050 at the latest. Net Zero now law !
- Requires a 78% reduction in UK territorial emissions between 1990 and 2035 to meet the Paris Agreement conditions.
- Challenging and advantageous. It creates new green jobs with wider gains in health & nature.
- Low carbon investment must scale up to £50 billion each year <1% GDP for next 30 years.
- A critical moment arrives in the early 2030s, as sales of most high- carbon goods are phased out altogether.
- UK emissions fall sharply over the 2030s, before levelling off in the 2040s,
- The 2020s must be decade ot decisive action.
- Costs and benefits must be distributed fairly.



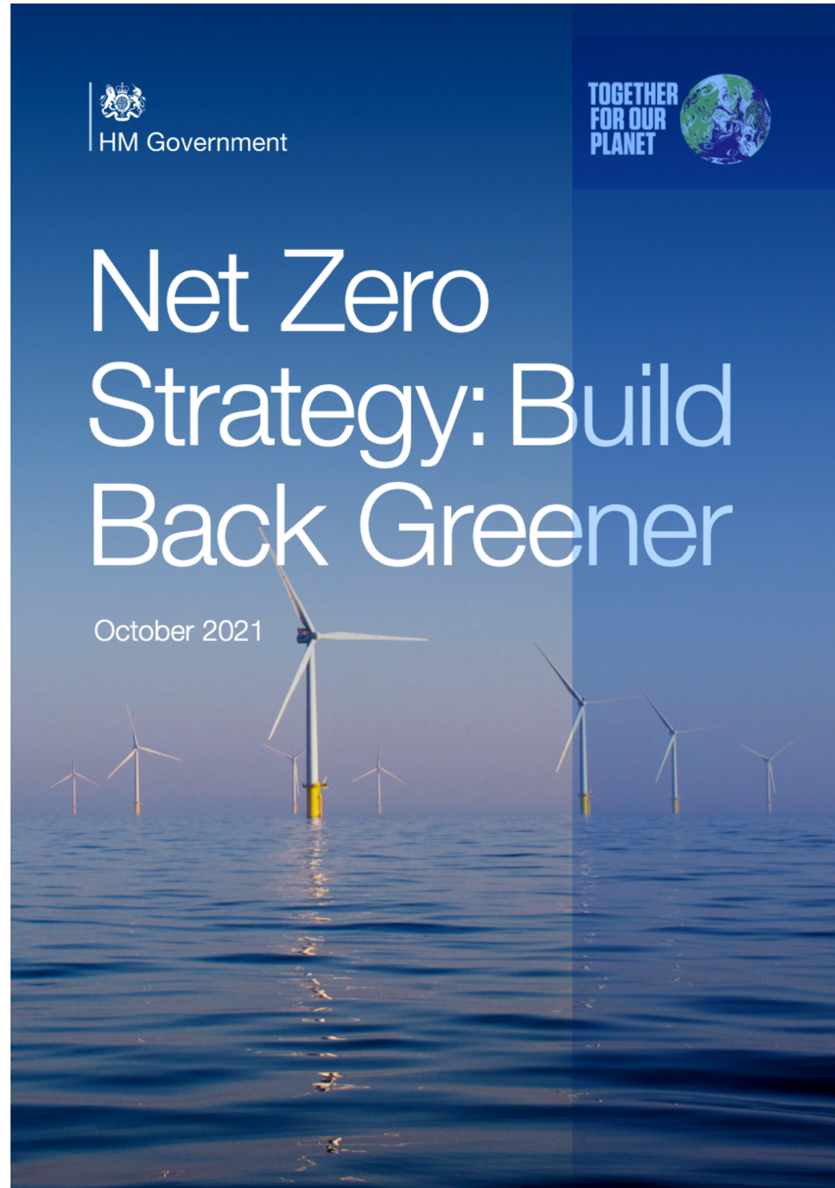
UK Government Net Zero Strategy Oct 2021

Why Net Zero

The Journey to Net Zero

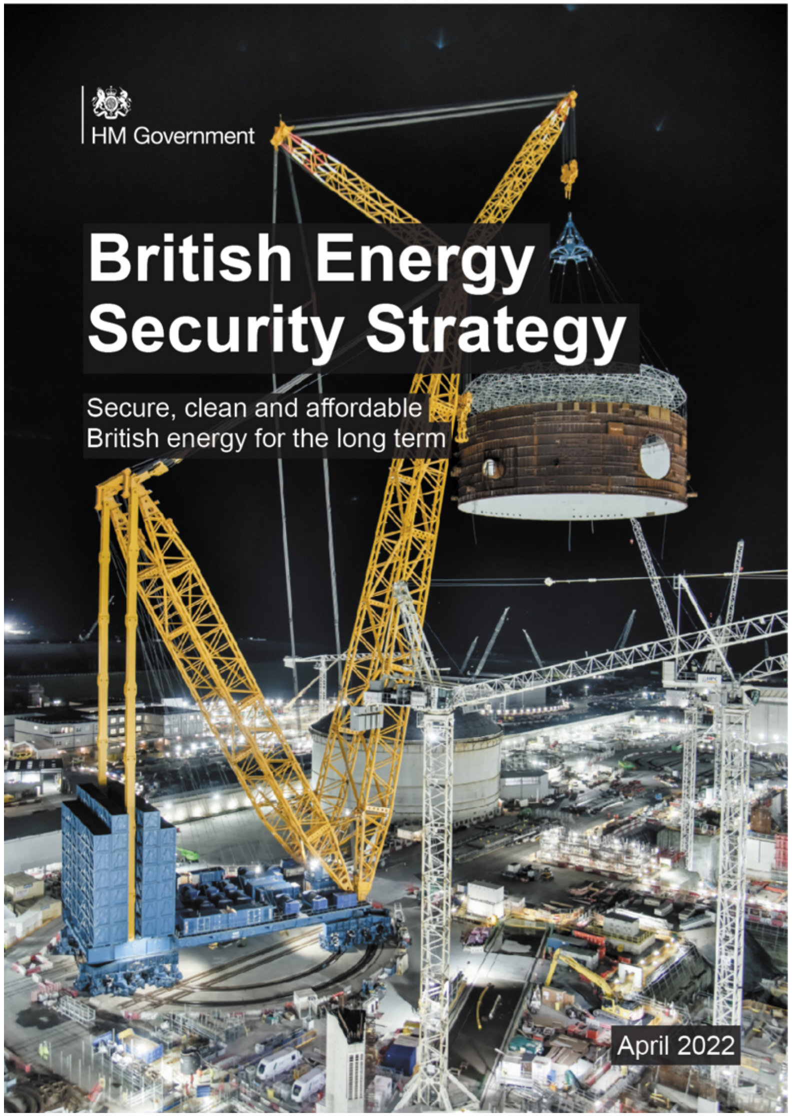
Reducing Emissions across the Economy
- Power
- Fuel Supply and Hydrogen 107
- Industry
- Heat & Buildings
- Transport
- Natural Resources, Waste & F-Gases
- Greenhouse Gas Removals

Supporting the Transition across the Economy
- Innovation for net zero
- Green Investment
- Green Jobs, Skills, and Industries
- Embedding Net Zero in Government
- Local Climate Action
- Empowering the Public and Business to Make Green Choices
- International Leadership and Collaboration

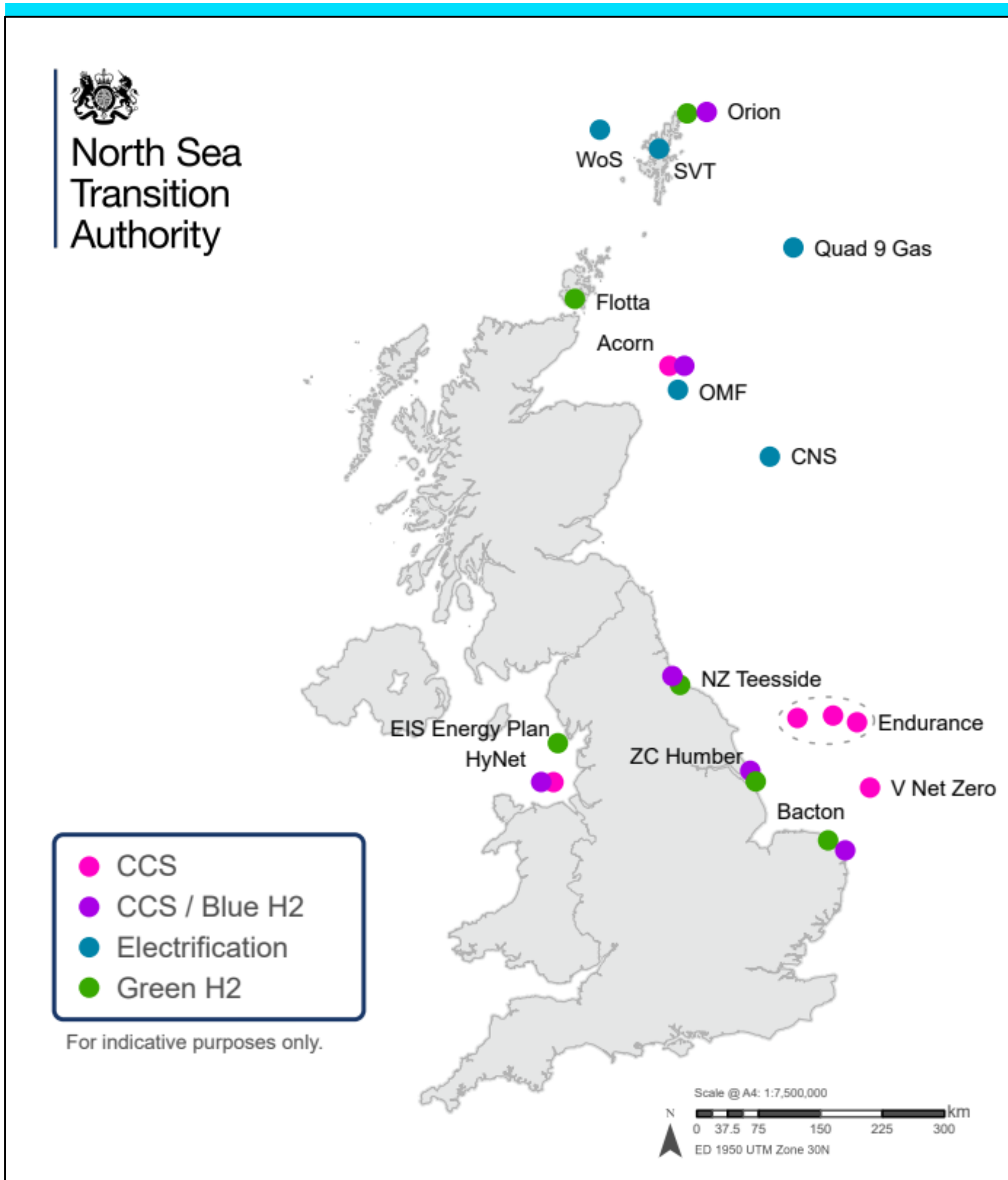


UK Government Apr 2022

- UK government has made CCUS a core part of its Ten Point Energy Secutity Strategy, which lays out the future of the UK's energy market.
- It has promised to establish four CCUS industrial "clusters" of big carbon emitters and storage facilities by 2030.
- These will collectively capture 20-30 million tonnes of carbon dioxide every year.
- The government also aims to boost employment by using the UK's existing proficiency and skills in the oil, gas and engineering industries to make it happen.



North Sea Licences



Licenses

- 13 current Licences
- 2 Track 1 Licences (Hynet and ECC), 2 Track 2 in 2023
- 13 more storage licences from 26 Applicants in 2023

Finances

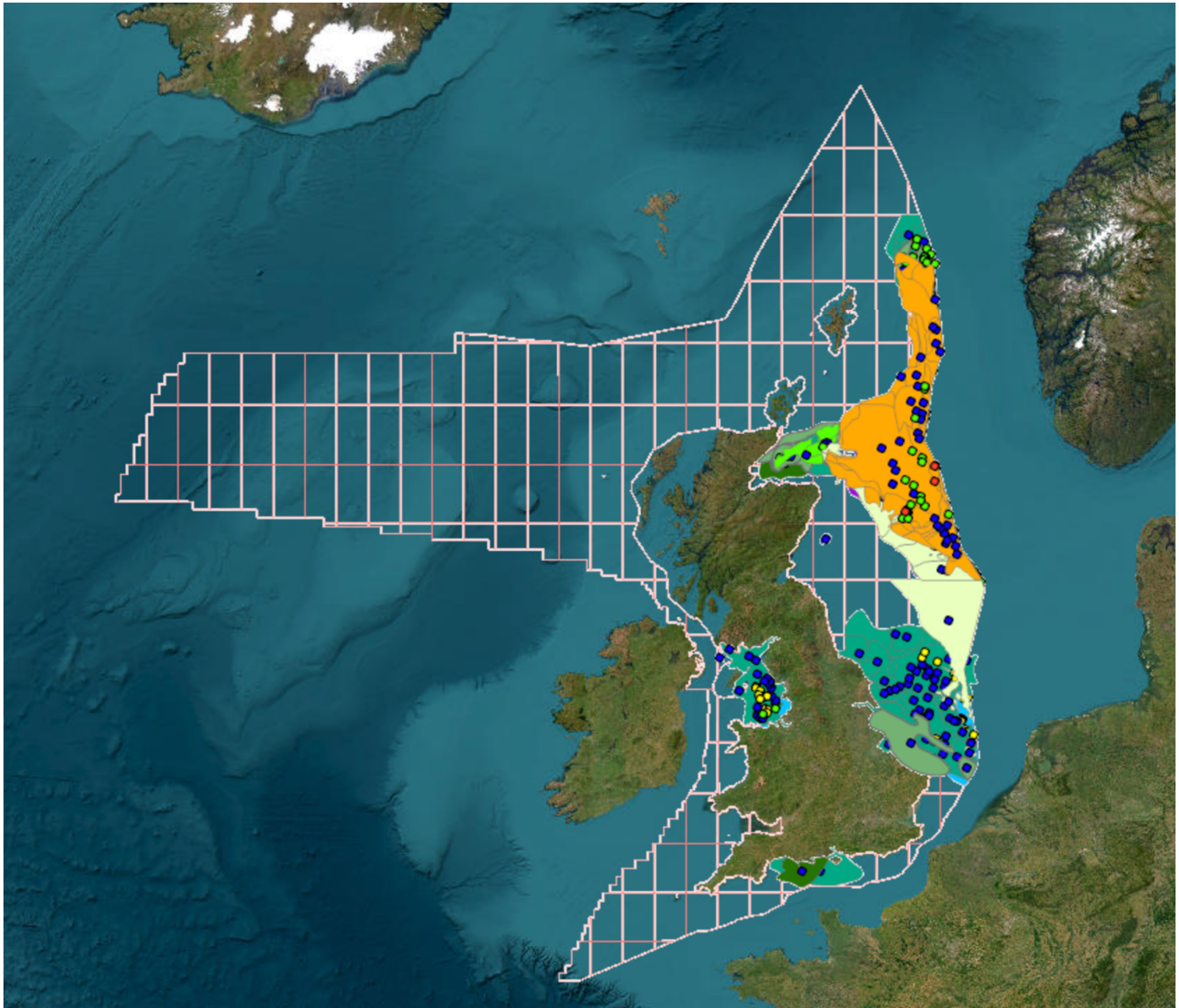
- £1billion through CCUS Infrastructure Fund (CIF)

Targets

- Two CCS clusters by the mid-2020s. Two more by 2030.
- Capture and store 20-30MtCO2/y by 2030 and over 50 MtCO2/yr by 2035.

Source: NSTA Web Site

CO2 Stored – Database of Storage Sites



CO2 Stored provides access to world-leading data for over 500 potential CO2 storage sites offshore UK.

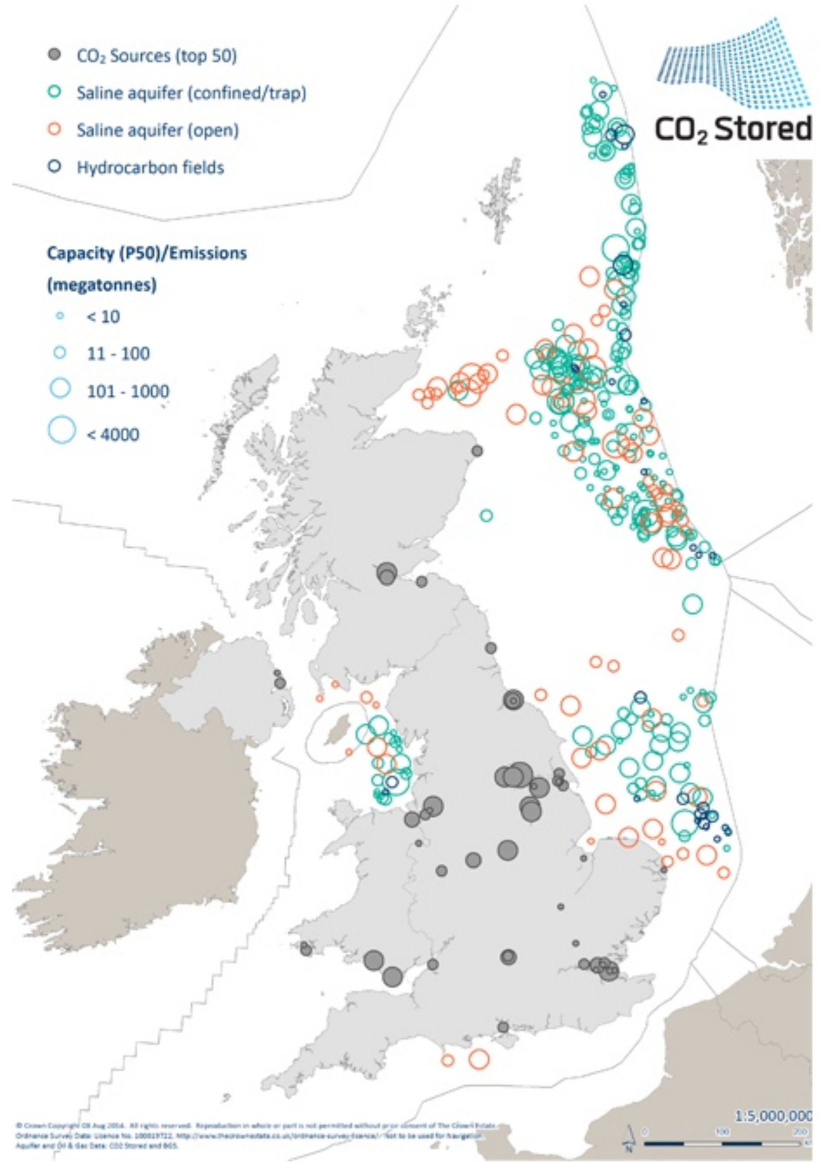
The database was developed by the Energy Technologies Institute (ETI) to provide a comprehensive, auditable estimate of UK CO2 storage capacity.

The project was executed by a consortium of academic, public and private sector organisations:

- The British Geological Survey (BGS)
- Durham University
- Element Energy Limited
- GeoPressure Technology Limited (GPT, an Ikon Science company)
- Geospatial Research Limited (GRL)
- Heriot Watt University
- Imperial College London (ICL)
- RPS Energy Limited
- Senergy Limited
- University of Edinburgh (UoE)

CCS BGS CO2 Stored

- Two types of store: Depleted gas reservoirs and Saline Aquifers
- Integration of offshore energy systems including CCS could deliver around 30% of total carbon reduction needed to meet 2050 net zero target
- 75-180 MtCO2/y captured and stored by 2050
- 78 billion tonnes of CO2 potential storage capacity in the UKCS sufficient to meet hundreds of years of demand (BGS)



Source: CO2 Stored Web Site

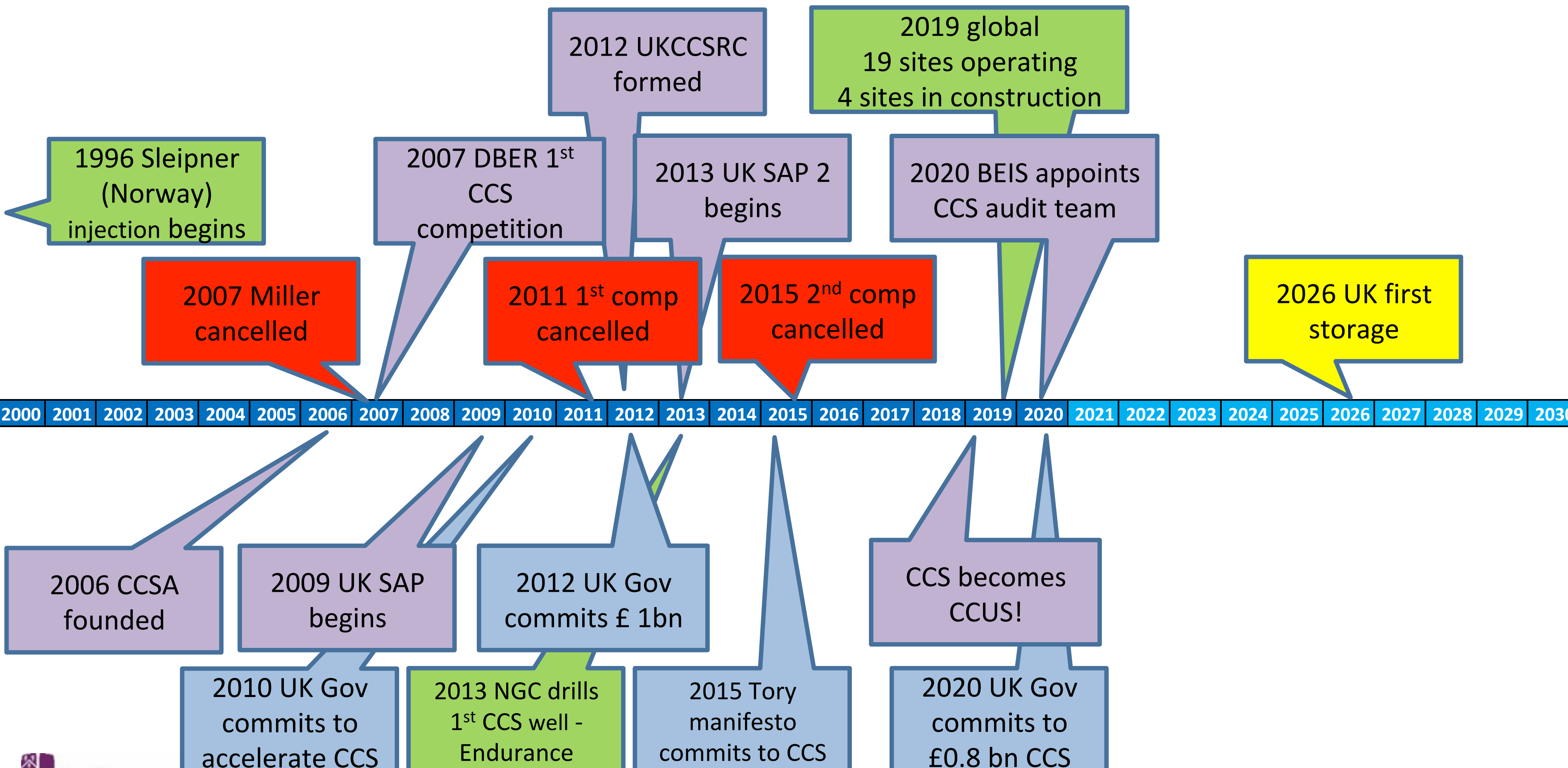
UK Position on CCS

Our Energy Integration Project illustrates that integration of offshore energy systems, including CCS, could deliver around **30% of total carbon reduction requirements** needed to meet the 2050 net zero target.

75–180 million tonnes of CO_2 / year captured and stored by 2050, or up to one third of the current UK emission baseline (CCC (2020) The Sixth Carbon Budget: The UK's path to Net Zero)

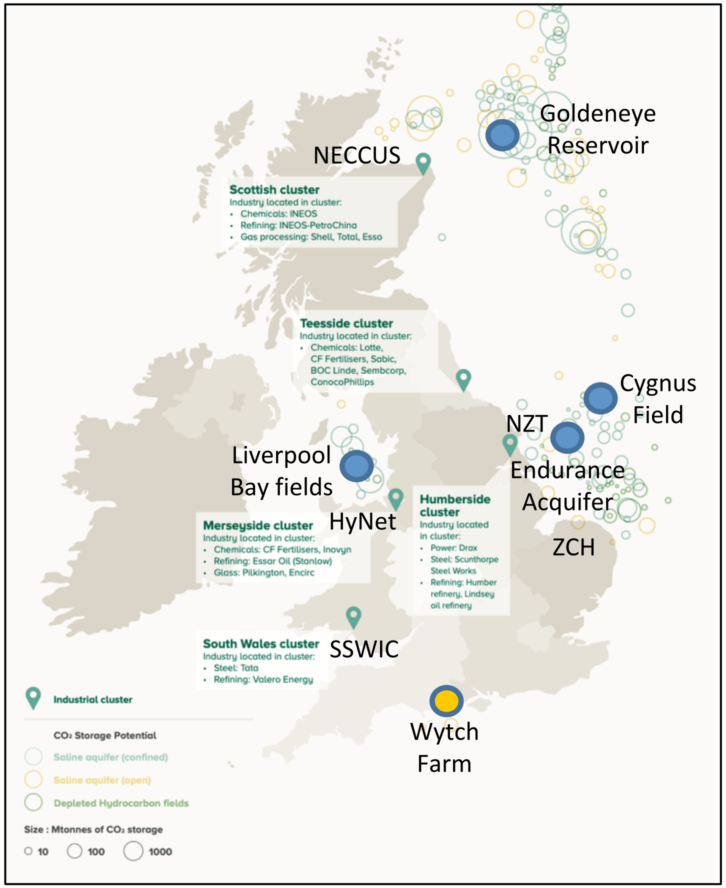
78 billion tonnes of CO_2 potential storage capacity on the UKCS, sufficient to meet hundreds of years of UK demand (British Geological Survey, co2stored.co.uk)

UK CCS Timeline



Durham University
Durham Energy Institute

CCS Projects in the UK (GCCSI)



UK Highlights

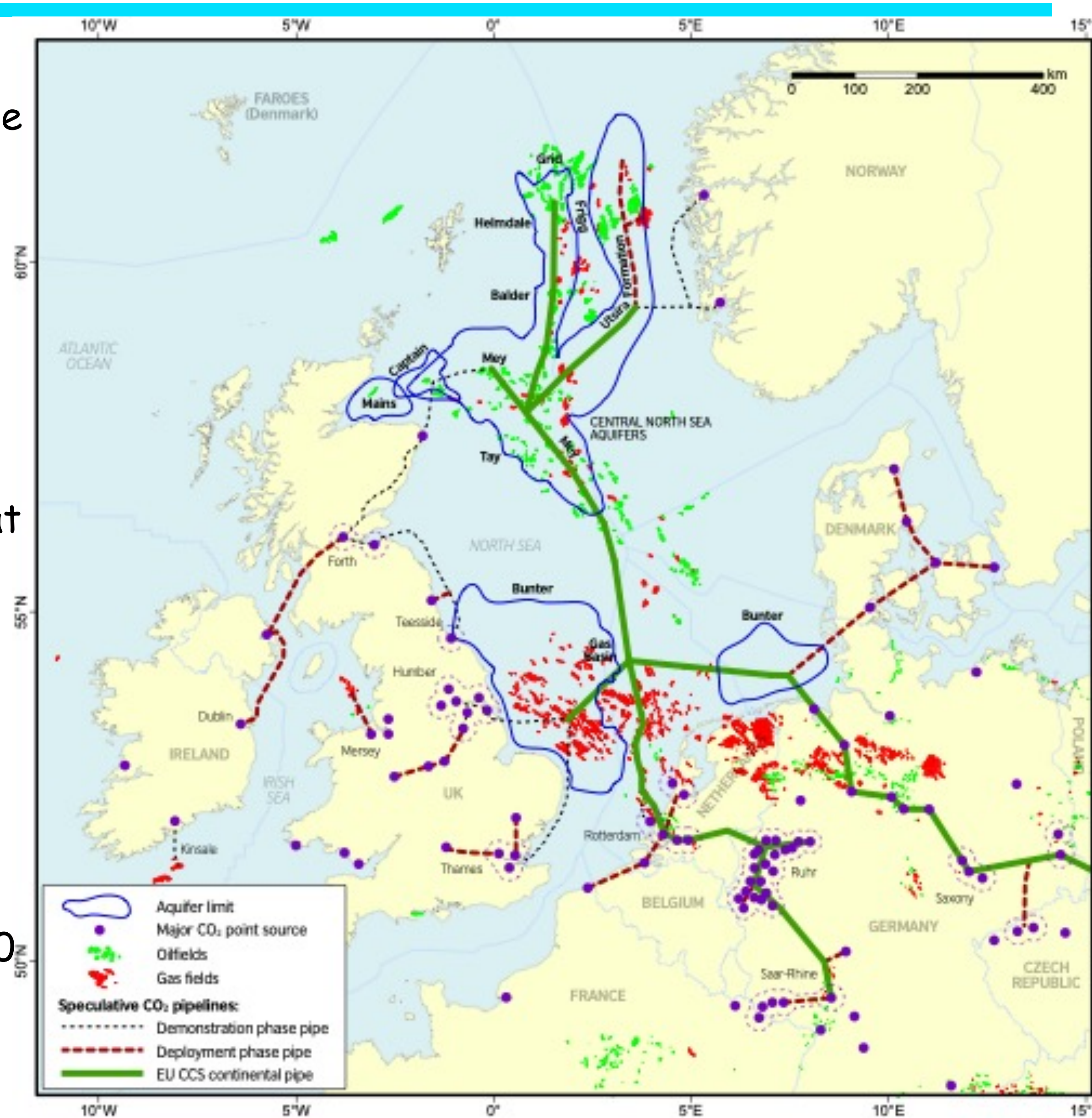
- UK emissions ~350 Mtpa a 29% drop since 2010.
- UK target of 68% emission reduction by 2030.
- CCS in 2 industrial clusters by the mid-2020s.
- Establish 4 such sites by 2030.
- Capturing up to 20-30 Mtpa CO2 by 2030.
- £1 billion CCUS infrastructure fund.

CCS Potential Hubs

- Hynet North West 4.5-10.0 Mtpa
- South Wales Cluster 9.0 Mtpa
- Net Zero Teeside 0.8-6.9 Mtpa
- Humber Zero and Zero Carbon Humber 26.0 Mtpa
- DelphHYnus
- Acorn 5.0-10.0 Mtpa

• Emitter Clusters and Storage in Europe

- 73 CCS facilities in development across Europe and the UK (2022)
- Supportive climate policy programs and measures
- Funding through the EU Innovation Fund and host countries
- In 2021 the European Commission confirmed that reaching climate objectives will require a significant scale-up of carbon removal solutions, particularly within the next 10 years.
- The EU Innovation Fund, which aims to invest around €38 billion by 2030 toward innovative clean technologies in Europe

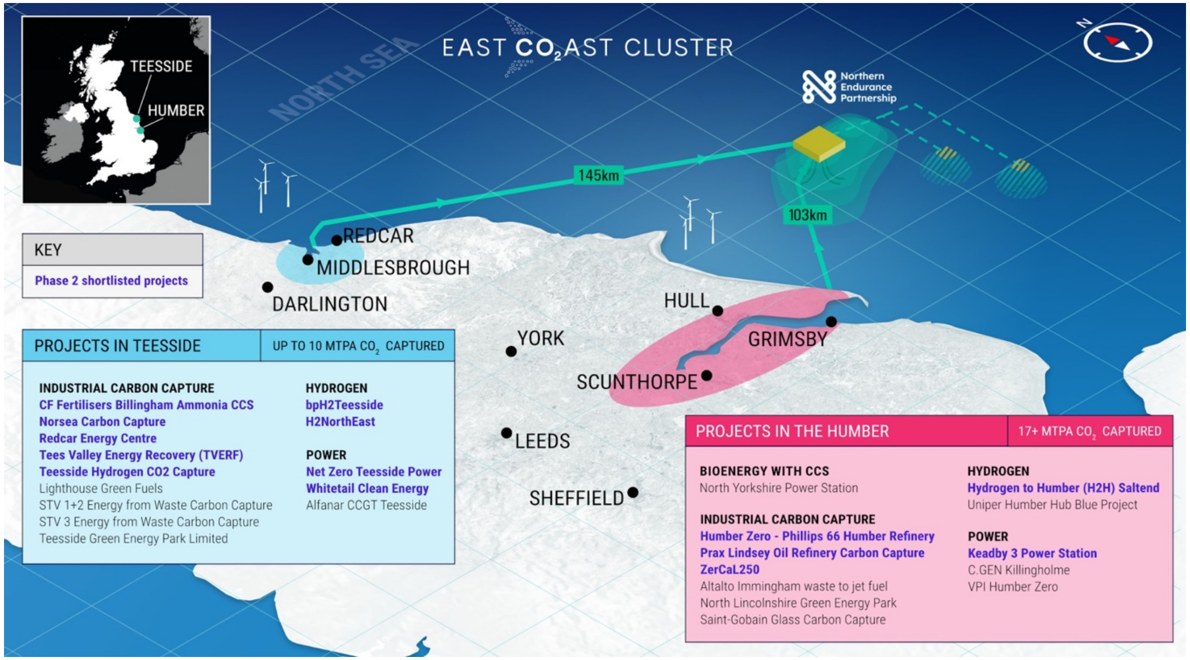


Projects in the UK

East Coast Cluster (ECC)

Northern Endurance Partnership (NEP)

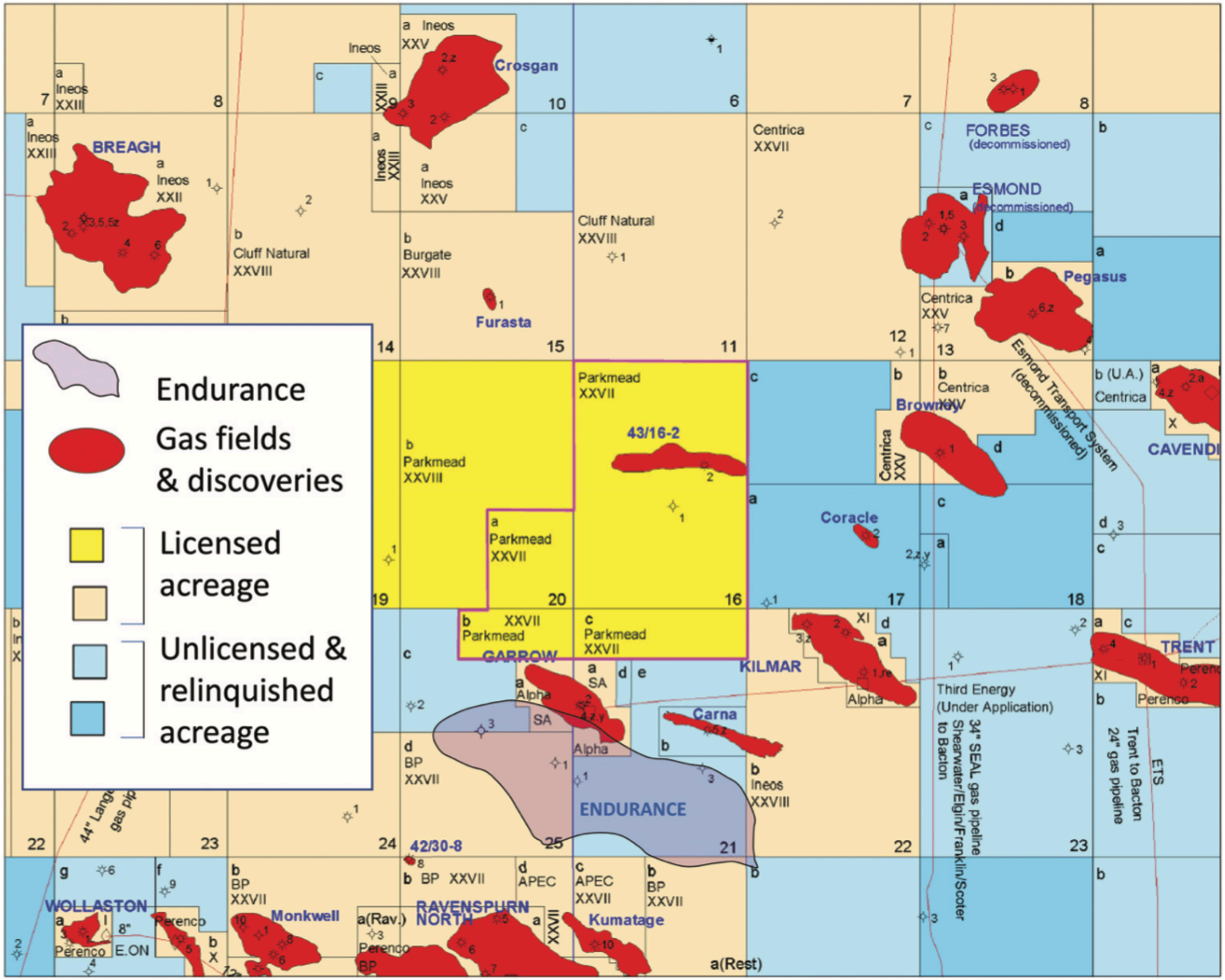
- Two of the UK's largest industrial clusters: Zero Carbon Humber (ZCH) and Net Zero Teeside (NZT)
- Partners include: BP, Shell, Total Energies, Equinor, National Grid
- Final Investment Decision (FID) in 2023, first CO2 capture and injection in 2026.
- CO2 at the Endurance saline aquifer offshore
- Endurance has capacity for up to 450MtCO2
- Storage up to 10 MtCO2/y by 2030 up to 23MtCO2/y by 2040



Project Includes:

- World's first –ve emissions power station at Drax and hydrogen power station
- World's first flexible gas power plant with CCUS.

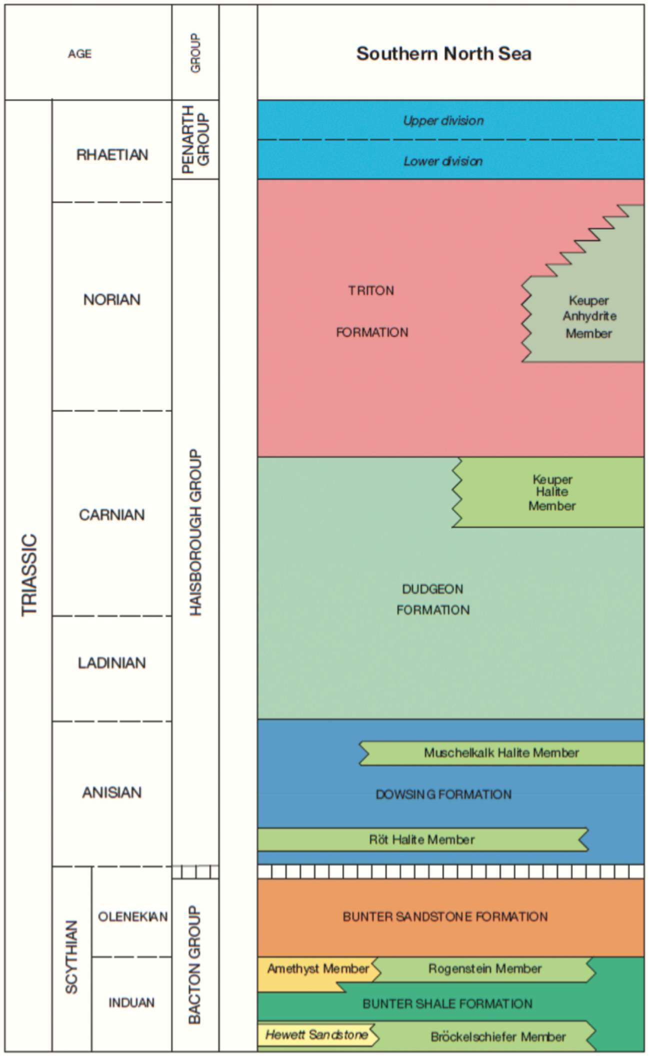
Regional Map showing the Location of the Endurance Saline Aquifer.

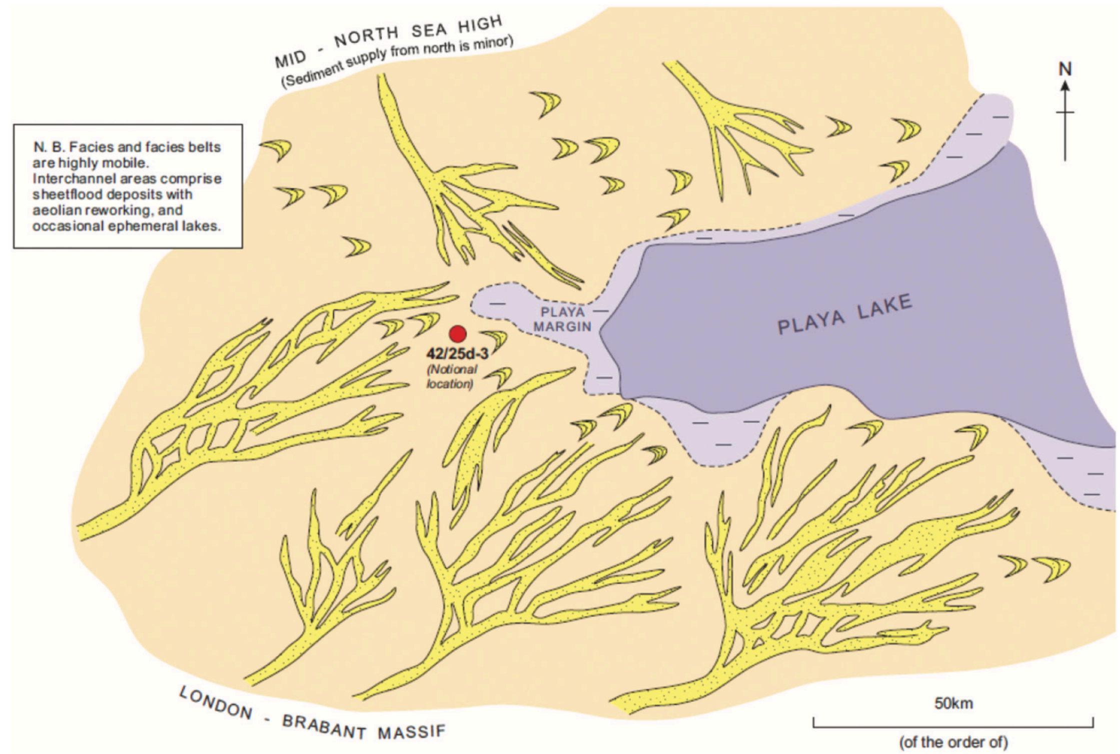


Source: Gluyas and Bagudu, 2020. The Endurance CO2 storage site, Blocks 42/25 and 43/21, UK North Sea

Giles Watts Feb 2023

Stratigraphy and Depositional Environment of Bunter Sandstone



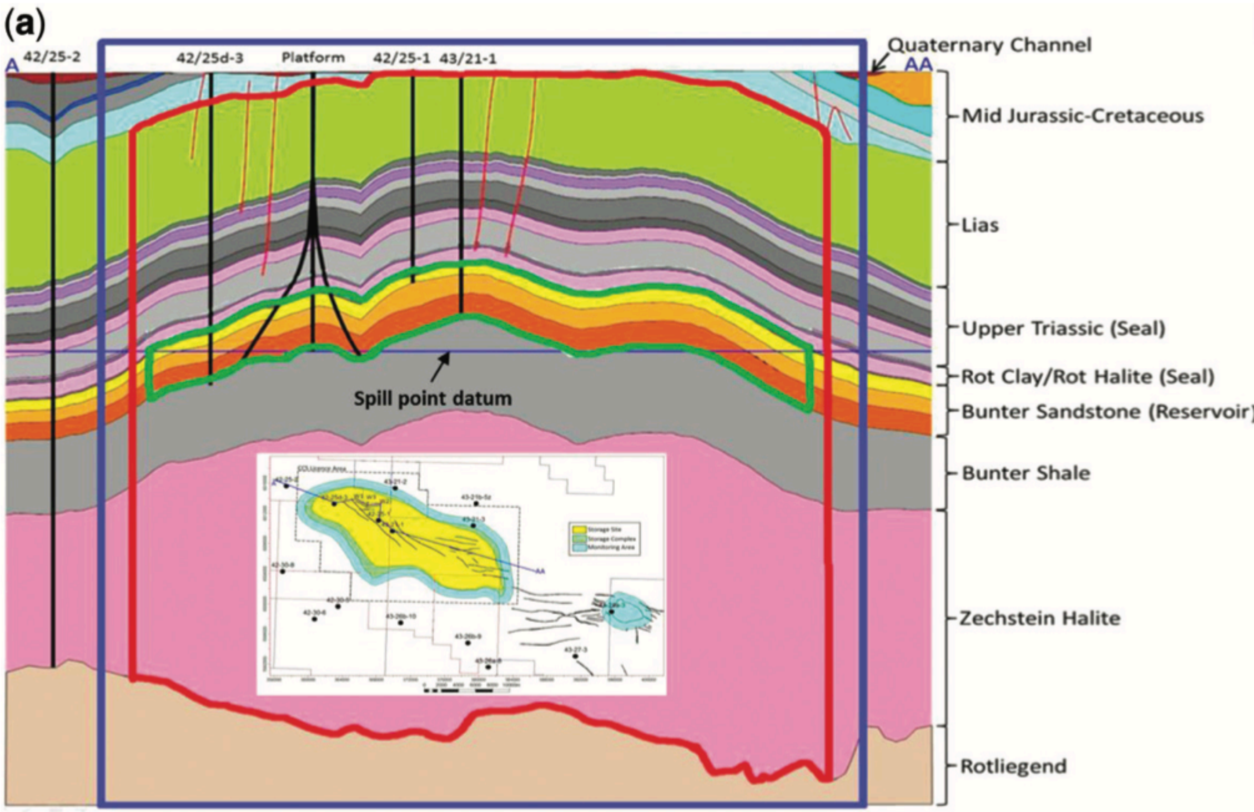


Sketch of Bunter Sandstone Formation depositional environments in the Endurance area.

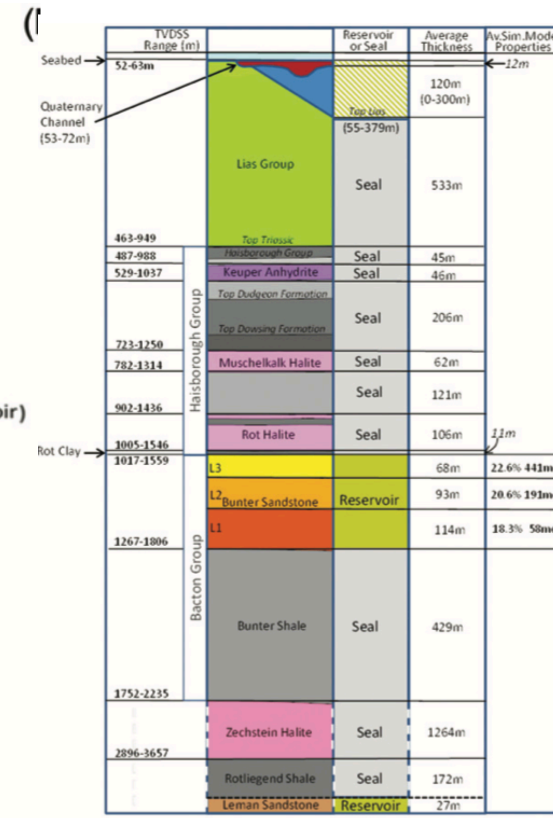
Source: Gluyas and Bagudu, 2020. The Endurance CO2 storage site, Blocks 42/25 and 43/21, UK North Sea

Giles Watts Feb 2023

Vertical section and Stratigraphic through Endurance storage site and storage complex.



Vertical Section

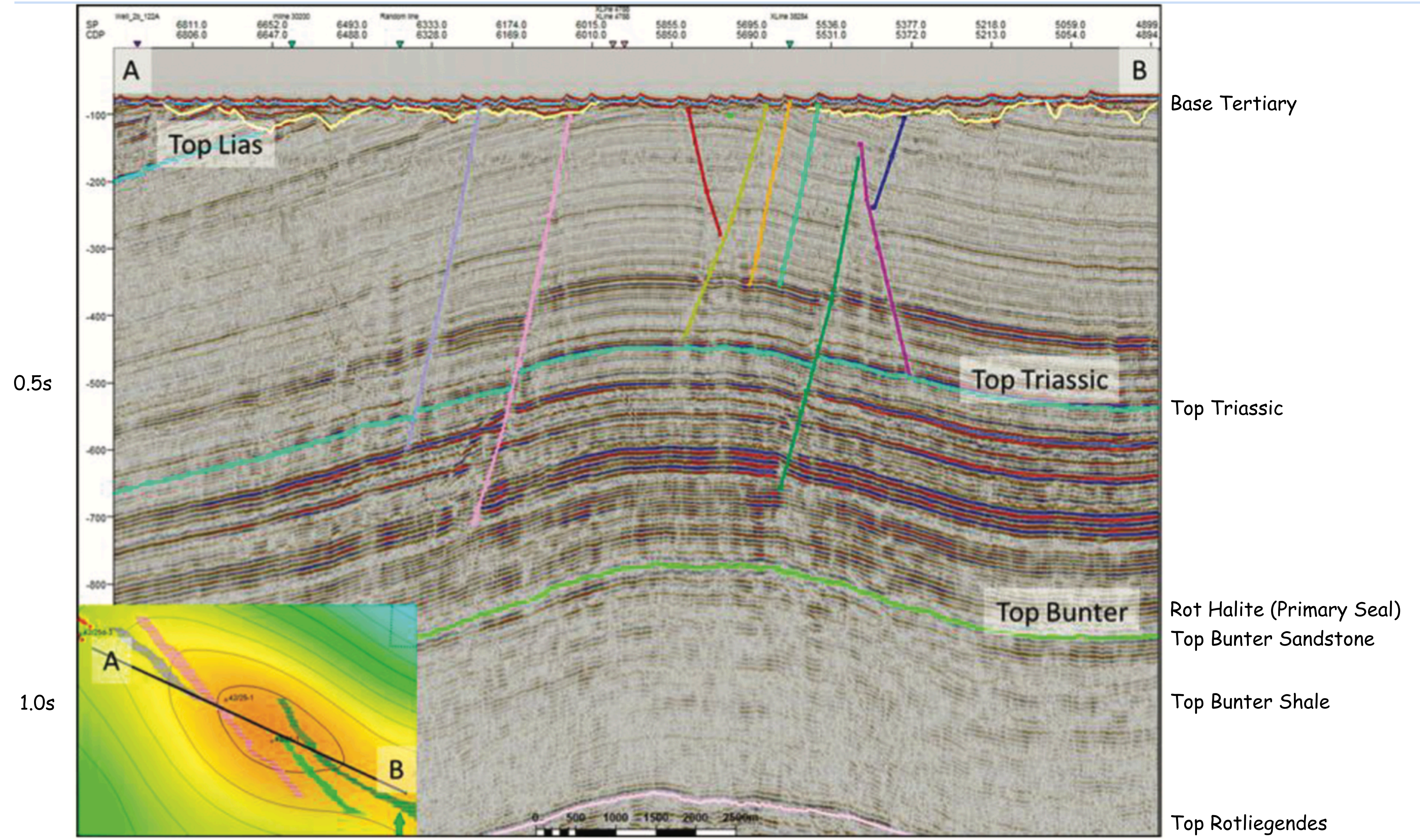


Stratigraphic Section

Source: Gluyas and Bagudu, 2020. The Endurance CO2 storage site, Blocks 42/25 and 43/21, UK North Sea

Giles Watts Feb 2023

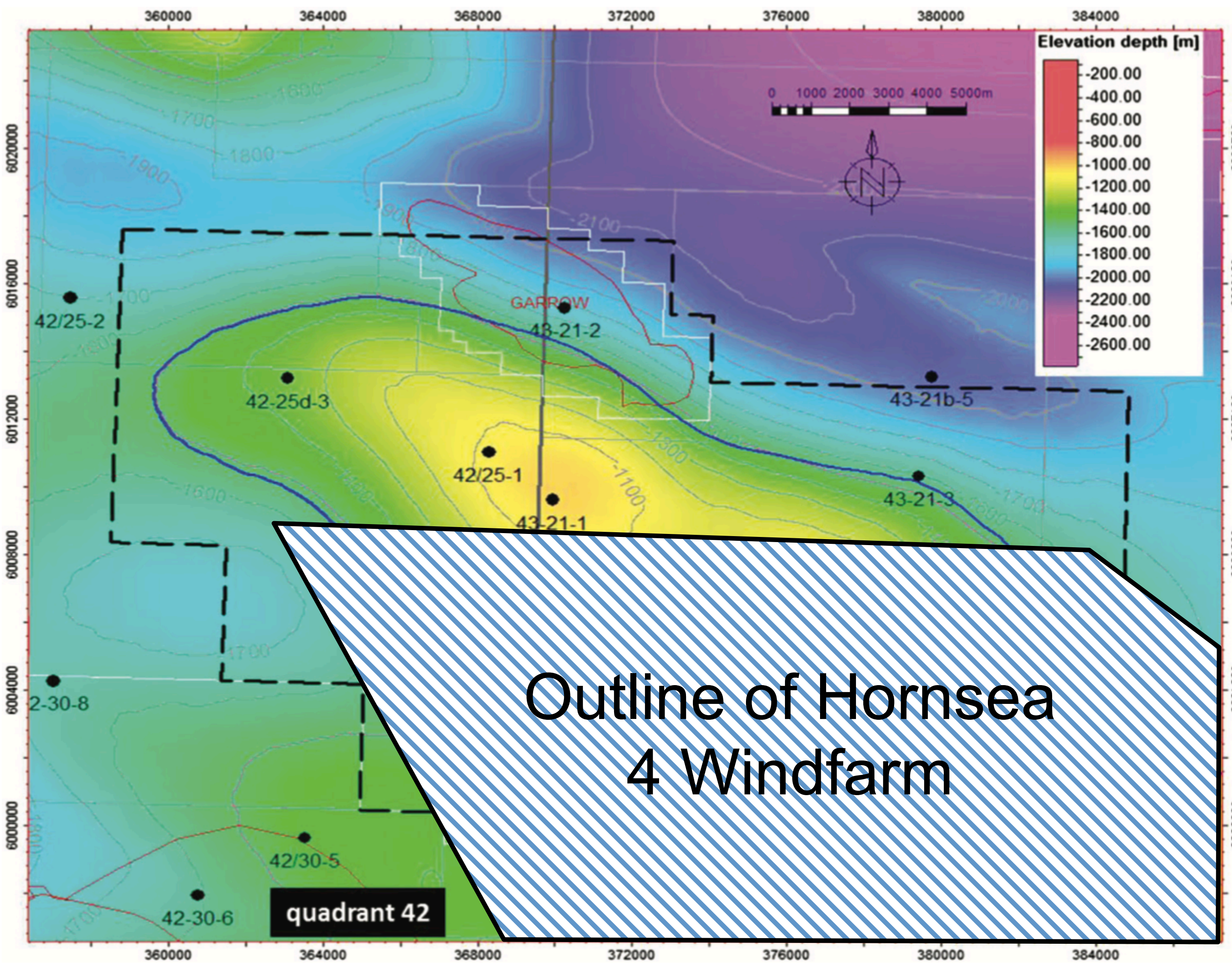
NW-SE arbitrary seismic line showing dip closure and faults in the overburden.



Source: Gluyas and Bagudu, 2020. The Endurance CO2 storage site, Blocks 42/25 and 43/21, UK North Sea

Giles Watts Feb 2023

Depth structure of the Endurance Top Bunter Sandstone with the outline of the Hornsea 4 Windfarm

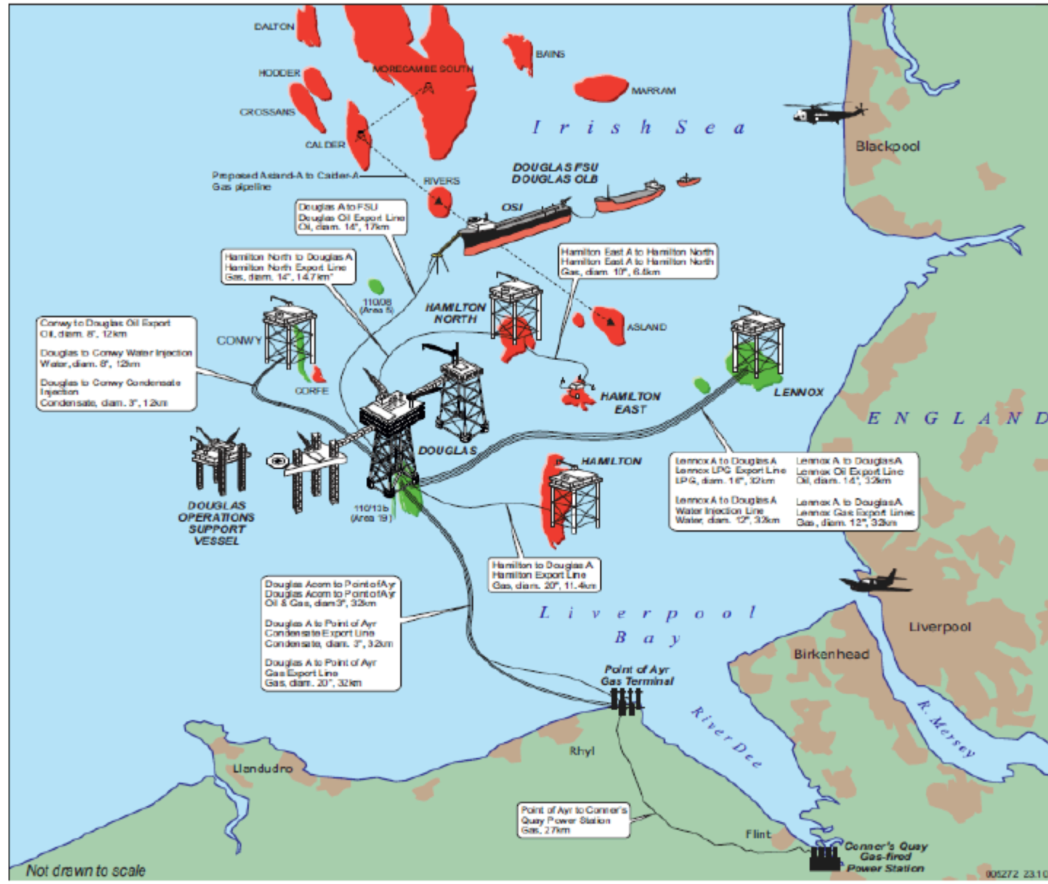


Source: Gluyas and Bagudu, 2020. The Endurance CO2 storage site, Blocks 42/25 and 43/21, UK North Sea

Giles Watts Feb 2023

Hynet Northwest Cluster (NW England)

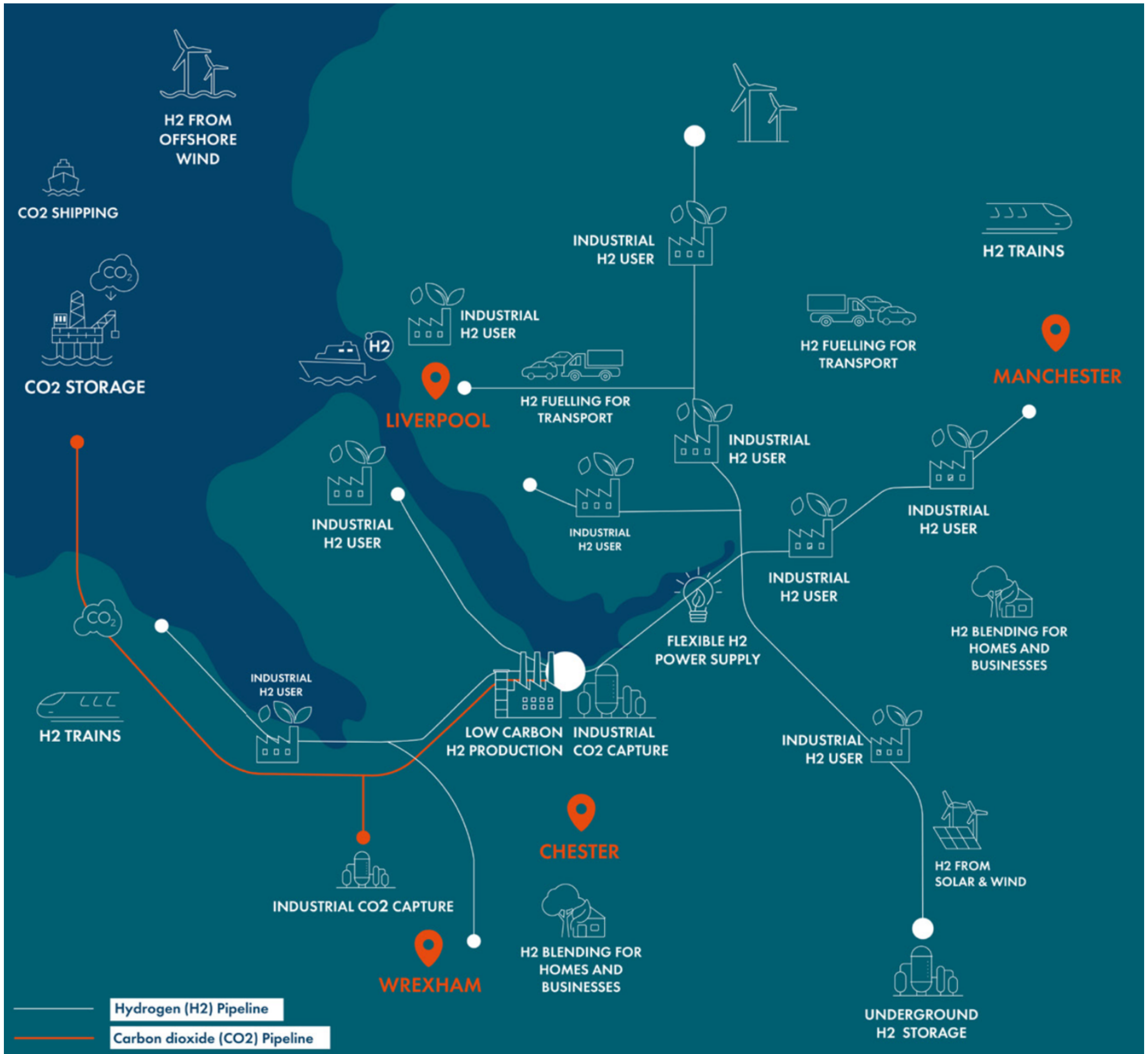
- Three depleted gas fields in Liverpool Bay area: Hamilton, Hamilton North and Lennox (ENI)
- Cumulative production 1.3TCF with recovery of 83-96%
- LicenceCS004 awarded Sep 2020 Track 1 CCS license in Oct 2021



Source: Chedburn et al. Critical Evaluation of CO2 subsurface storage sites: Geological Challenges in the depleted fields of Liverpool Bay. AAPG Bulletin v109 2022.

- Base Case: 109 $MtCO_2$ in 25 years
- 8 injector wells, Δp 112bar to 7bar
- 10$MtCO_2$/y by 2030

HyNet North West – Long Term vision

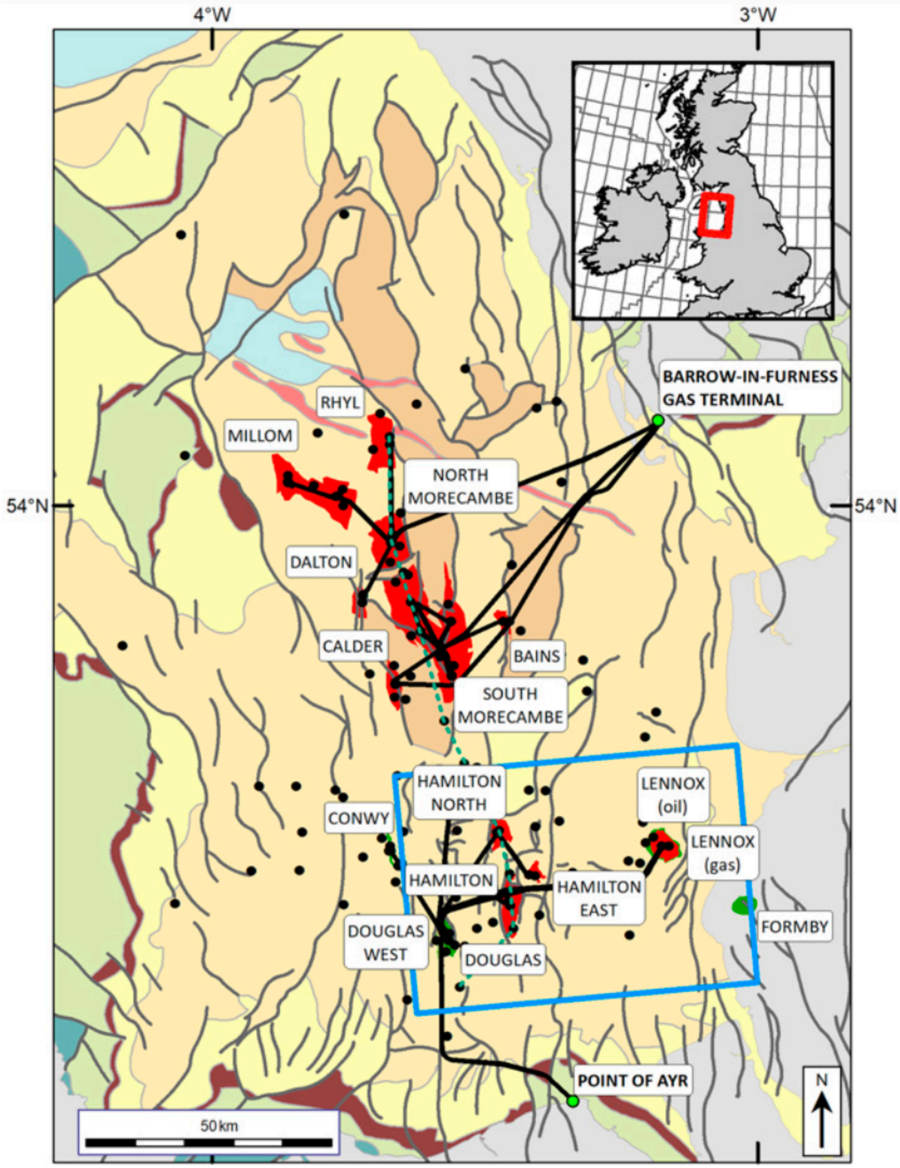


- Very large Industrial Cluster
- Vision for heavy industry fed with H2.
- Initially supplying Blue Hydrogen
- Later with Green Hydrogen from Offshore Wind

Main Industrial Partners:

- Hydrogen production: Vertex Hydrogen
- Hydrogen transport: Cadent
- Hydrogen storage: INOVYN
- CO2 pipeline: Eni
- CO2 storage: Eni

Structural Framework

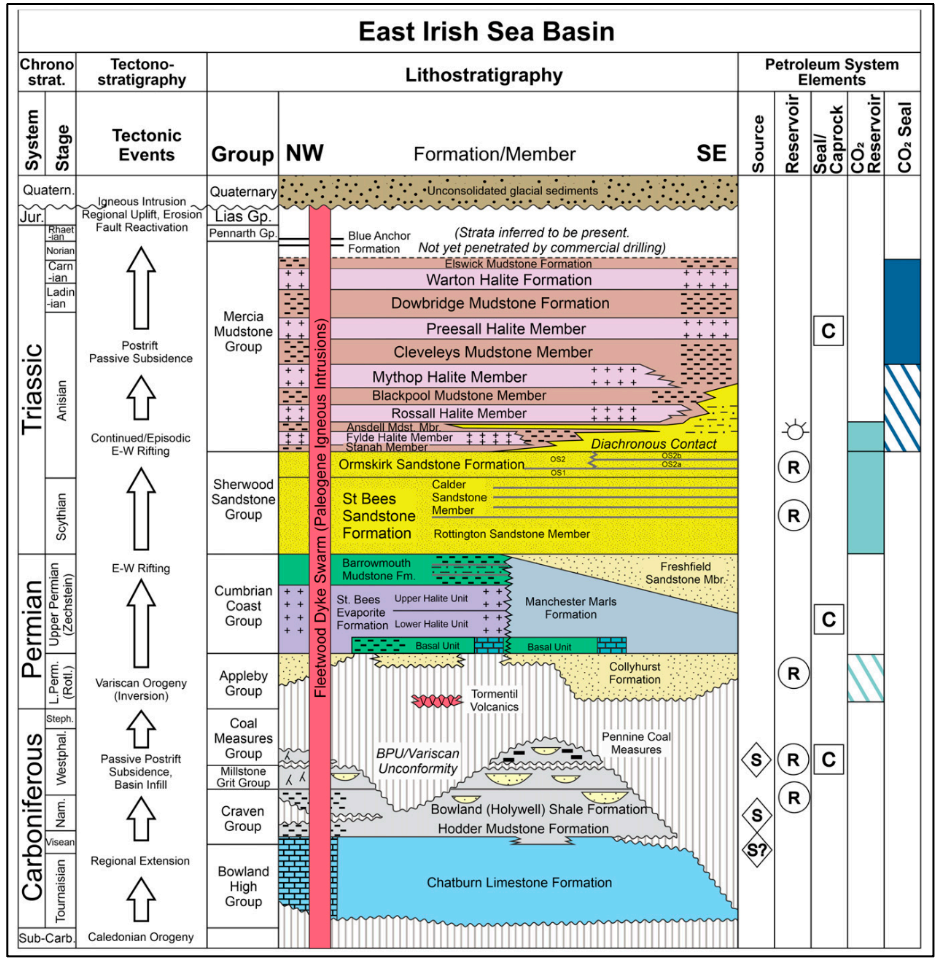


- East Irish Sea Basin Regional Geology
- Permo-Triassic Rift system
- Structurally complex
- Max burial in Late Cretaceous with Tertiary uplift and erosion

Source: Chedburn et al. Critical Evaluation of CO2 subsurface storage sites: Geological Challenges in the depleted fields of Liverpool Bay. AAPG Bulletin v109 2022.

Geology

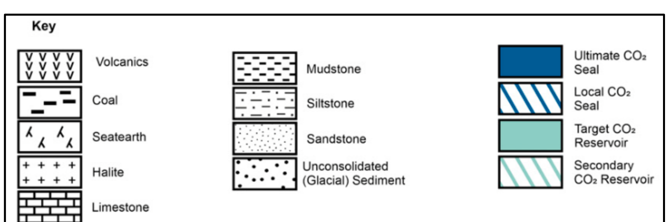
- Source: Carboniferous Hollywell Shale Formation
- Reservoir: Sherwood Sandstone, Ormskirk Formation (Fluvial and Aeolian deposits Sandstones, siltstones and mudstones)
- Seal: Mercia Mudstone (5 cycles of alternating red mudstones and thick halites deposited in lakes with periodic flooding) – approx. 700m thick



Secondary Seals

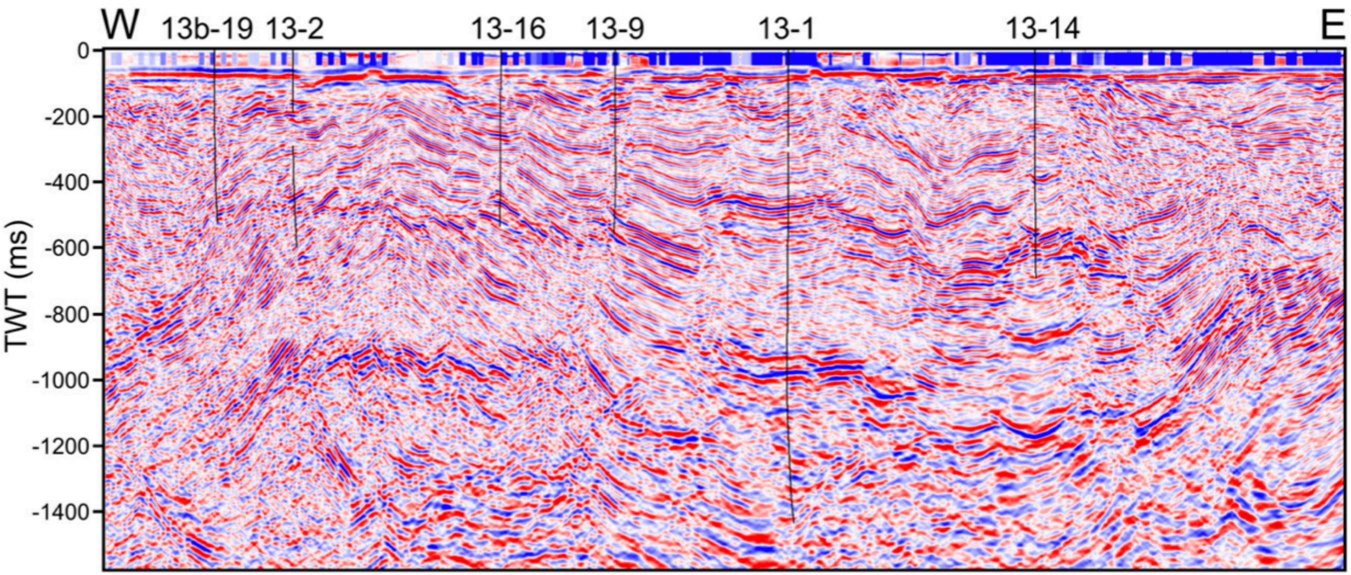
Primary Seal

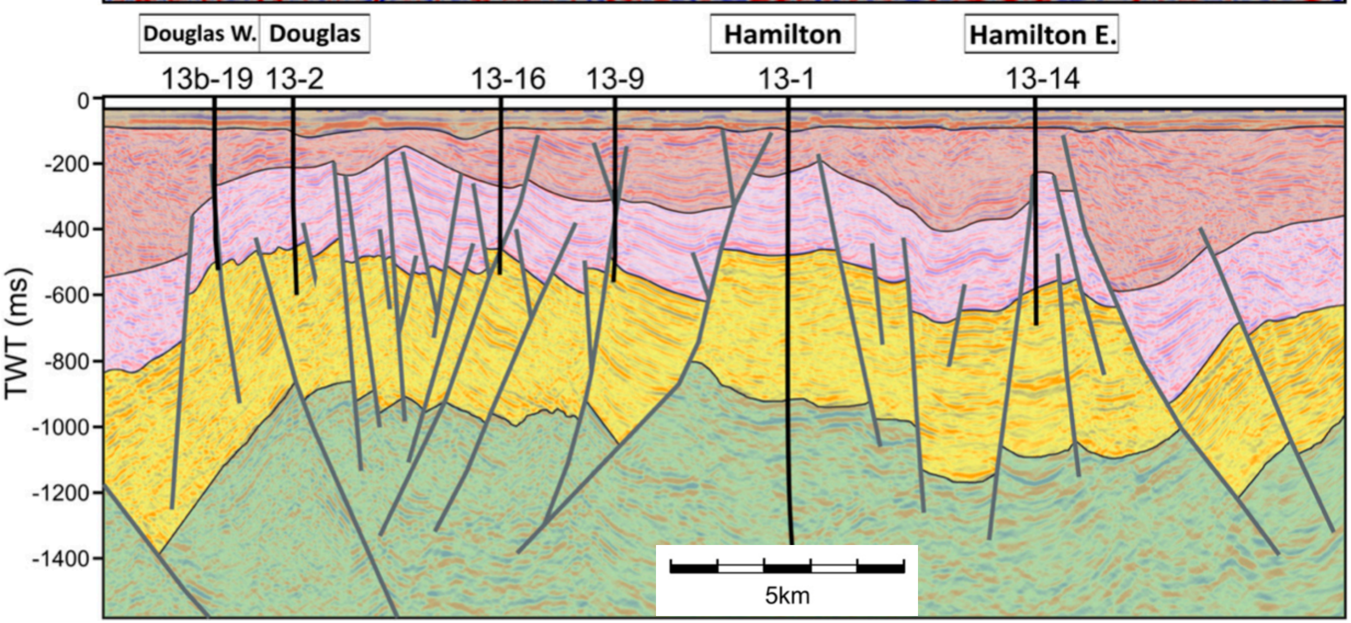
Main Reservoir



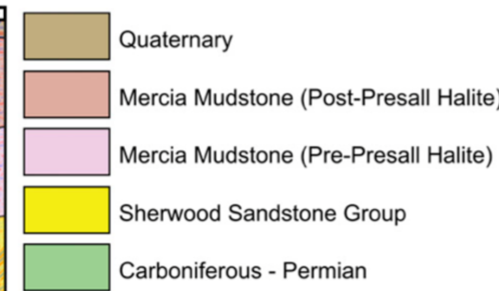
Source: Chedburn et al. Critical Evaluation of CO2 subsurface storage sites: Geological Challenges in the depleted fields of Liverpool Bay. AAPG Bulletin v109 2022.

E-W Seismic Section and interpretation through the Liverpool Bay Fields





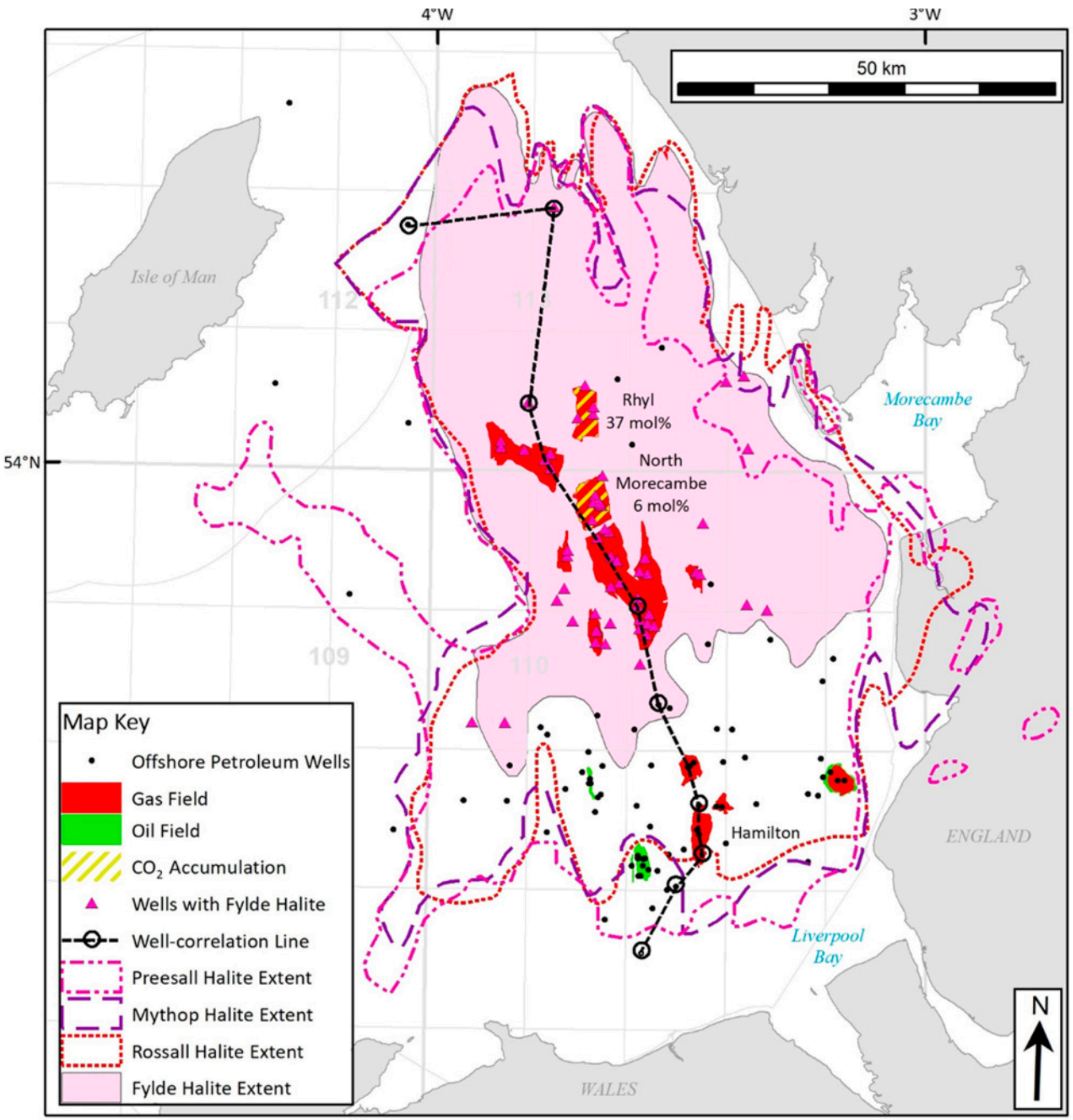
East-West line and interpreted geoseismic section highlighting the main stratigraphic units and structural features across the extent of the pre-stack time migration seismic volumne



Source: Chedburn et al. Critical Evaluation of CO2 subsurface storage sites: Geological Challenges in the depleted fields of Liverpool Bay. AAPG Bulletin v109 2022.

Giles Watts Feb 2023

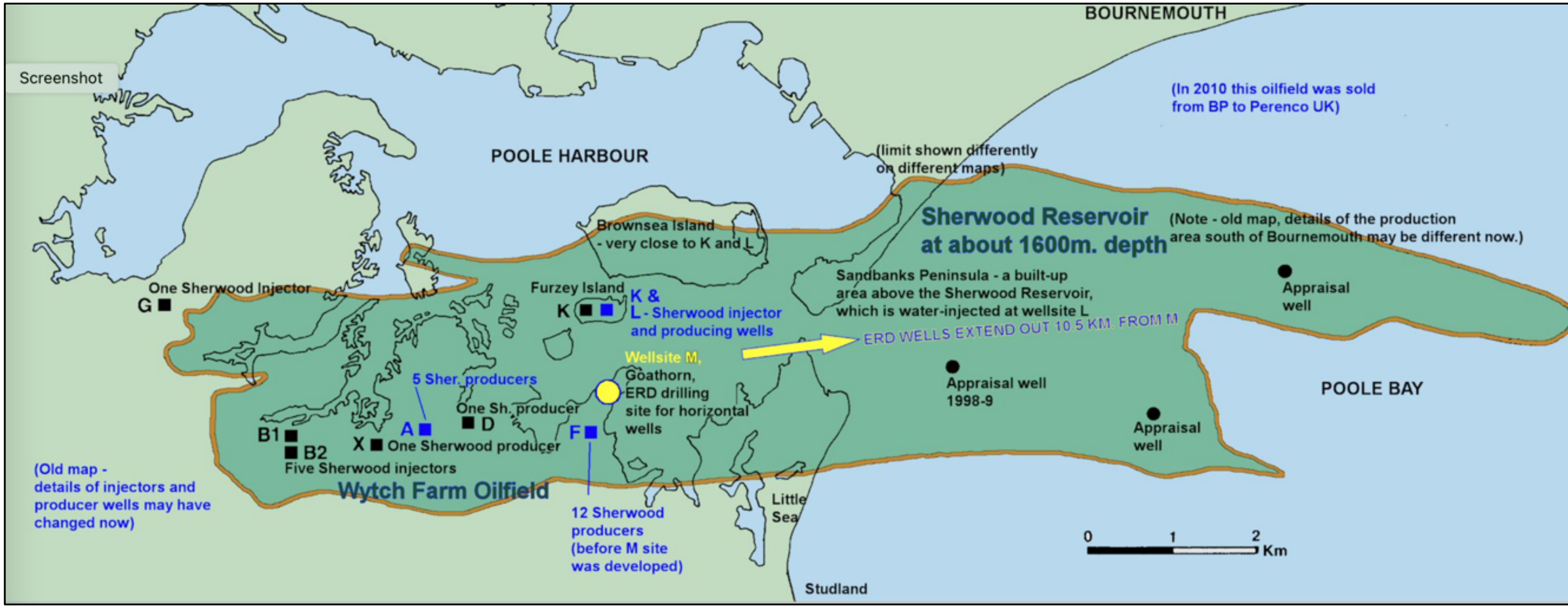
Plenty of other potential stores in the area



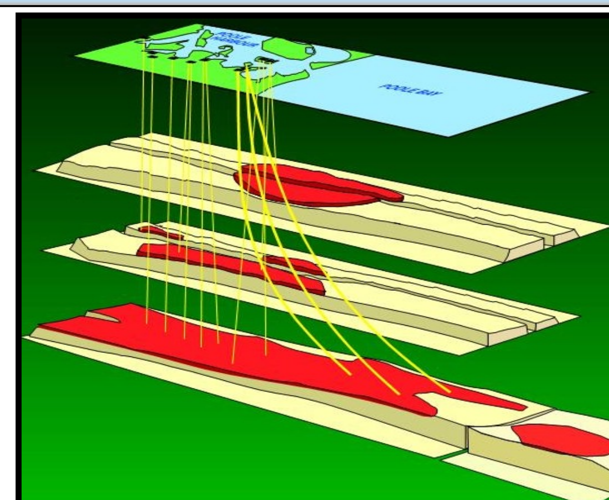
Source: Chedburn et al. Critical Evaluation of CO2 subsurface storage sites: Geological Challenges in the depleted fields of Liverpool Bay. AAPG Bulletin v109 2022.

Projects in the UK

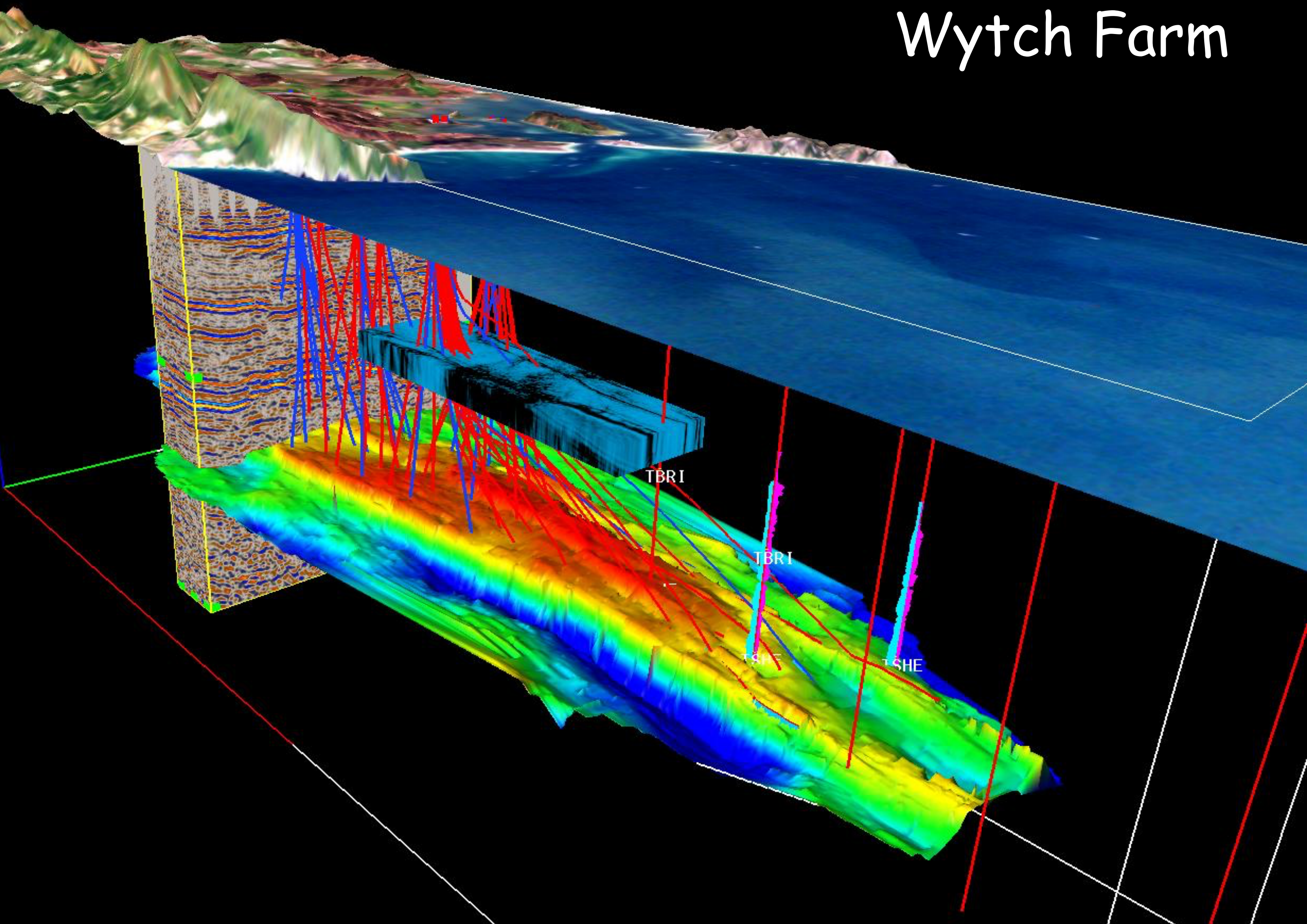
Wytch Farm



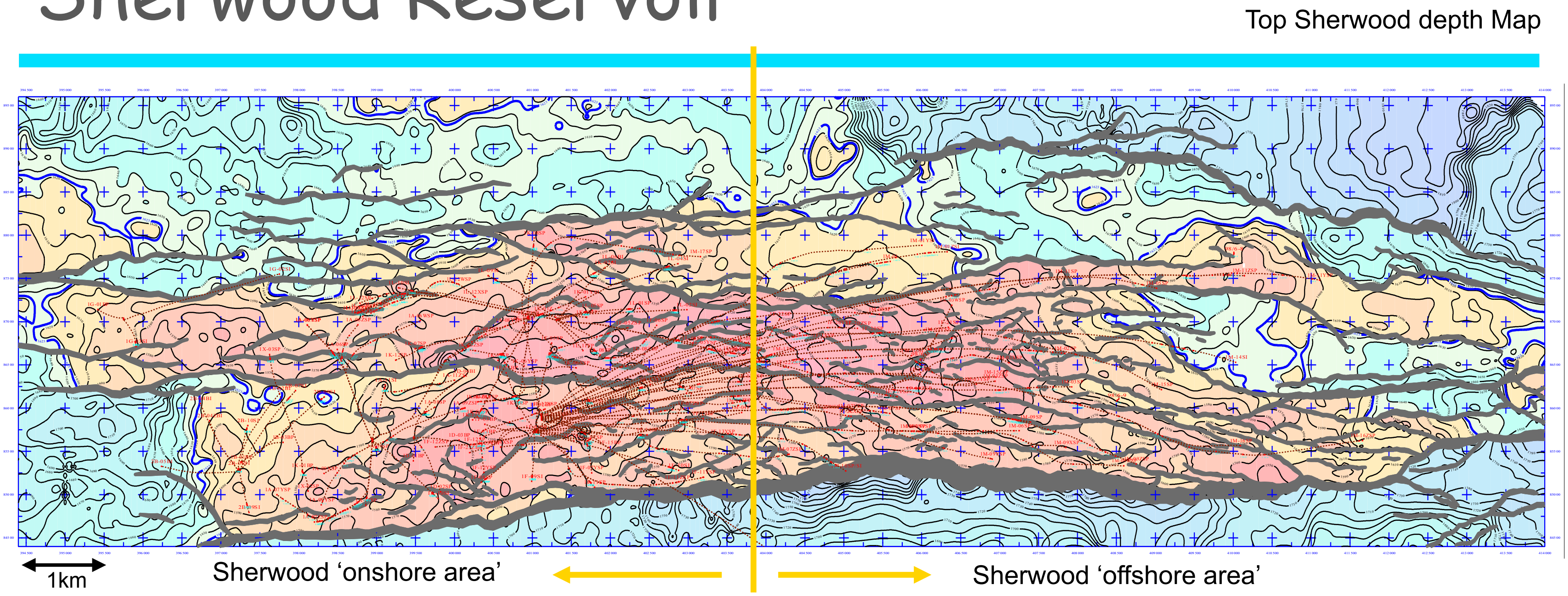
- Operated by Perenco
- Approximately 1 billion barrels oil in place
- Reserves ~ 500mmboe
- Production start 1979, peak 10kbopd, now ~14kbopd
- Frome, Bridport and Sherwood Reservoirs.
- Wytch Farm, Wareham, Beacon and Kimmeridge Fields



Wytch Farm

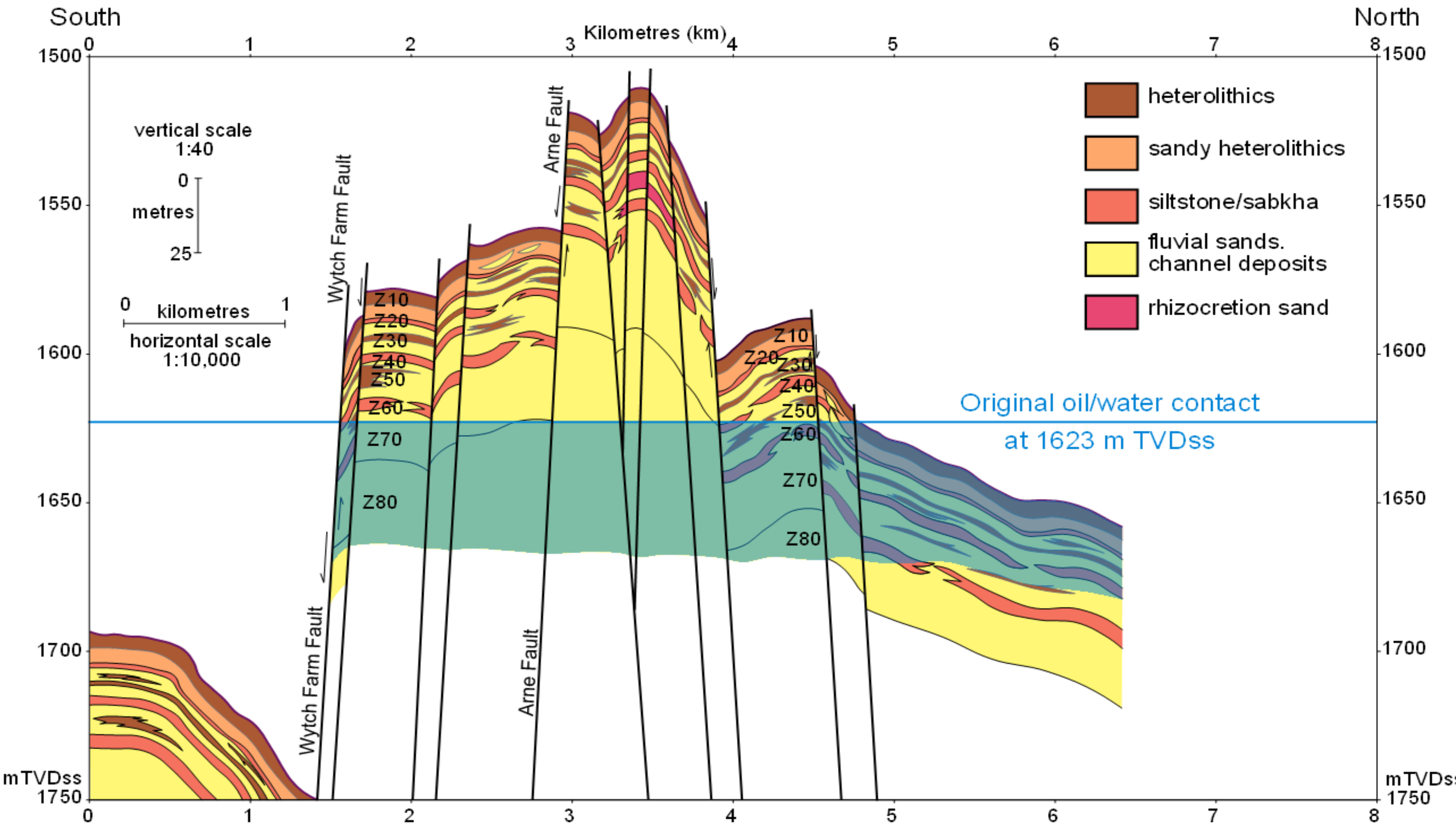


Sherwood Reservoir

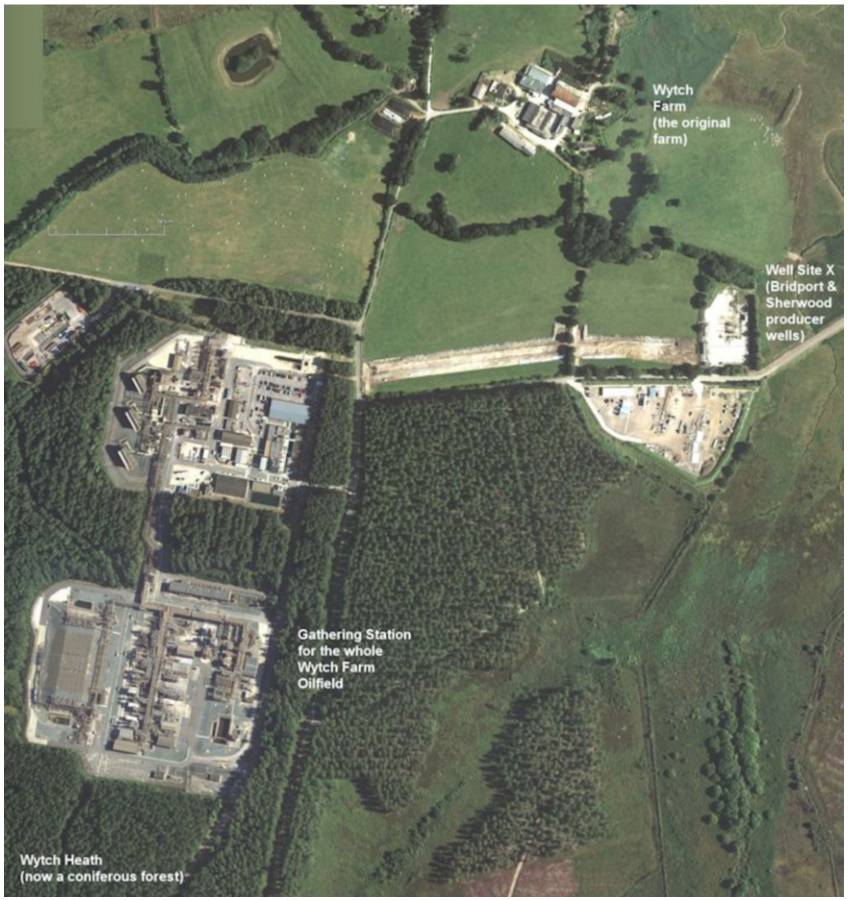


- Sherwood reservoir is Triassic braided dryland river system
- ~180m thick succession of fluvial, sheetflood, sabkha and mudstone deposits – limited aeolian
- Fault bounded/dip closure trap
- Mercia Mudstone cap-rock
- Source kitchen in Blue Lias south of major boundary fault
- Dominated by E-W Variscan age faults, reactivated during Tertiary inversion
- Kv reduced by field wide mudstones, open fractures influence water movement
- General increase in N:G from W>E and from upper to lower reservoir

Sherwood Cross Section N-S

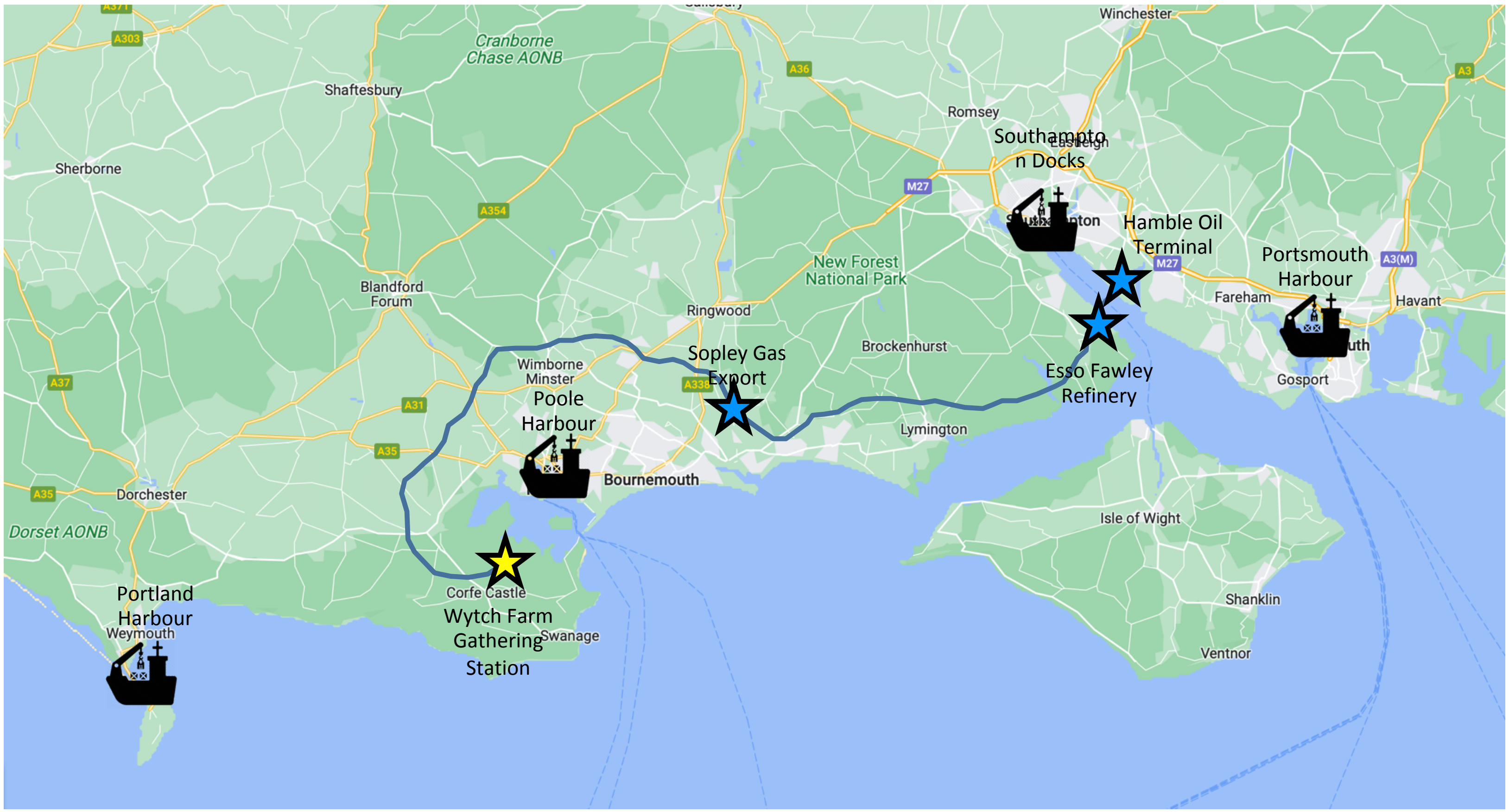


Wytch Farm



- Operation License to 2037 granted in 2013.
- CO_2 from compressors, gas processing, DAC and external
- 50 Acre Gathering Station with plenty of space for additional Carbon Capture Technology
- Closest Wellsite nearby with access to both reservoirs
- Oil export to export via 91km long and 16-inch diameter pipeline to Hamble Terminal via the Fawley refinery
- Natural Gas piped to Sopley, north of Christchurch.

Pipeline to Hamble Terminal by Fawley Refinery



Solent Cluster of emitters formed in 2022 and looking for a CO2 Storage site

Conclusions

- Global Warming is happening and has significant consequences
- CCS has a significant role in removing CO_2 from the atmosphere
- CCS is a proven technology which is being scaled up worldwide
- The UK has world-class geology for CCS
- The UK government is pressing ahead with a major expansion of CCS in the UK
- Dorset (Wytch Farm) has the potential to be a world-class CO_2 store for the future

Thank You

Questions