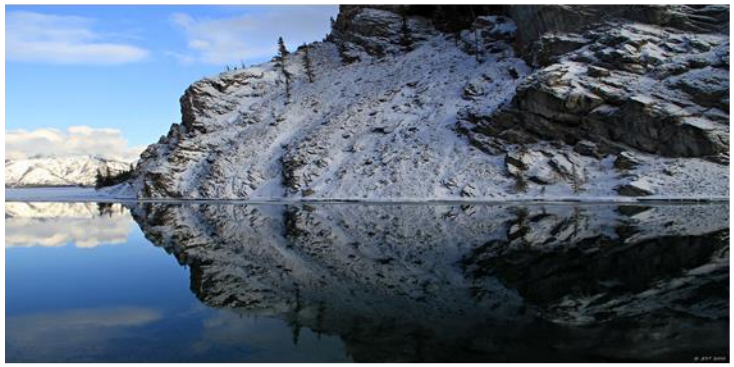
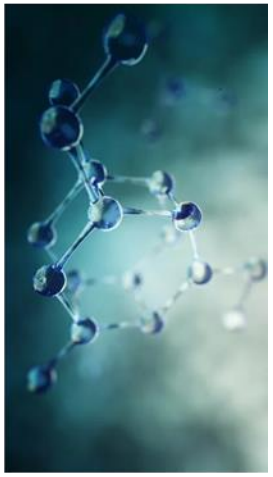
An Independent Perspective on CCS in the UK

SPE-WA October Technical Meeting





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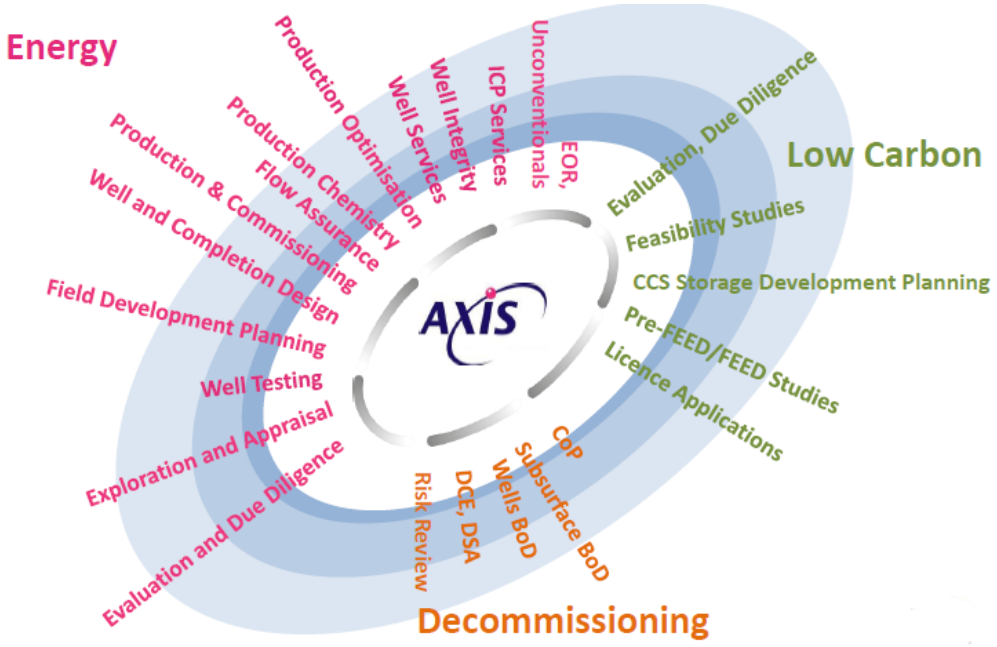
AXIS

Outline

- Introduction – Axis, Shaun
- Background, Drivers and Objectives
- History of CCS in the UK
- Current Status
- Key Projects
- Case Study – Bunter Closure 36 Saline Aquifer Storage Site
- Case Study – Viking A Depleted Gas Field Storage Site
- Licensing and Regulation
- Summary Observations
- Resources

Axis

- Independent well and reservoir consultancy since 2001.
- Two multi-disciplinary teams working across 3 markets:
  - Well and Reservoir Studies (WRS)
    - >50 geoscientists, engineers and chemists.
  - Well Operations
    - >120 well completion, testing and well services personnel.
- More than 2000 projects in over 50 countries.
- Closely involved with major CCS projects in the UK since 2015:
  - DECC, UK Storage Appraisal Project
  - Storegga, Acorn CCS and East Mey Build Out
  - Harbour Energy, V Net Zero
  - Maiden CCS licensing round



- BEng (Hons) UWA (2003), MSc Imperial College London (2010).
- Various assignments for Schlumberger spanning 10 years (Egypt, UK, France and Norway).
- Senior Reservoir Engineer with Axis since 2013.
- Recent project highlights:
  - Cygnus gas field infill drilling evaluations (UKCS)
  - Cambo deep water oil field appraisal and development (UKCS)
  - Iguana & Zandolie gas field developments in the Gulf of Paria (Trinidad & Tobago)
  - Tight NFR exploration support (Kuwait)
  - CO_2 Storage Appraisal Project (UKCS)

The Opportunity for CCS

Real

- Committed to reduce emissions >80% from 1990 levels by 2050, UK Climate Change Act (2008),
  - Including reduction to 50% between 2023-2027, Carbon Budget Order (2011).
- Committed to <2°C temperature increase from pre-industrial levels, Paris Agreement (2015),
  - With an ambition of < 1.5°C warming.
  - Current warming has already reached 1.1°C.

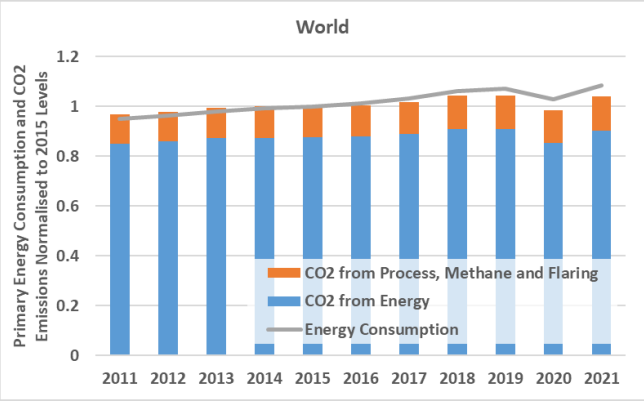
Large

- Legislated reduction to 1950 $MtCO_2$ equivalent between 2023-2027 (~390 $MtCO_2e$ per year).
- In 2019 (pre-COVID) emissions were 448 $MtCO_2e$ and fell to 406 $MtCO_2e$ in 2020.
- Good progress on legislated reduction, but significant challenges to reach Net Zero.
  - CCS has its part to play (hard-to-abate industry, offsets for power, transportation, heating).
  - Net Zero ambition requires up to 100 stores and 75-180 $MtCO_2$ per year sequestered by 2050 (1/3 of baseline UK emissions).

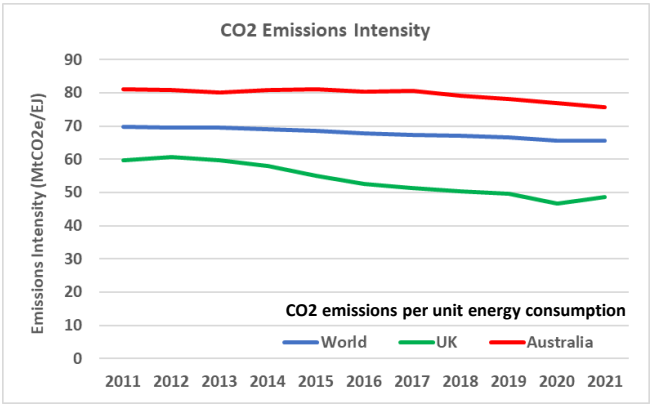
Now

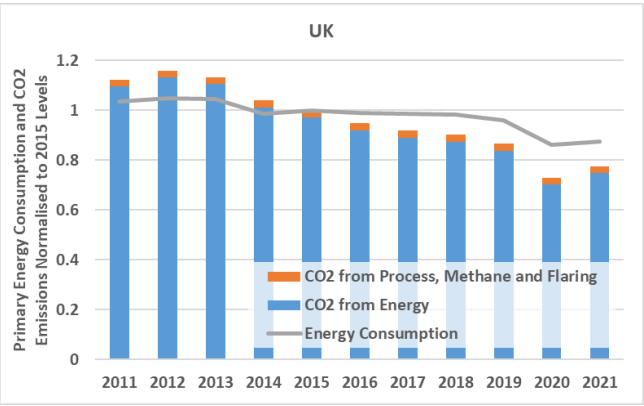
- Oil and gas regulator (OGA) was rebranded the North Sea Transition Authority (NSTA) in 2022.
- Six active CO_2 appraisal and storage licenses on the UKSC
- The UK's maiden CCS licensing round, closed in September, attracted 26 bids from 19 companies, to be awarded in Q1-2023. 2nd Round proposed for 2023.
- Aiming for 20-30 $MtCO_2$ per year stored by 2030, with >50 $MtCO_2$ per year targeted by 2035.

Energy and Emissions



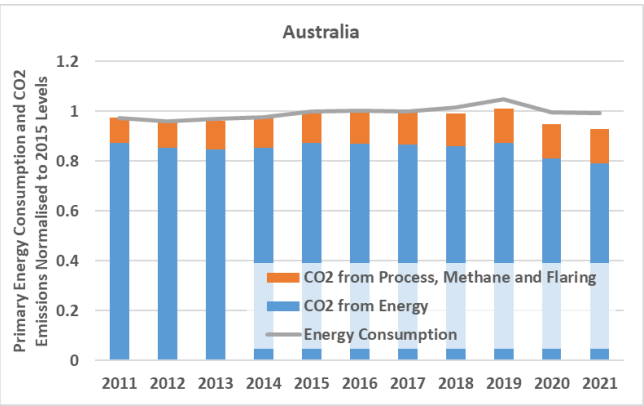
World (2015):
Energy Consumption = 548 EJ
Total CO_2 Emissions = 37517 Mte
Total CO_2 Intensity = 68 Mte/EJ





UK (2015):
Energy Consumption = 8.2 EJ
Total CO_2 Emissions = 451 Mte
Total CO_2 Intensity = 55 Mte/EJ

Proportion of UK CO2 Emissions by Sector (2020)

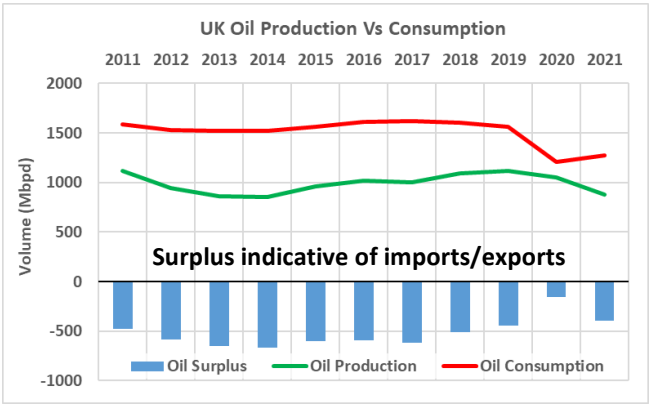


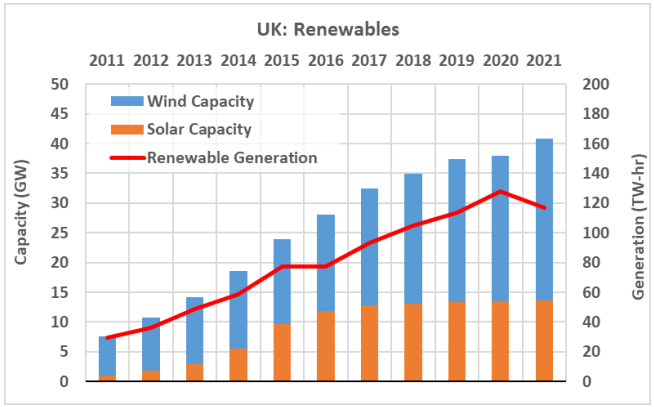
Australia (2015):
Energy Consumption = 5.8 EJ
Total CO_2 Emissions = 466 Mte
Total CO_2 Intensity = 81 Mte/EJ

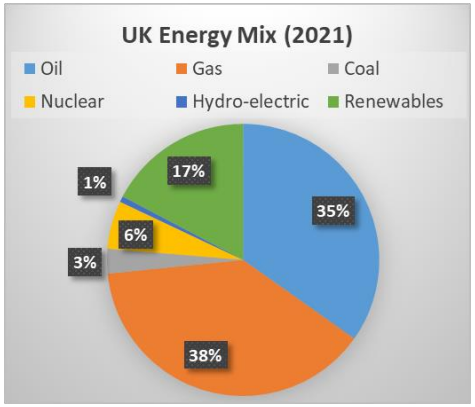
- Pre-COVID (2019) and post-COP21 (Paris, 2015):
  - The UK had made material progress to reduce primary energy consumption and carbon emissions.
  - UK carbon intensity was below world standards and declining more quickly.
- UK policy seems to be working, but is still considered insufficient to meet climate goals.

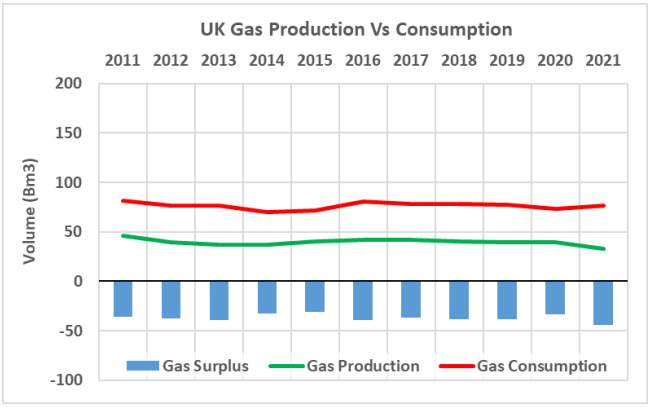
Source(s):
https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2022-full-report.pdf
Final UK greenhouse gas emissions national statistics: 1990 to 2020 - GOV.UK (www.gov.uk)

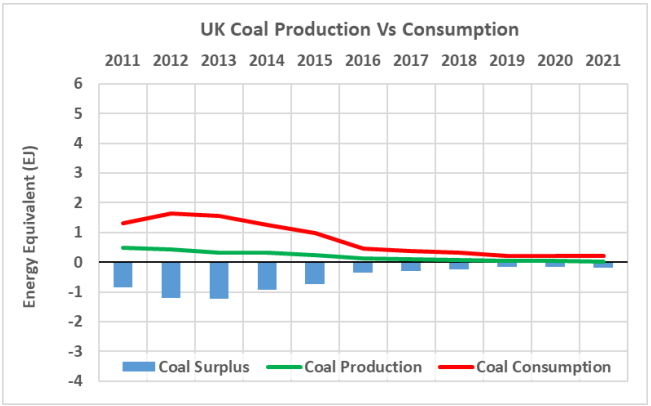
National Energy Security and Supply









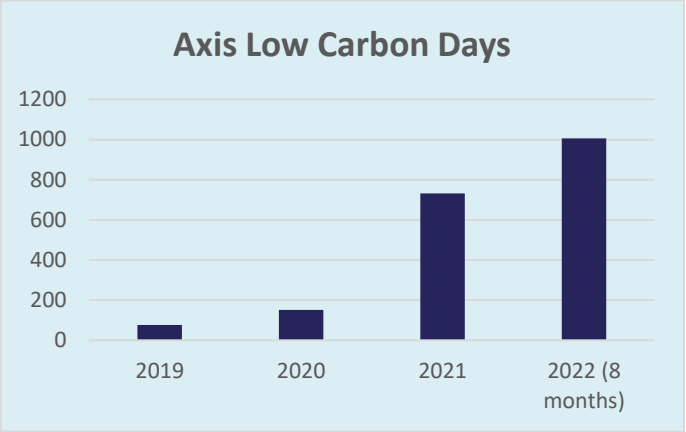


- North Sea production generally in decline.
- UK suffers a distinct energy supply deficit.
  - Wood Review (2014) lead to the OGA adopting a strategy for Maximum Economic Recovery.
  - The strategy was revised in 2020 in view of obligations for Net Zero by 2050.
  - Recent geo-political events have seen a policy shift to sure up domestic energy supply – especially gas.
- Fossil fuels continue to dominate (75%) the energy mix
  - Despite the increasing role of renewables.
- Gas-combustion yields ~400 gCO_2/kWh
  - 2050 target requires an average grid intensity of 50-100 gCO_2/kWh by 2030.
  - Strong mandate to urgently progress CCS.

Source(s):
https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2022-full-report.pdf
https://publications.parliament.uk/pa/cm201516/cmselect/cmenergy/692/692.pdf

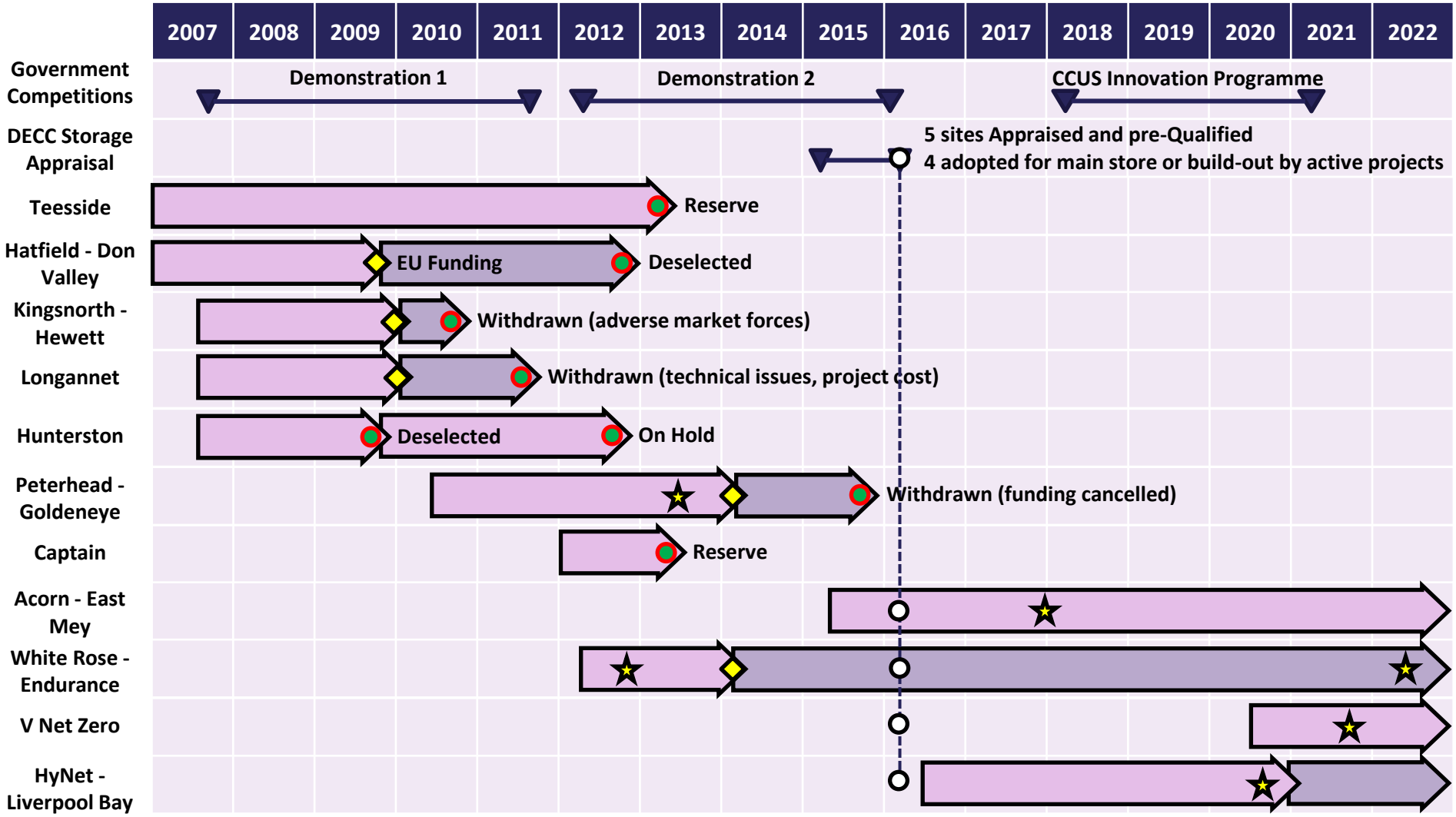
Activity Level and Skills Transfer

- But is there any evidence of urgency?
- Let's use Axis as an example.
  - Days increase almost 2000% in 4 years
  - In 2019 only 1 client (PBD)
  - In 2022 already have 6 – some of which include support for multiple CCS projects in UK and internationally



- Healthy range of workscopes
  - Evaluation due diligence, feasibility studies, storage development planning (SDP), pre-FEED studies, licence applications
- Market diversification apparent
  - Early projects were government funded. Now it's O&G companies sweating their mature assets as well as new CCS specific developers. Range in scale from large national to single emitter/single store projects.
- All require significant upstream skill-set resources.

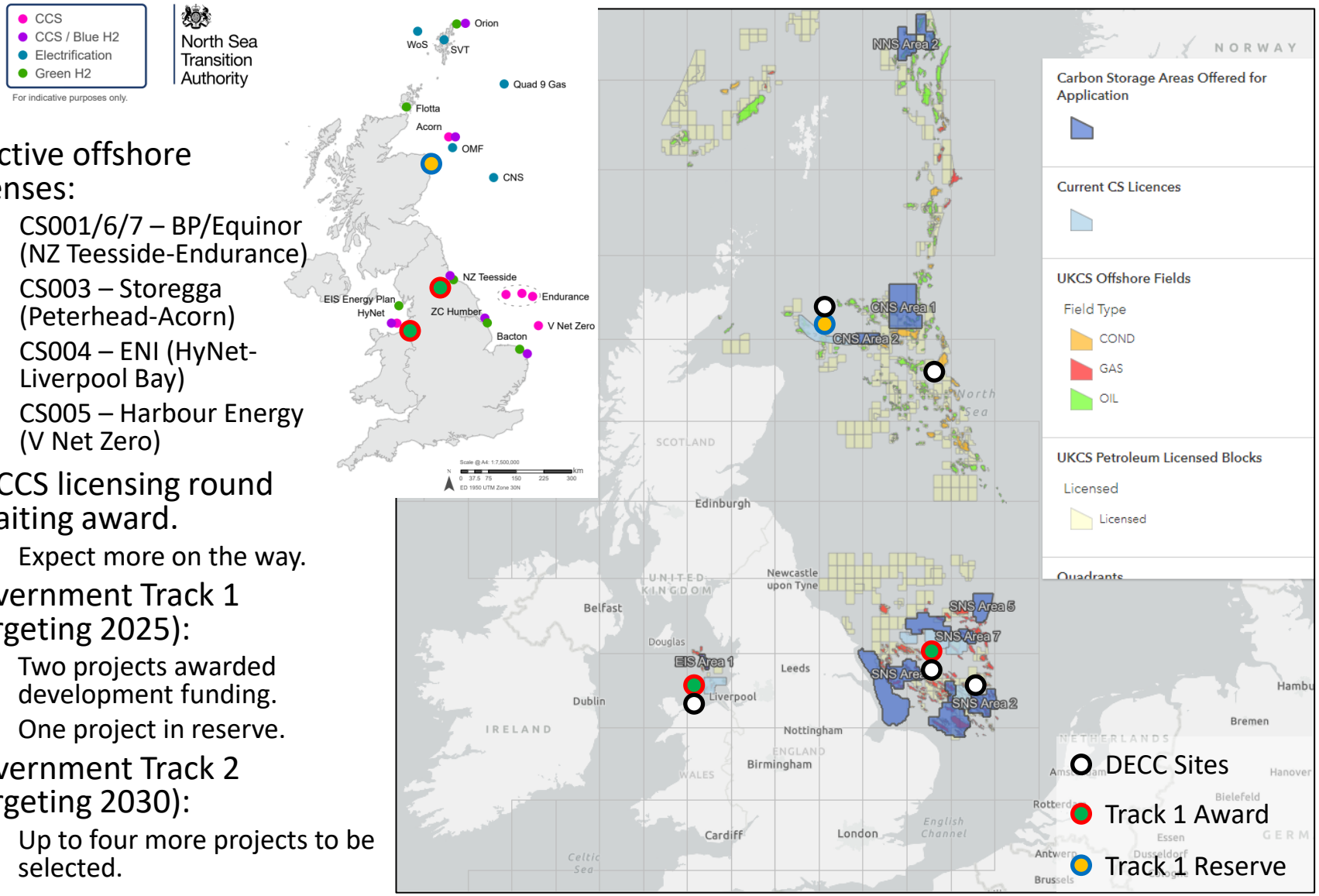
CCS History and Project Maturation



Demo-1: First UK CCS competition. Terminated due to costs exceeding the agreed £1 billion capital limit.

Demo-2: CCS Commercialisation Programme. Government funding withdrawn just prior final bids.

Current Status

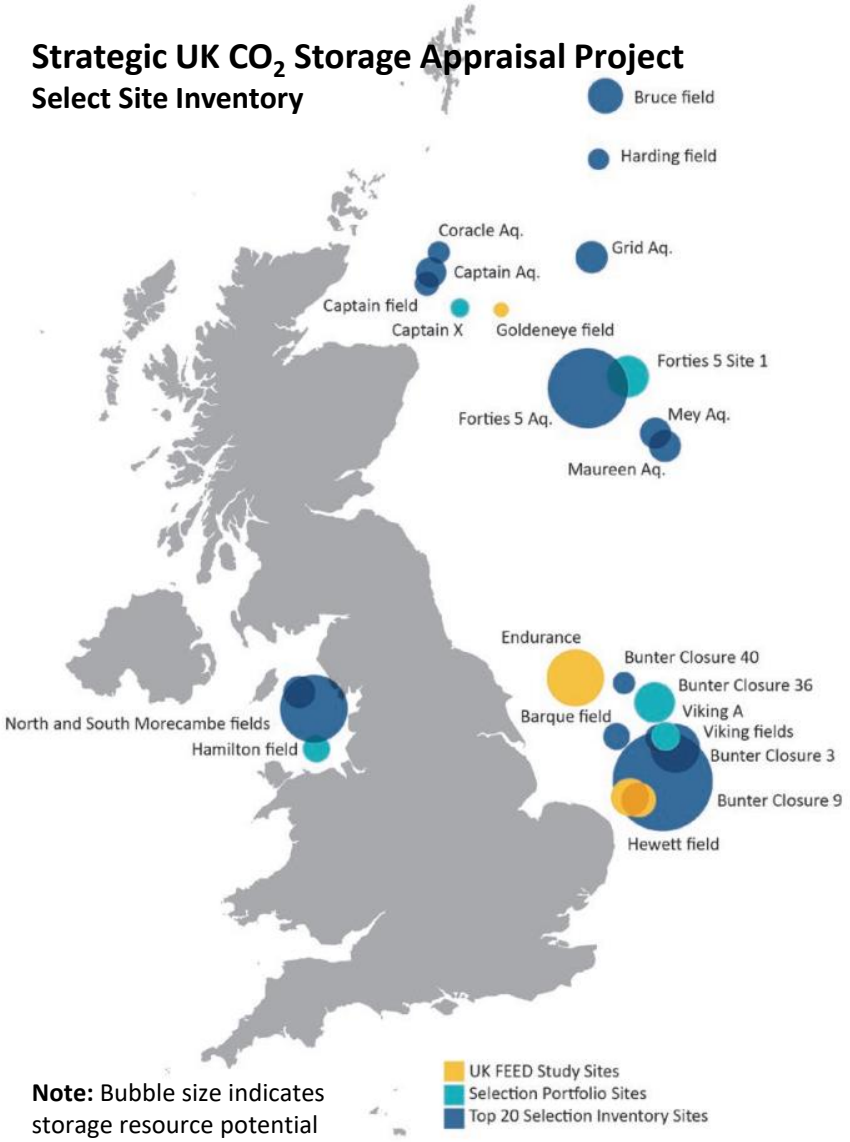


- 6 active offshore licenses:
  - CS001/6/7 – BP/Equinor (NZ Teesside-Endurance)
  - CS003 – Storegga (Peterhead-Acorn)
  - CS004 – ENI (HyNet-Liverpool Bay)
  - CS005 – Harbour Energy (V Net Zero)
- 1st CCS licensing round awaiting award.
  - Expect more on the way.
- Government Track 1 (targeting 2025):
  - Two projects awarded development funding.
  - One project in reserve.
- Government Track 2 (targeting 2030):
  - Up to four more projects to be selected.

Source(s): https://www.nstauthority.co.uk/data-centre/nsta-open-data/carbon-storage/

Key Projects: UK Storage Appraisal Project

- Commissioned by the Department of Energy and Climate Change (DECC) in 2015.
  - Funded with £2.5 million from the Department of Business, Energy and Industrial Strategy (BEIS)
  - Jointly awarded to Pale Blue Dot Energy and Axis. Completed in 2016.
- Strategically appraised and matured 5 selected CO_2 stores towards readiness for FID.
  - Selected from a short-list of 20 after screening 579 potential sites.
  - Qualified c. 900 $MtCO_2$ of contingent resource from an otherwise unclassified national resource estimated at c.78,000 $MtCO_2$.
  - Only 2 of 5 sites requiring further appraisal drilling courtesy of oil and gas E&P activities.
  - Criteria for technical and geographical diversity with differing risk profiles.
  - Portfolio with tangible potential for commercial-scale adoption of CCS for UK power generation and industrial sectors.
- Study deliverables available in full within the public domain:
  - Data, reports, static and dynamic models, site development plans, budget estimates (URL below).
  - Includes screening and down-select, due diligence, and storage development plans.

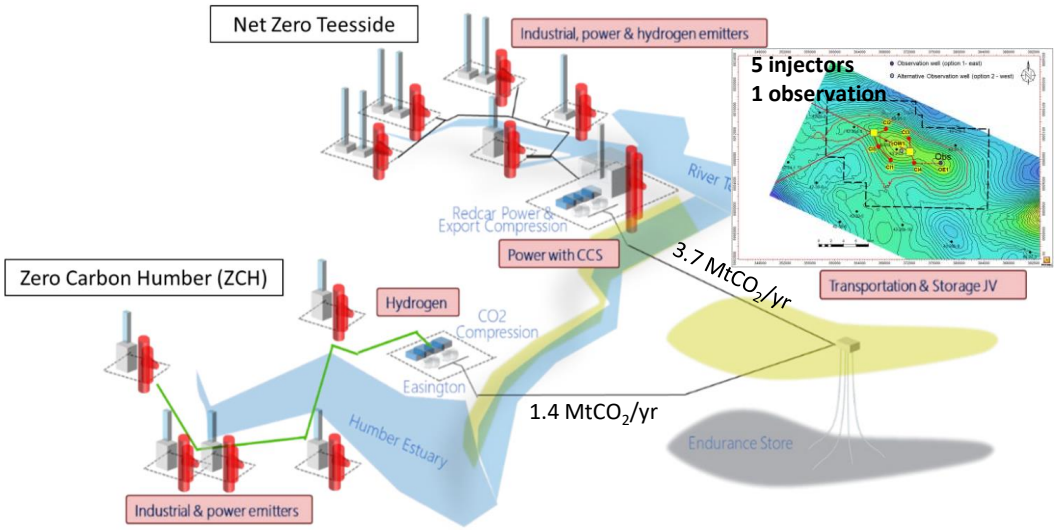


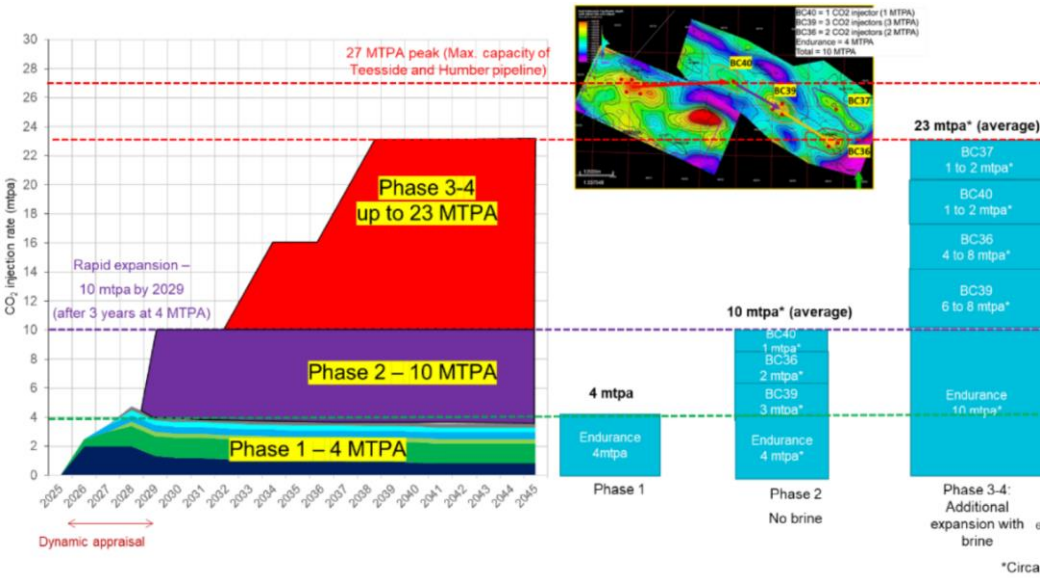
Note: Bubble size indicates storage resource potential

Source(s): https://www.eti.co.uk/programmes/carbon-capture-storage/strategic-uk-ccs-storage-appraisal

Key Projects: NZT-NEP-Endurance

- bp lead consortium aiming to decarbonise Teesside gas-fired power plant (NZT) and industrial emitters.
- In addition combines decarbonisation of the Humber industrial cluster (ZCH).
- CO_2 sequestration using the Endurance saline aquifer store.
  - Selected from two SNS sites appraised, including the Hewett depleted gas field.
  - Scope for multi-store build out strategy.
- Partners include:
  - Eni, Equinor, Total, Shell and National Grid.
- Initial scope to store >4 $MtCO_2$/yr and provide ~850 MW low-carbon power generation.
  - Infrastructure sized for throughput of up to 27 $MtCO_2$/yr, initially limited by wells.
  - Significant scope to add further industrial emitters.
- A comprehensive collection of knowledge deliverables are available within the public domain (URL below).

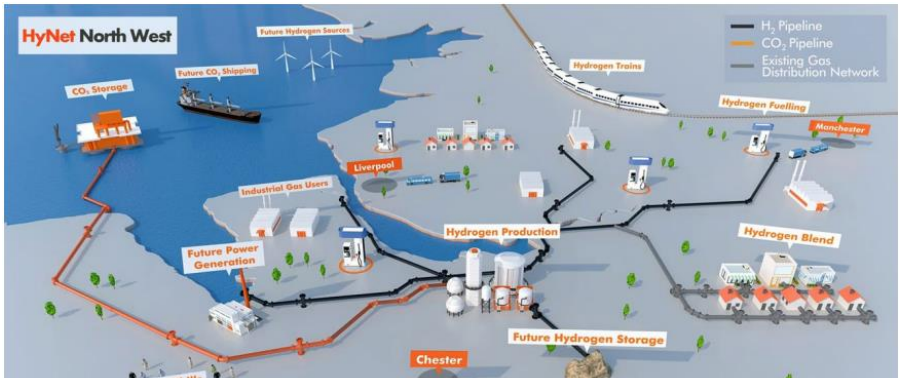


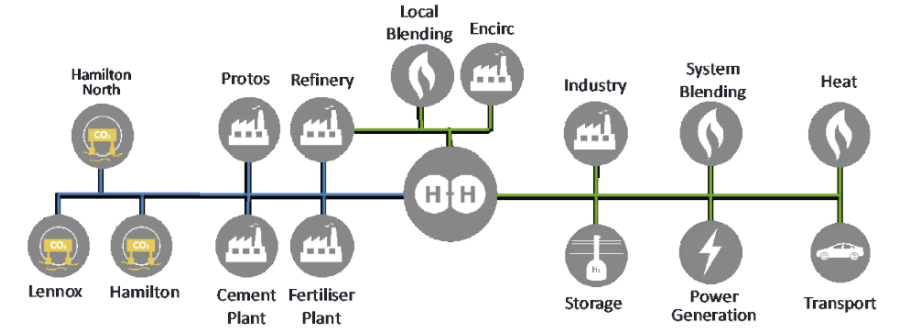


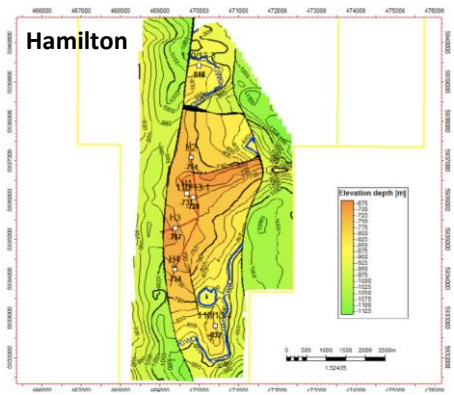
Source(s): https://www.gov.uk/government/publications/carbon-capture-usage-and-storage-ccus-innovation-nepnzt-key-knowledge-deliverables

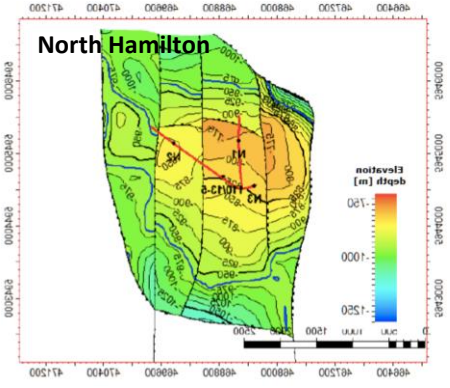
Key Projects: HyNet - Liverpool Bay Area

- Consortium lead integrated hydrogen and CCUS project based in NW England to tackle emissions from heat, industry, transport and flexible power.
  - Funded by BEIS and partners – Progressive Energy, Cadent, CF Fertilisers, Essar Oil UK, Peel L&P Environmental and University of Chester
  - In parallel with self-funded study into offshore transport and storage by Eni, owner and operator of the LBA oil and gas assets.
- A complete system of hydrogen production, supply and utilisation partnered with carbon capture, transport and sequestration.
  - Exploits cost/risk advantages of close proximity between full-chain system components.
  - The concept is readily scalable beyond it's initial scope and replicable to decarbonise industrial clusters elsewhere.
- Immediate capture of 1-10 $MtCO_2$/yr and supply of 1-6 x 300MW H_2 plants.
- Key knowledge deliverables are available within the public domain (URL below).





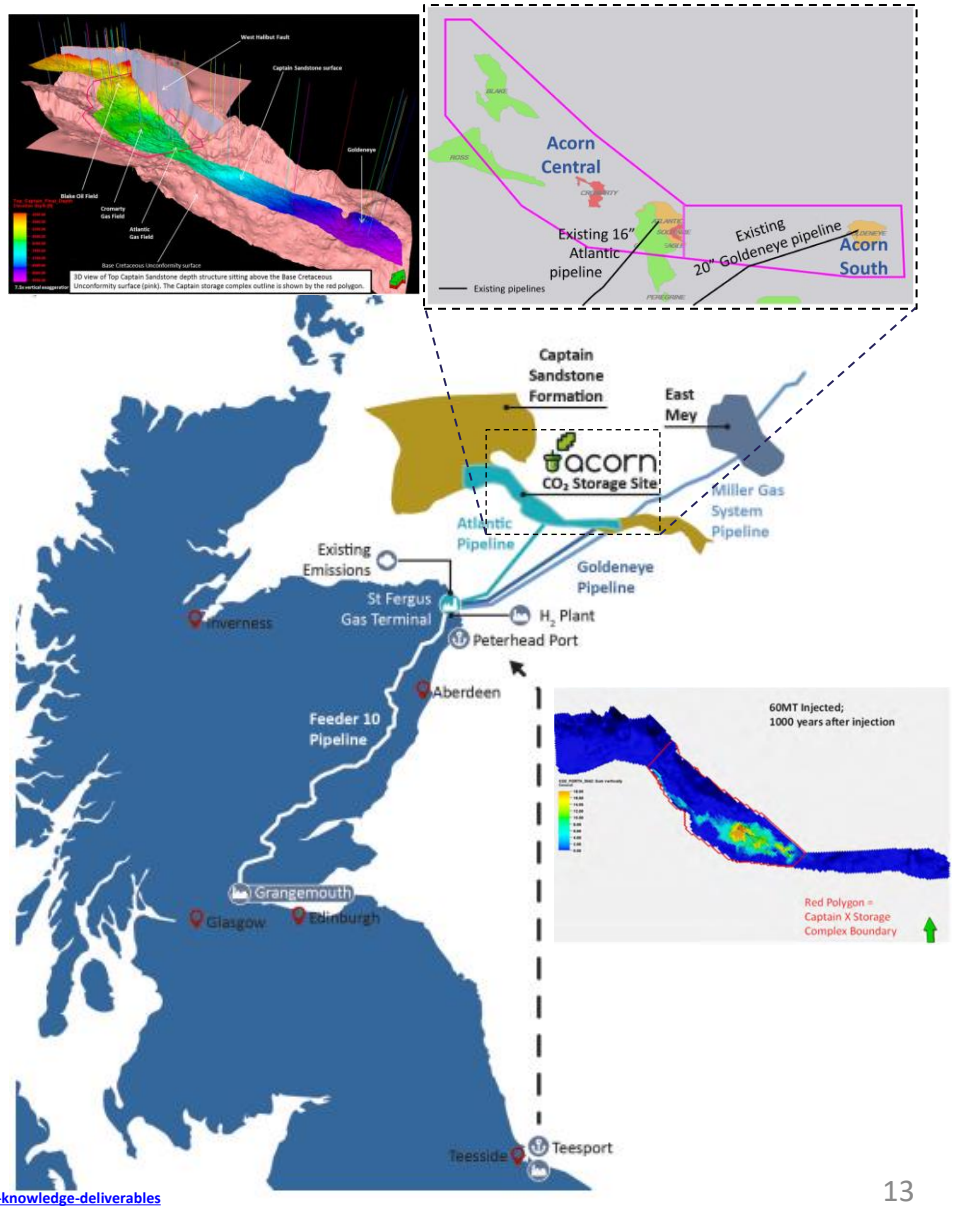




Source(s): https://www.gov.uk/government/publications/carbon-capture-usage-and-storage-ccus-innovation-hynet-ccus-key-knowledge-deliverables

Key Projects: Acorn CCS and East Mey

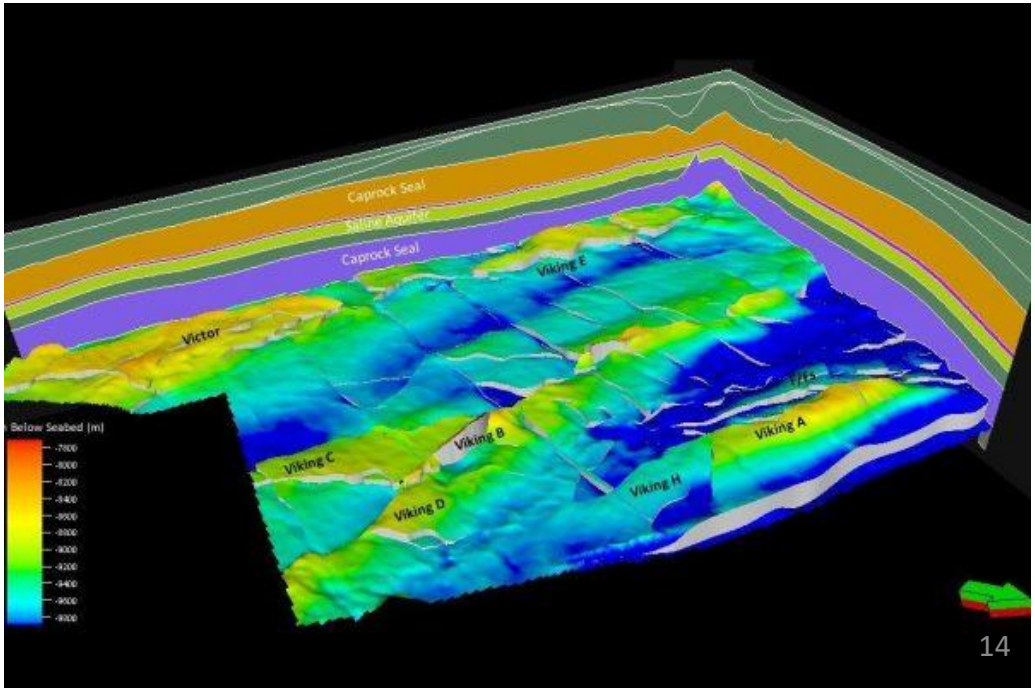
- First development CCS license in the UK.
- Lead by Storrega in partnership with Shell, Harbour Energy and NSMP, focussed on the Scottish cluster:
  - Partly funded by EU (Project of Common Interest) and BEIS (CCUS Innovation Fund) grants.
- Initial capture of 345 ktCO_2/yr from flue gas at St Fergus, stored using the Goldeneye depleted gas field.
- Strategically located for significant build-out and re-purpose of infrastructure.
  - Goldeneye pipeline.
  - Atlantic pipeline to Captain aquifer.
  - Miller pipeline to East Mey, also offers international interconnection.
  - Feeder 10 pipeline for import from Grangemouth.
  - Import/export via Peterhead Port.
- Partnered with Acorn Hydrogen
  - Blue H_2 production.
  - Aims for H_2-natural gas blend input to the National Transmission System
- Key knowledge deliverables available within the public domain (URL below).



Source(s): https://www.gov.uk/government/publications/carbon-capture-usage-and-storage-ccus-innovation-acorn-key-knowledge-deliverables
https://www.eti.co.uk/programmes/carbon-capture-storage/strategic-uk-ccs-storage-appraisal

Key Projects: V Net Zero

- Harbour Energy lead consortium focussed on power, heat and refinery emissions from the South Humber industrial cluster.
  - Partners VPI Immingham, Phillips 66, Prax Lindsey and EP UK Investments.
  - Funded through a BEIS (CCUS Innovation Fund) grant.
- Strategic location close to industry and key infrastructure to be repurposed.
  - High capacity Lincolnshire Offshore Gas Gathering System pipeline.
- Aims to appraise depleted SNS gas field – Viking and Victor – for storage of up to 11 $MtCO_2$/yr.
  - Multiple high-quality stores providing long-term build-out capacity.
- Limited information currently available within the public domain.

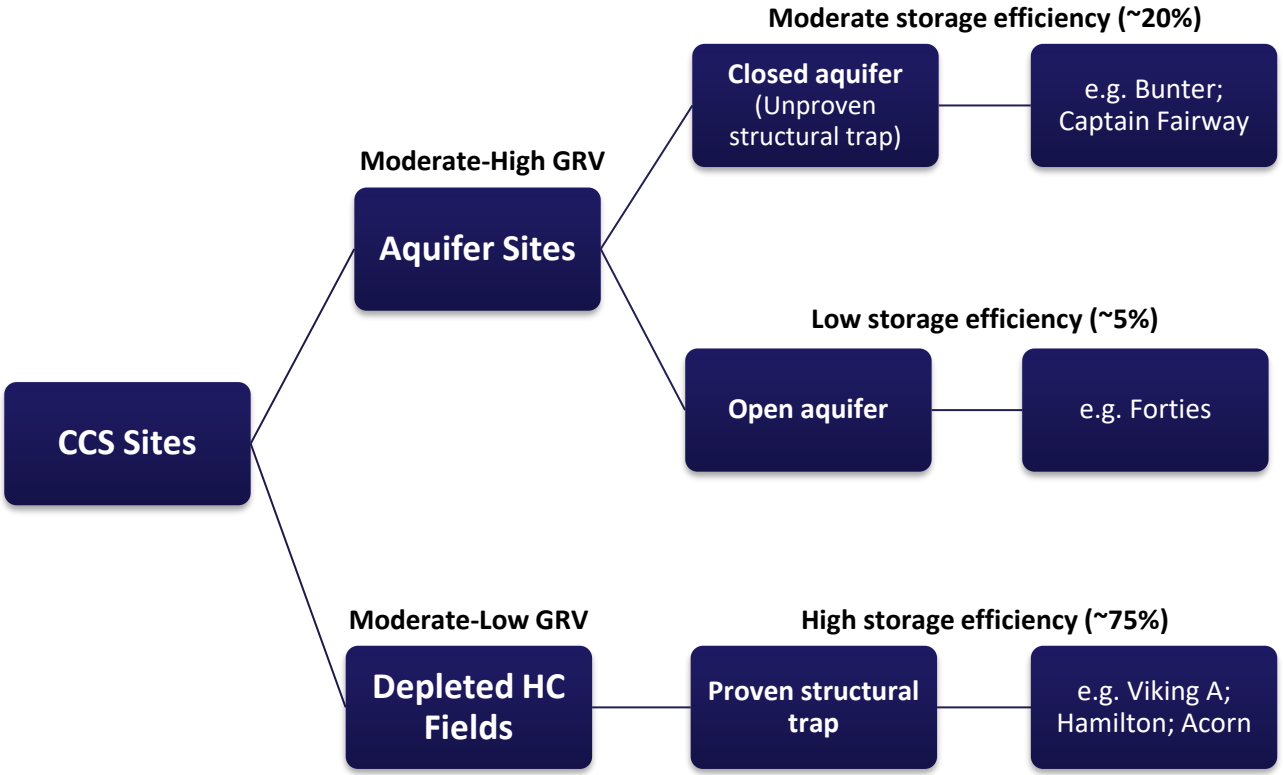


Source(s):

V Net Zero (vnetzerocluster.co.uk)

V Net Zero Pipeline (vnetzeropipeline.co.uk)

Two Key Types of Store Emerging

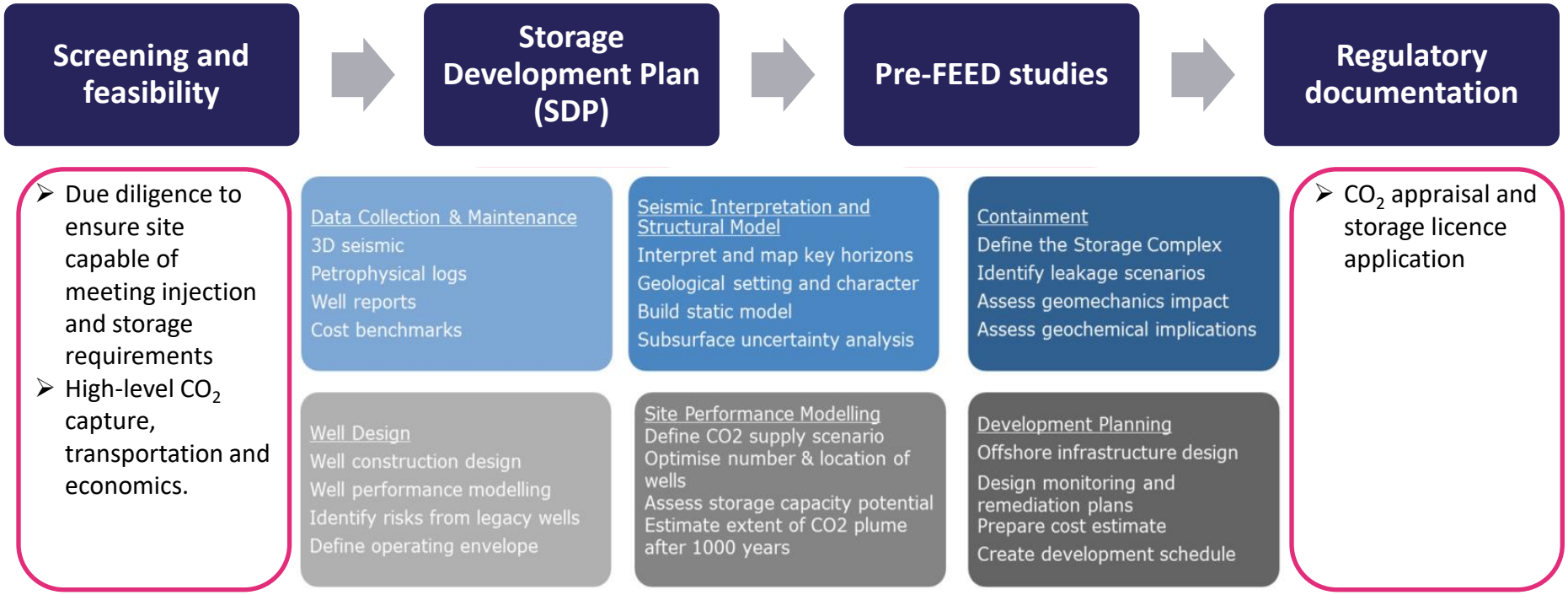


- Injection pressure > $P_{initial}$
- Fracture pressure gradient limit impacts injectivity and storage capacity.
- Inject deep due to fluid density differences.
- Well location - balance between pressure limit and spill point.

- Containment risk high - identify structural traps for added security.
- More difficult to define storage complex boundary.

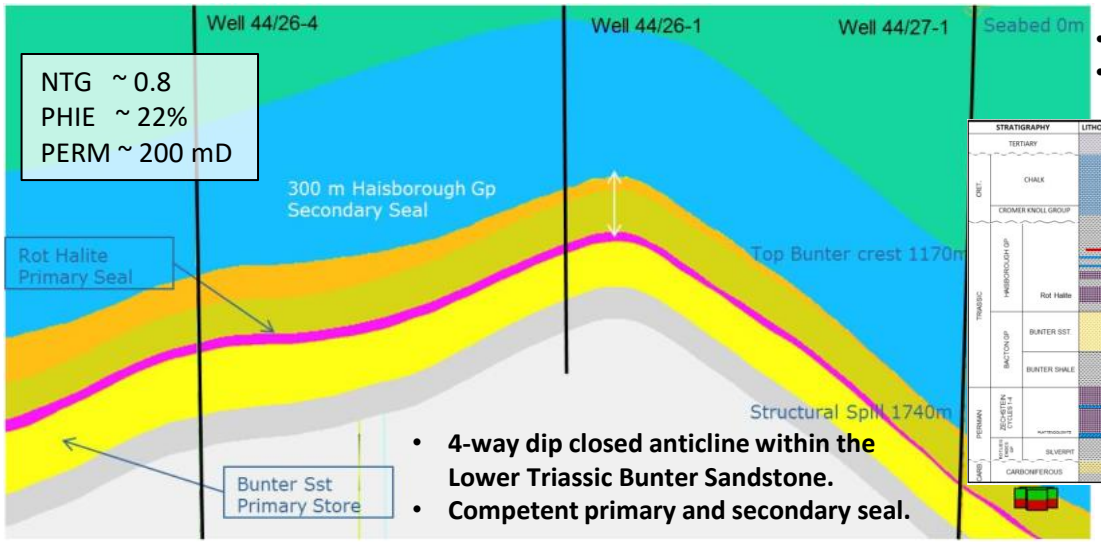
- Low reservoir pressure at initial injection conditions - challenges due to CO_2 fluid phase.
- Uncertainties in fracture pressure change with depletion and then with re-pressurisation. Hysteresis effect?
- Usually higher legacy well density than aquifer sites.

Storage Site Appraisal Workflow

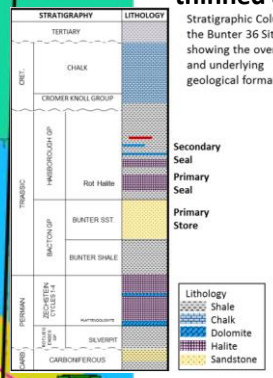


Capacity, injectivity and containment are consistently thought of as the key technical outcomes of storage appraisal.

Case Study: Bunter Closure 36

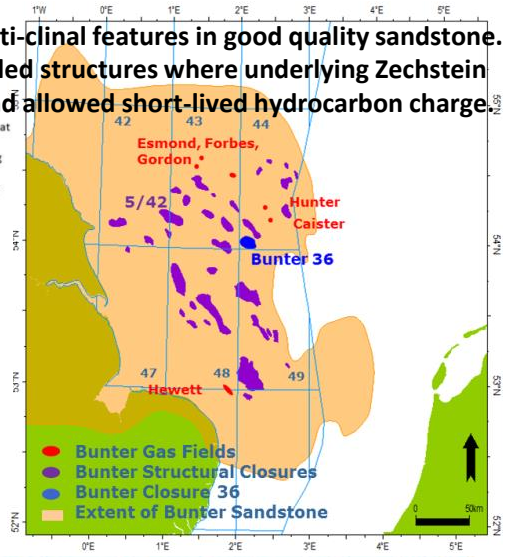


- 4-way dip closed anticline within the Lower Triassic Bunter Sandstone.
- Competent primary and secondary seal.

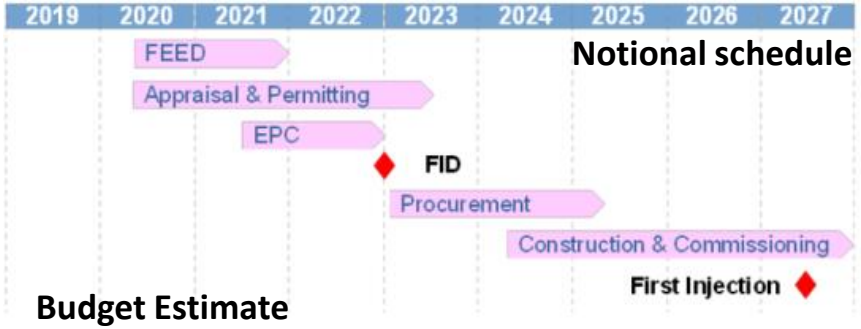


Stratigraphic Column at the Bunter 36 Site, showing the overlying and underlying geological formations

- Various anti-clinal features in good quality sandstone.
- Few gas filled structures where underlying Zechstein thinned and allowed short-lived hydrocarbon charge.



- **Site:** Closed structure, saline aquifer in the SNS.
  - Progressed as part of the UK Storage Appraisal Project portfolio (1 of 5 stores).
  - Analogous to Endurance 5/42 (and currently part of the NZT build-out scope).
- **Development premise:** 7 $MtCO_2$/yr from Barmston on the Yorkshire Coast. Equivalent to the emissions from a 1200 MW coal-fired power station. First injection 2027.
- **Facilities:** New 160km 20" pipeline and 2-storey minimum facilities platform (NUI) on single 4-leg steel jacket in 75m water. 40-yr design life.
- **Wells:** 5 deviated 5.5" injectors (4 active), 20-yr design life (with provision for replacements).
- **Storage:** 280 $MtCO_2$
- **Levelized cost:** £15.9/tCO_2 (PV_{10})



Notional schedule

Budget Estimate

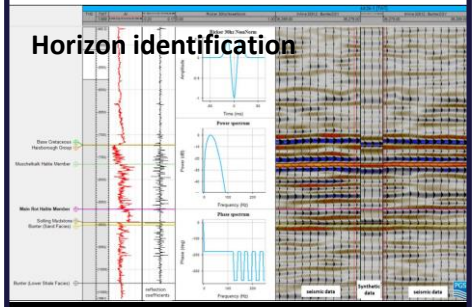
£ million (PV10 in 2015)	Phase I	Phase II	Total
Transportation	117		117
Facilities	48		48
Wells	77	12	89
Opex	90		90
Decommissioning & MMV	3		3
Total	335	12	347

Source(s): https://www.eti.co.uk/programmes/carbon-capture-storage/strategic-uk-ccs-storage-appraisal

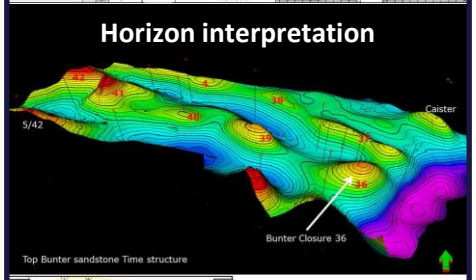
Case Study: Bunter Closure 36

GEOPHYSICAL INTERPRETATION

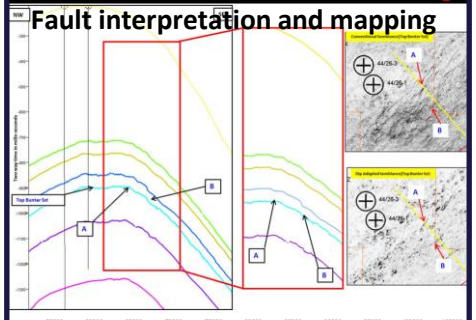
Horizon identification



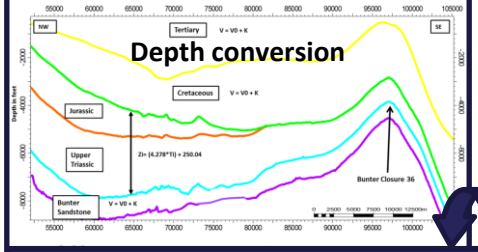
Horizon interpretation



Fault interpretation and mapping

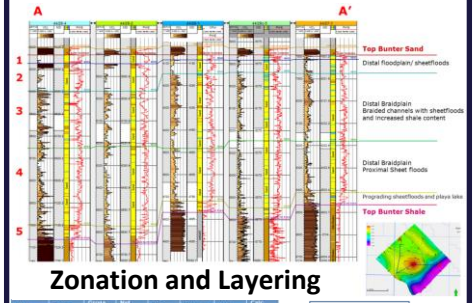


Depth conversion

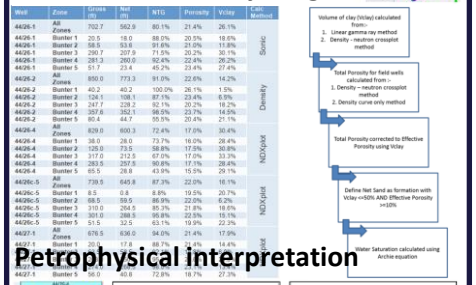


GEOLOGICAL MODEL

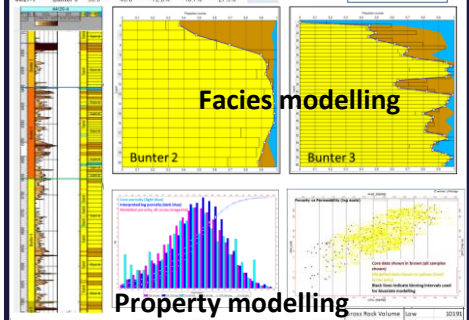
Zonation and Layering



Petrophysical interpretation

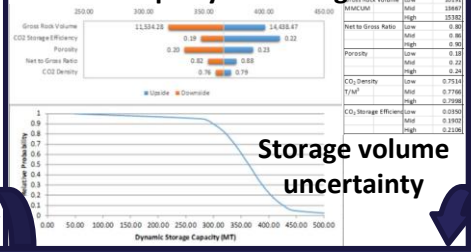


Facies modelling



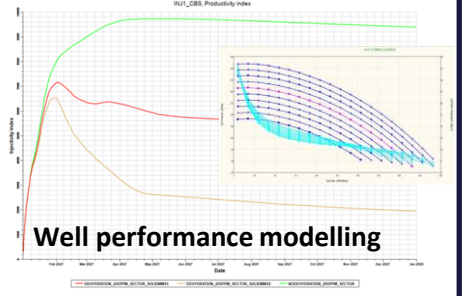
Property modelling

Storage volume uncertainty

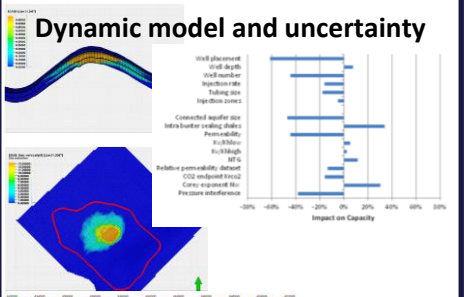


RESERVOIR ENGINEERING

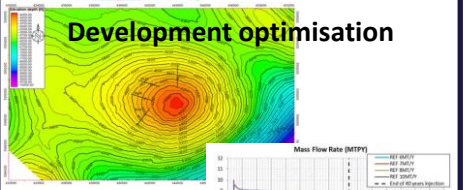
Well performance modelling



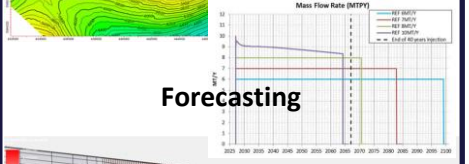
Dynamic model and uncertainty



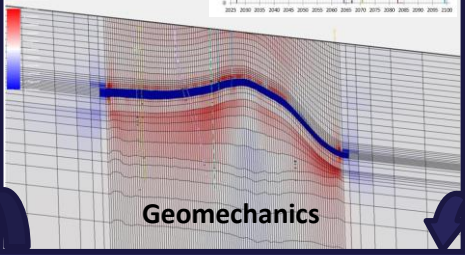
Development optimisation



Forecasting

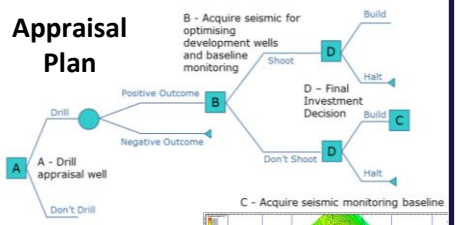


Geomechanics

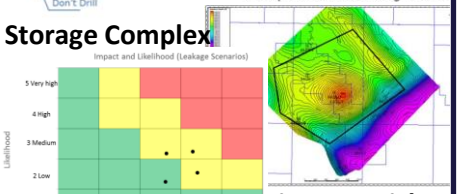


DEVELOPMENT PLAN

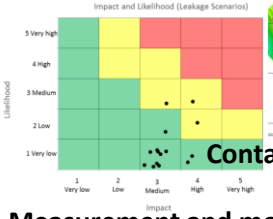
Appraisal Plan



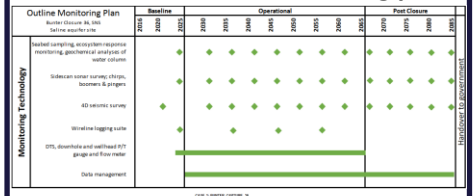
Storage Complex



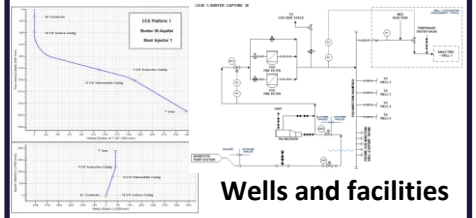
Containment Risk



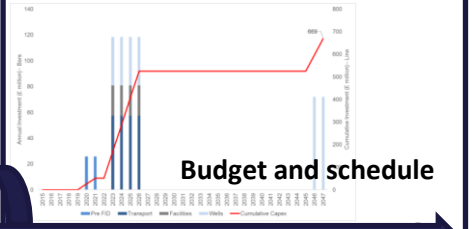
Measurement and monitoring plan



Wells and facilities



Budget and schedule

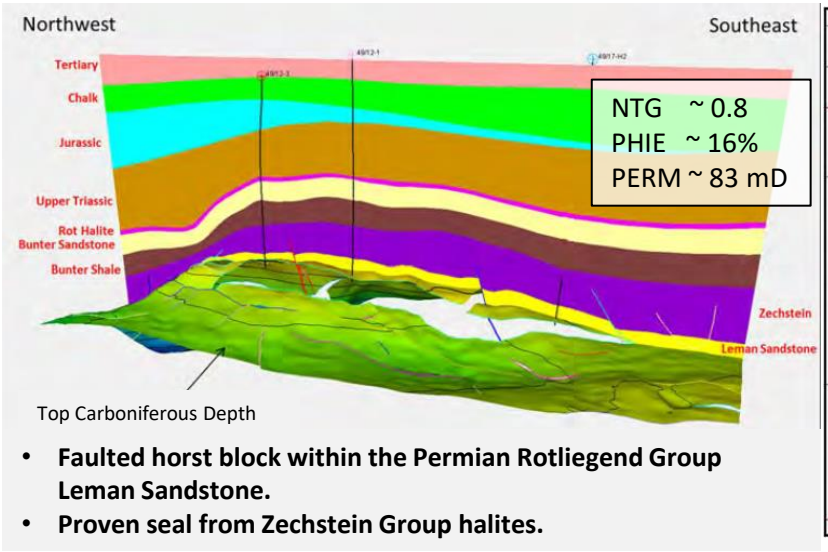


INTEGRATED WORKFLOW

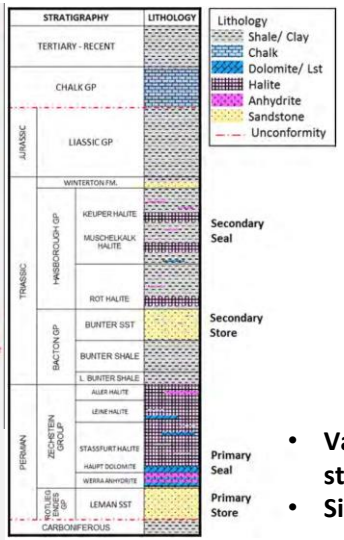
Case Study: Bunter Closure 36

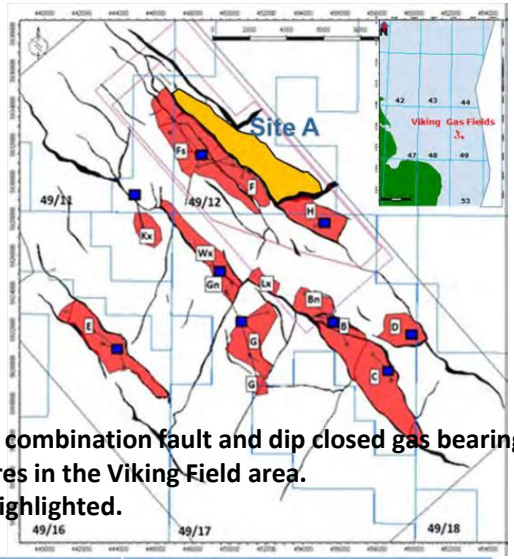
Key Risks	Screening Risk Level	Store Characterisation	Risk Mitigations	Mitigated Risk Level
• Capacity		• **Depth conversion uncertainty** due to limited seismic-well tie data	• **Appraisal well** to de-risk velocity field • **New seismic** optimised at Bunter level	
• Reservoir and injectivity performance		• **Limited reservoir quality data** (2 exploration wells on structure, 1 partial core within storage complex) • Uncertain vertical connectivity (shales and cemented intervals in high net sand) • **No SCAL data** (Pc, Kr hysteresis) • **No dynamic reservoir data for model calibration** (production/injection) • No formation brine chemistry • Favourable matrix mineralogy and low formation temperatures	• **Appraisal well** data acquisition plan • Seismic attribute generation (amplitude volume for reservoir quality and cemented interval ID) • Offset analysis and regional analogues (reservoir quality, log analysis of cemented intervals) • Geochemistry to de-risk poro-perm impairment (mineral trapping, scales) • **Fairway interpretation / models** (aquifer performance) • **Development well optimisation** • **Uncertainty management**	
• Engineering containment		• **Low existing well density** (few leak paths)	• Legacy well integrity review • Legacy well abandonment plan (underlying Schooner Field)	
• Geological containment		• Good quality seismic data • Minor faulting within site area • **Unproven seal integrity** (pore entry-pressure, rock mechanics)	• Seismic attribute generation (semblance volume for fault ID) • Dynamic fracture pressure limits incorporated during reservoir simulation. • **3D geomechanical modelling** and **well bore stability assessment** • Geochemistry to de-risk CO_2 store seal integrity • **Overburden interpretation / models** (leak containment) • **Offset analysis and regional analogues** (gas field seal integrity)	

Case Study: Viking-A Depleted Gas Field



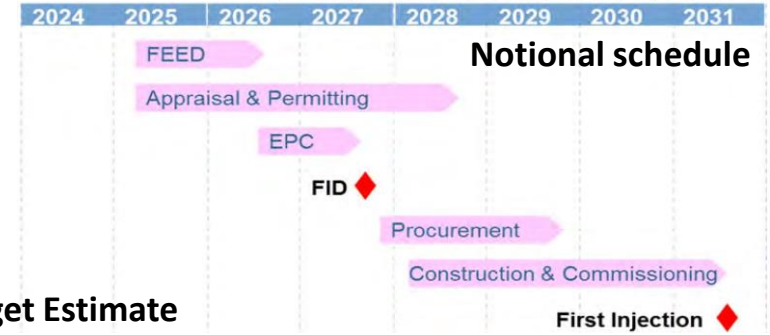
- **Faulted horst block within the Permian Rotliegend Group Leman Sandstone.**
- **Proven seal from Zechstein Group halites.**





- **Various combination fault and dip closed gas bearing structures in the Viking Field area.**
- **Site A highlighted.**

- **Site:** Depleted gas field in the SNS.
  - Progressed as part of the UK Storage Appraisal Project portfolio (1 of 5 stores).
  - Adopted as the primary store for Harbour Energy's V Net Zero project.
- **Development premise:** 5 $MtCO_2$/yr from Barmston on the Yorkshire Coast. Equivalent to the emissions from a 850 MW coal-fired power station. First injection 2031.
- **Facilities:** New 185km 20" pipeline and minimum facilities platform (NUI) on single 4-leg steel jacket in 28m water. 26-yr design life.
- **Wells:** 3 deviated 7" injectors (2 active), 26-yr design life (with provision for workovers).
- **Storage:** 130 $MtCO_2$
- **Levelized cost:** £23.4/tCO_2 (PV_{10})



Notional schedule

Budget Estimate

£million (PV_{10}, 2015)	Total
Transportation	74
Facilities	47
Wells	29
Opex	79
Decommissioning & MMV	4
Total	233

Source(s): https://www.eti.co.uk/programmes/carbon-capture-storage/strategic-uk-ccs-storage-appraisal

Case Study: Viking-A Depleted Gas Field

Key Risks	Screening Risk Level	Store Characterisation	Risk Mitigations	Mitigated Risk Level
• Capacity		• **Minor depth conversion uncertainty** (good well control) • Proprietary reprocessed seismic unavailable. • **Pore volume proven** by production	• Obtain reprocessed pre-stack depth migrated 3Dseismic (to improve interpretation of faults and steeply dipping flanks).	
• Reservoir and injectivity performance		• **Good quality petrophysical data** (13 wells in area of interest, 4 wells cored) • Some SCAL data (petrophysical only) • Known formation fluid properties • **Incomplete dynamic reservoir data** for model calibration (production but no well pressure histories) • **Formation integrity risks** to injectivity (under initial pressure depletion) • Favourable matrix mineralogy (unreactive quartz dominates)	• **Reservoir engineering analysis** to de-risk connectivity and aquifer performance • Geochemistry to de-risk poro-perm impairment (mineral trapping, scales) • **Sand control** assessment • Provision for near-well water wash facilities • **Development well optimisation** • **History matching** and **uncertainty**	
• Engineering containment		• **High existing well density** (many leak paths) • **CO_2 phase behaviour** in low pressure injection period risks formation integrity	• Legacy well integrity review • Legacy well abandonment plan • **CO_2 phase management** (heating to avoid gas/liquid phase transition)	
• Geological containment		• Excellent quality seismic data • Highly faulted reservoir that is constrained within overlying halites • **Proven seal** • Favourable seal mineralogy • **Fault reactivation** and **fracture pressure hysteresis** during re-pressurisation	• Seismic attribute generation (semblance volume for fault ID) • Dynamic fracture pressure limits incorporated during reservoir simulation • **Thermal modelling** of in-situ temperature effects • **1D** and **3D geomechanical modelling** • **Legacy well LOTs** for fracture pressure • Geochemistry of CO_2 store seal integrity • **Overburden interpretation / models** (leak containment)	

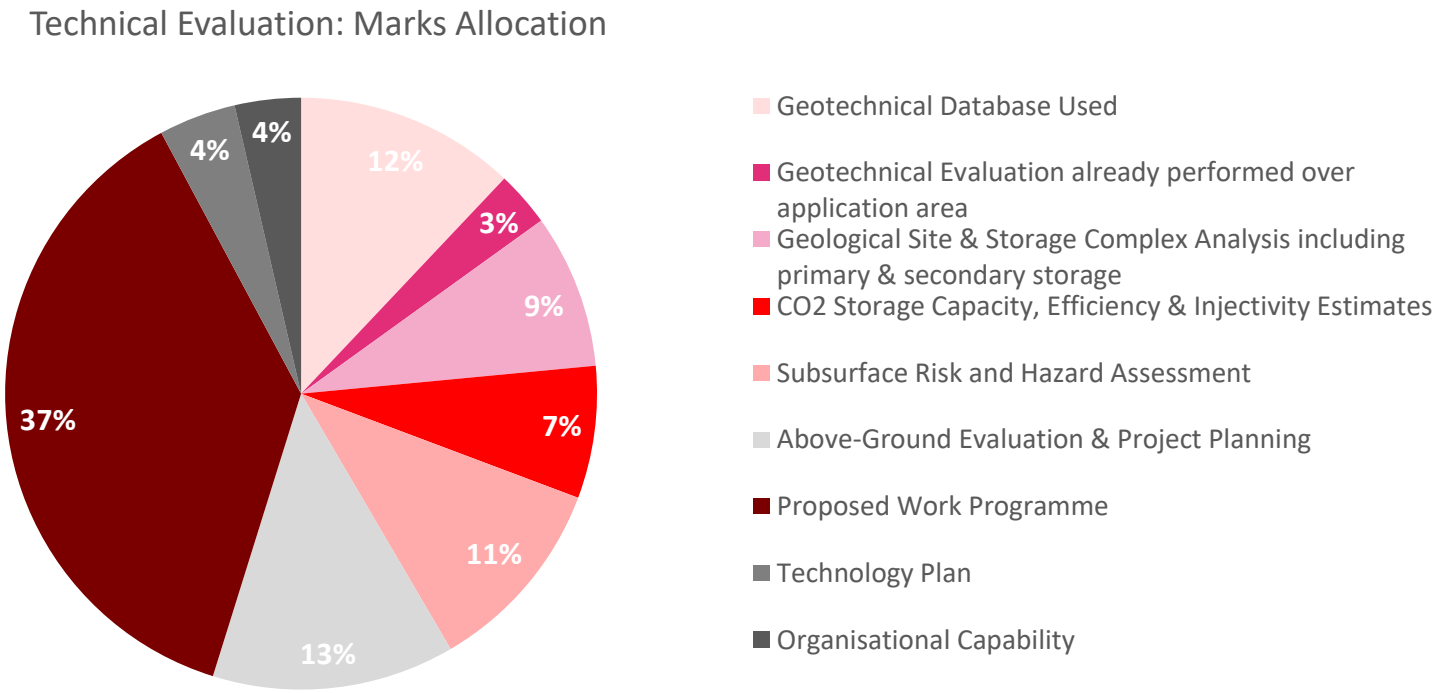
CCS Licensing and Regulation

- Carbon storage licensed and regulated by NSTA under Section 18 the Energy Act (2008) and the Storage of Carbon Dioxide Regulations (2010).
- Separate Crown Lease also required in UK territorial waters.
  - Crown Estate Act (2008).
- CS License for exploration and appraisal (initial term), followed by a storage permit during the operational term.
  - A work programme defines the minimum commitment during the initial term and is binding.
  - Expiry follows the initial term if application for storage permit is not made or if the permit application is not approved.
- Comprehensive MMV an essential part of the CO_2 storage permit.
  - Baseline, operational and post-closure monitoring
  - Transfer of liability from operator to the regulator 20 years post-closure.
- NSTA controls which areas are offered and when (licensing rounds) including consideration to:
  - The Strategic Environmental Assessment of the Offshore Petroleum Regulator for Environment and Decommissioning (OPRED)
  - Conflicts with other permit areas (e.g. offshore oil, gas and wind energy)
- First CS licensing round opened 14th June 2022 and closed on the 13th September attracting 26 bids from 19 companies over 13 areas offered.
- Similar process / mechanisms to licensing of petroleum acreage coordinated by the same regulatory body (NSTA).

Source(s): https://www.nstauthority.co.uk/licensing-consents/carbon-storage/

1st UK CCUS Licensing Round

- Clear guidance issued by NSTA.
- Marking scheme supplied.
- Greatest marks awarded for proposed workplan in which seismic acquisition and/or planned appraisal well is included – illustrates commitment.
- Subsurface evaluation carries significant weight – advantage in modelling at this early stage.



Recommended Workflow for UK Licence Application

Data assimilation

- Review and gather all relevant seismic and well data (from NDR or other), including interpreted data, study documentation and models.

Screen and rank injection sites

- First stage review and evaluation including seismic interpretation over storage complex area and injectivity assessment.
- Carry out capacity checks for each site
- Rank (based on perceived risk and capacity)
- Select injection site.

Site characterisation

- Build screening level dynamic model to evaluate site performance.
- From seismic - top, base and faults.
- Reservoir property modelling (at appropriate level)
- Define safe operating range for injection
- Assess capacity and injectivity performance

Risk Assessment

- Confirm security of geological containment
- Identify secondary stores
- Review phase management requirement
- Incorporate findings from legacy well review
- Assess overall containment risk

Proposed workplan

- Confirm requirement for new and/or reprocessed seismic
- Confirm requirement for appraisal well(s)

Summary Observations

- CCS activity is rapidly accelerating in the UK driven by increased urgency to decarbonise hard-to-abate industry.
- Policy support for early CCS activity provided the impetus to progress commercial-scale opportunities.
  - Although numerous projects have been deferred, or withdrawn, considerable value was realised through knowledge delivery.
- More recent CCS activity has largely been driven by industrial players and independent corporate "greening" initiatives largely in the absence of tangible government support.
- The UK Storage Appraisal Project commissioned by DECC, undertaken by Axis and PBD in 2015, has proven a catalyst for CCS maturation.
  - Strategic storage capacity screened, appraised and pre-qualified.
  - 4 of 5 high-graded storage sites are now the forerunners for commercial development.
- These workflows are being adopted by current developers and applicants of the 1st UK licensing round.
  - Still represents state-of-the-art within the nascent UK CCS industry.
  - Could equally be applied elsewhere to progress national, state or corporate portfolios.
- Adoption of oil industry skills and technology has proven crucial to deployment of CCS programmes.

Additional Resources

- The following represent additional CCS knowledge sharing resources available within the public domain:
  - Demo-1: First UK CCS Competition
    - Kingsnorth FEED Study
    - Longannet FEED Study
  - Demo-2: UK CCS Commercialisation Competition
    - Peterhead and White Rose - Subsurface and Well Engineering
    - Peterhead and White Rose - Power and Capture
    - Peterhead and White Rose - Full Chain
    - Peterhead and White Rose - Commercial, Project Management and Lessons Learned
    - Peterhead and White Rose - Transport
- Links to other key resources have been supplied within the main body of this presentation.

Thank you

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