Oil & Gas Authority

UKCS Energy Integration

Final report

Annex 2. Carbon Capture and Storage

August 2020

Department for Business, Energy & Industrial Strategy

The Crown Estate

ofgem

UKCS Energy Integration project

Oil & Gas Authority

Funded by £900k grant from the Better Regulation Executive's Regulators' Pioneer Fund

Led by Oil & Gas Authority

in collaboration with

Department for Business, Energy & Industrial Strategy

The Crown Estate

ofgem

- Engaged widely across industry and regulators
- Understood potential of UKCS assets and technologies for net zero, and synergies across the different energy sectors
- Identified hurdles (economic, regulatory) and recommend avenues to realise full technologies' value

Project timeline

1. **Technical options** *1Q-2Q 2019* (Lloyd's Register)
2. **Economic and regulatory assessment** *3Q2019-1Q2020* (EY)
3. A **Phase 3** is proposed to follow to implement recommendations, accelerating UKCS energy integration projects

This document is an annex to the final report of the UKCS Energy Integration Project available on the OGA web site.

This annex should be read in conjunction with the assumptions and notes contained in the main report.

Information and findings in this CCS Annex should be considered in the context of ongoing Government work on policy approaches for Carbon Capture, Usage and Storage (CCUS), which was out of the scope of our project.

References to Government's guidance and ongoing work related to CCUS are given in the Appendix.

Contents

Oil & Gas Authority

Carbon Capture and Storage – findings

Oil & Gas Authority

CCS can be critical to achieve UK net zero, and UKCS role is key

- 75-175 $MtCO_2$ / yr captured and stored by 2050[1], or up to one third of the current UK's emission baseline
- 78 $GtCO_2$ potential storage capacity[2] on the UKCS, could be sufficient for 100s of years of UK's demand

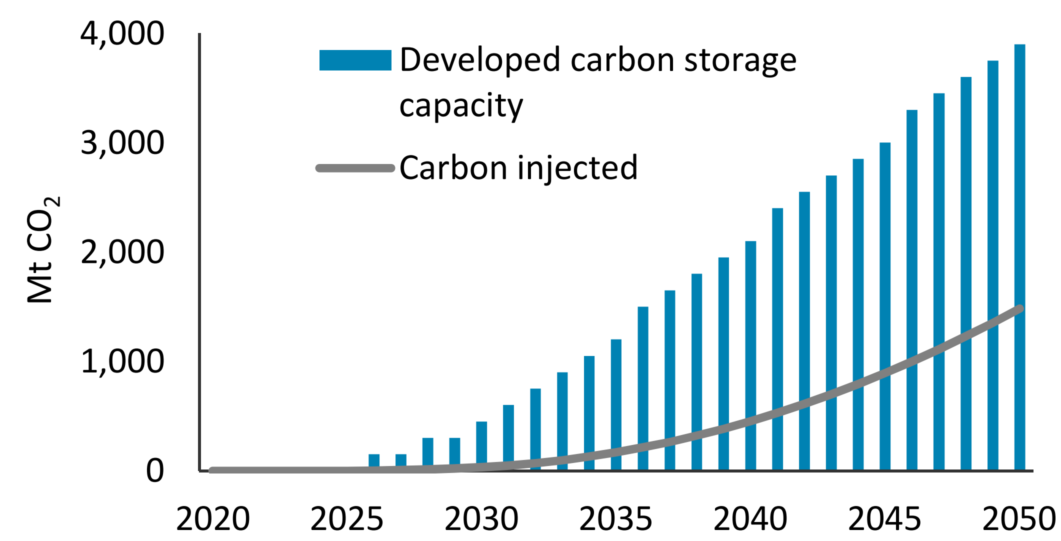
Accelerating projects would be needed to achieve expected CCS volumes

- >2 pilots followed by >2 commercial-scale projects developed by 2030 necessary to provide critical learnings for the subsequent expansion
- 130 $MtCO_2$/yr by 2050 flow rate (central case) would then require ~4 Gt CO_2 storage capacity developed across >20 individual stores[3]

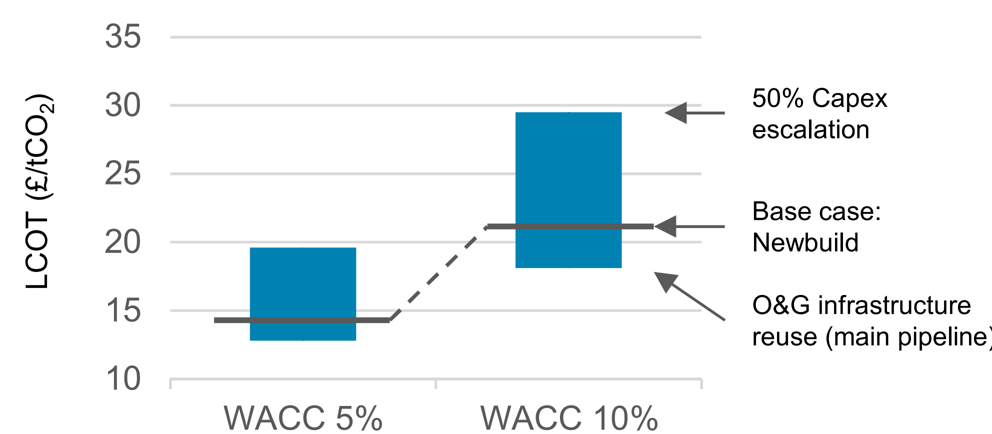
CCS could be economically competitive as emission abatement technology

- Levelised transport and storage costs of £12-30/tCO_2 could be attained
- Adding onshore capture costs, CCS is cost-competitive against long-term carbon price forecasts
- Combination with blue hydrogen can enhance economics and create scalable business models
- Levers to reduce CCS costs include economies of scale (e.g. CCS clusters and hubs) and reuse of O&G infrastructure

Developed CO_2 T&S capacity and cumulative injection (EIP central case[4])



Levelized costs of T&S (£/tCO_2, notional project examples[4])



1. CCC (2019) 'Net Zero: The UK's contribution to stopping global warming', 2. ETI ,BGS ,Co2stored.co.uk, 3. UKCS Energy Integration Project; 4. See note on methodology in appendix

Carbon Capture and Storage – recommendations

Oil & Gas Authority

1. Ensure the timely ramp up of CCS

- The Government has emphasised the importance of CCS to support its Clean Growth Strategy and net zero target, with an aim to deploy the technology at scale during the 2030's
- The Government has been providing funding towards CCS technology deployment and the establishment of net zero industrial clusters
- BEIS has been consulting industry and other regulators on critical enablers, including business models, market frameworks and O&G infrastructure reuse policy[1]
- It is key that this good progress and industry engagement are maintained, to ensure CCS pilots and first commercial-scale projects are deployed in the 2020's
- Accelerating initial CCS projects is critical to mature the technology for the subsequent ramp-up in the 2030's
- In addition, this would allow to fully leverage the UK's O&G industry expertise, supply chain and existing infrastructure

1) See appendix

2. Enhance regulatory coordination on CCS and hydrogen

- Regulators coordination to expedite industry projects
- Align planning and consenting regimes to support cross-industry opportunities (e.g. O&G, CCS and blue H_2)

Enhanced coordination on CCS and hydrogen[1]
Vision: Provide proactive regulatory support for CCS and hydrogen projects, ensuring guidance to permit the timely execution of pilots and subsequent ramp-up of these novel technologies in the 2020's

Department for Business, Energy & Industrial Strategy; Oil & Gas Authority; Crown Estate Scotland; ofgem; The Crown Estate; HSE

1) Composition and vision of proposed 'coordination groups' yet to be agreed with relevant stakeholders

3. Improve data availability

- Improved access to data (including on subsurface, existing facilities and infrastructure developments) is critical for both government and industry to develop optimal CCS build-out plans

CCS build-up scenario

CCS potential for net zero

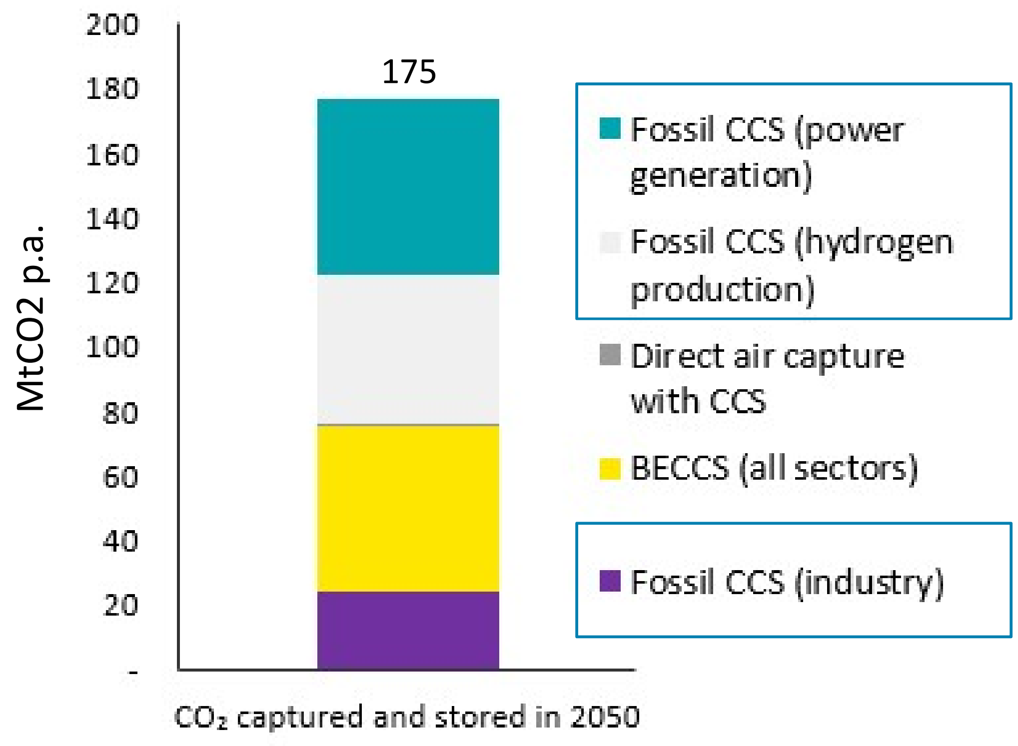
Oil & Gas Authority

CCS potential growth

- Carbon capture and storage (CCS) is likely to play a significant role for UK's net zero
- BEIS (2018) estimated ca.130MtCO_2 p.a. contribution from negative emissions technologies needed by 2050
- CCC (2019) estimated up to 175 MtCO_2 p.a. to be abated through CCS by 2050
- Of this, (see chart) 125MtCO_2 from (blue) hydrogen production and combustion of fossil fuels (power generation and industry)
- NG FES (2019) expects that up 377 TWh of natural gas p.a. would be converted to hydrogen by 2050, a process which would require 70MtCO_2 p.a. of CCS

For detail on references and sources see appendix

CO2 captured and stored in 2050 (CCC)



Source: CCC (2019) 'Net Zero: The UK's contribution to stopping global warming' (high case shown)

BECCS = Bio-Energy with CCS

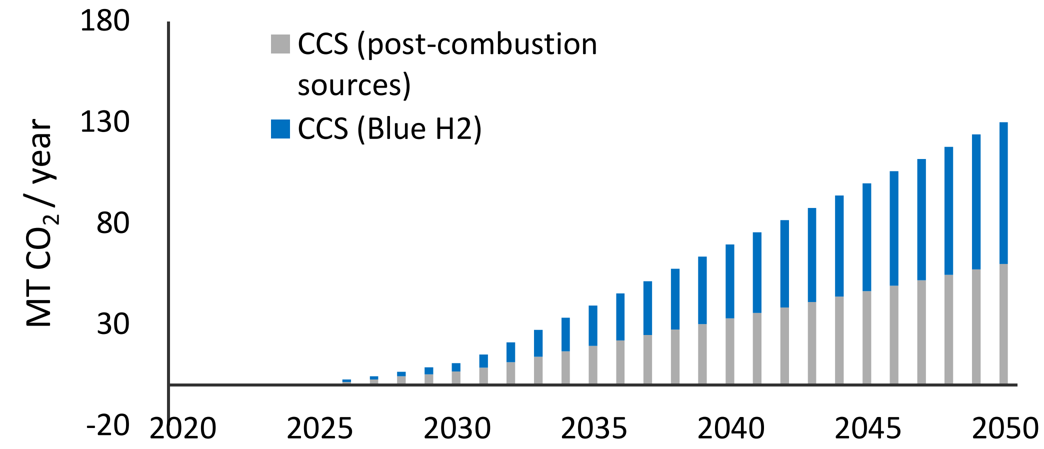
CCS build-up scenario

Oil & Gas Authority

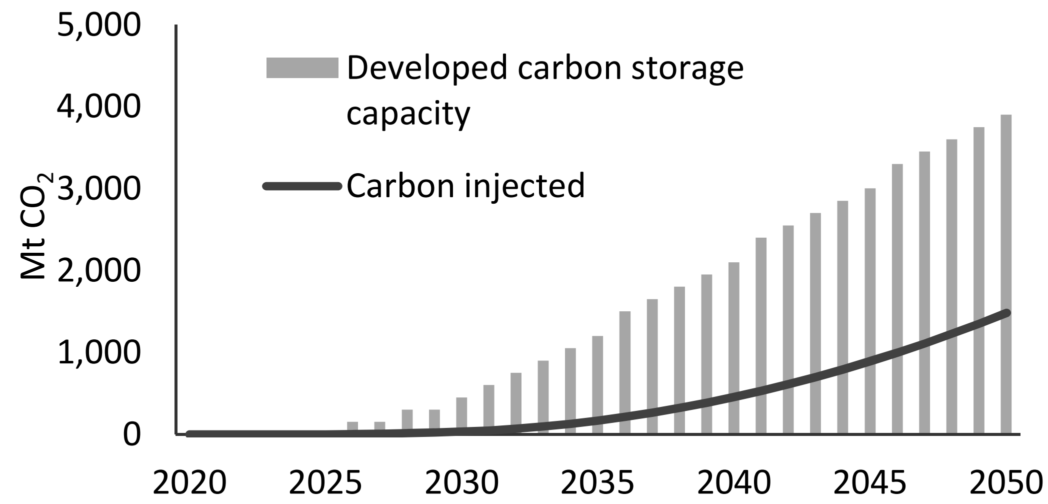
- Based on previous references, we assumed:
  - CO_2 injection rate achieving 130 $MtCO_2$ p.a. in 2050
  - 70-60 split between blue hydrogen and post-combustion CO_2 capture (power and industrial sources)
  - Growth reflecting initial pilot-scale projects planned for the 2020s, followed by commercial scale plants in the 2030s and 2040s
- Delivering this growth will be dependent on:
  - Onshore infrastructure to capture the CO_2 from power and industrial activities
  - Plants to produce blue H_2
  - Build onshore/offshore CO_2 transportation
  - Develop ~3.9 $GtCO_2$ of storage capacity and injection facilities

Source: EIP analysis, methodology described in appendix

UKCS CO_2 injection rates (EIP scenario)



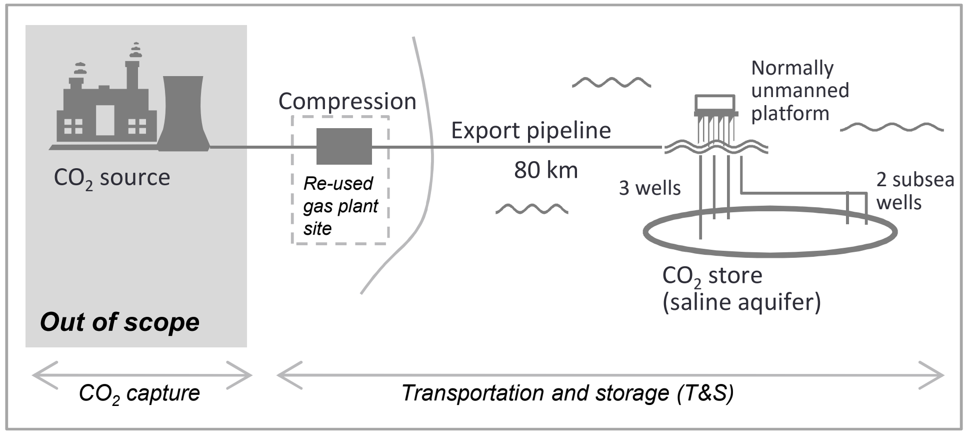
Developed CO_2 storage capacity and cumulative injection



CCS build-up scenario

Oil & Gas Authority

Notional CCS project



Transportation and storage scope

- CO2 store developed capacity: 150 $MtCO_2$
- Injection rate: 5 $MtCO_2$ p.a.

- 1 platform injection wells + 1 monitoring
- 3 subsea injection wells
- Wellhead platform (normally unmanned)
- Subsea injection centre (10km distance)
- Pipeline from shore (20 inch, 80 km)
- Power from shore – transmission cable
- Onshore compression (at re-purposed gas plant)

Source: EIP analysis, methodology described in appendix

CCS build-up scenario (2020-2050)

	2025	2030	2040	2050
Number of notional storage sites (150 $MtCO_2$ / ea.)	~2 pilots	~3 commercial scale	14	26
CO_2 storage capacity developed (Mt)	150	450	2100	3,900
CO_2 injection volumes (Mt/year)	4	10	69	130
Cumulative carbon stored (Mt)	0	33	455	1,483

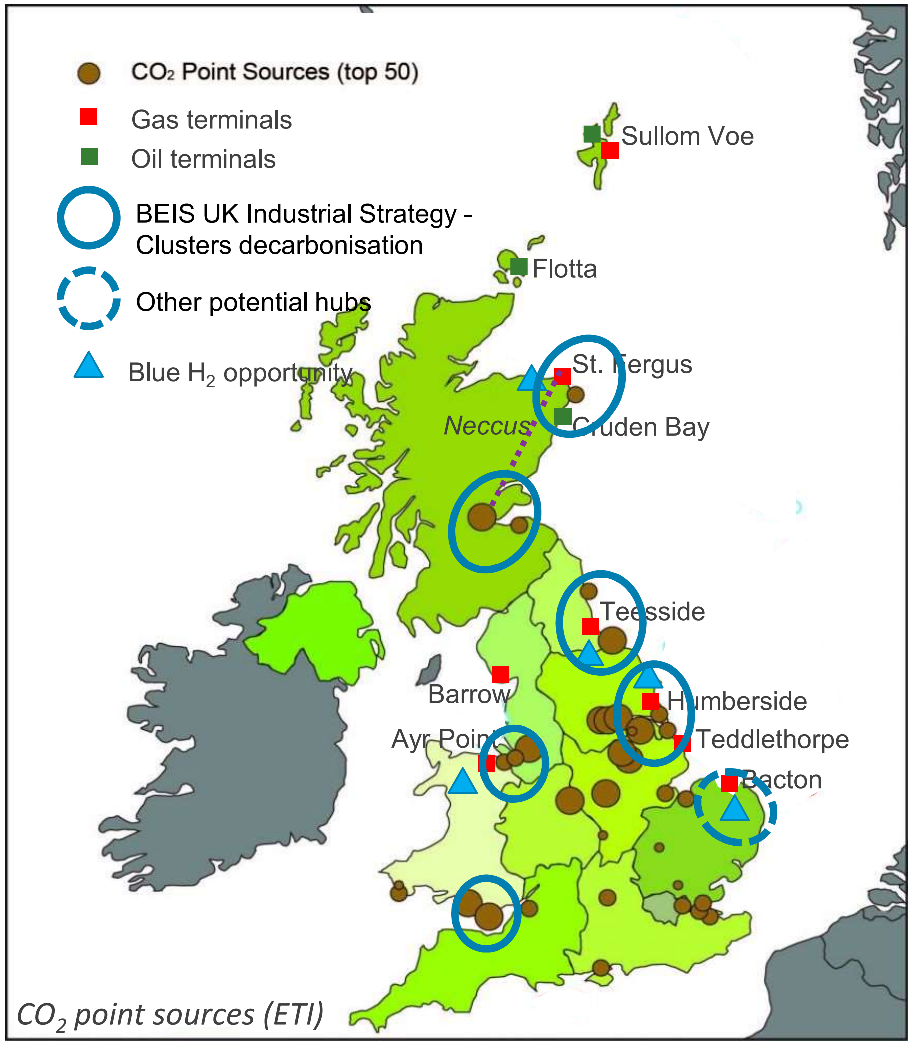
- CCS could contribute to over 130MtCO2 p.a. of UK's net zero by 2050 target
- ~26 CO2 offshore storage sites would be needed with developed storage capacity ~3.9 GtCO2
- To reach this, it would be critical to deliver ~2 pilots by mid-2020s and ~3 commercial projects by 2030
- Accelerating CCS plans is key to secure cost-efficient O&G infrastructure where appropriate

Potential CCS locations

Oil & Gas Authority

CCS growth (combined with blue hydrogen) could ideally support UK's industrial cluster decarbonisation priorities[1]

UK industrial clusters and largest CO_2 sources



CO_2 point sources (ETI)

Main UK industrial clusters[1] and CCS / blue hydrogen potential

Clusters and Hubs	CCS	Blue H_2	CCS / blue hydrogen development potential
St Fergus - Grangemouth			*Acorn* project. CCS from blue H_2 and combustion sources. NECCUS link from Grangemouth (4.3MtCO_2/yr)
Teesside			*Net zero Teesside* decarbonisation including blue H_2. Teesside industrial cluster emissions (3.1MtCO_2 p.a.)
Humberside			*Zero Carbon Humber* (12.4 MtCO_2/yr) includes blue H2, BECCS and links with H21 project sources (20MtCO_2/yr)
Bacton			Potential blue H2 from SNS gas and interconnector imports (green H2 from large expected windpower exp.)
Merseyside			HyNet blue hydrogen (volumes TBD) and additional CCS from industrial sources (2.6 MtCO_2/yr)
South Wales			Large industrial cluster with 8.2 MtCO2/yr emissions, CO_2 could be transported by ship to storage sites
Southampton			Industrial cluster with 2.6 MtCO_2/yr emissions, CO_2 could be transported by ship to storage sites

CCS volumes scenario	Year	2025	2030	2040	2050
	MtCO_2 p.a.	~4	~10	~70	~130

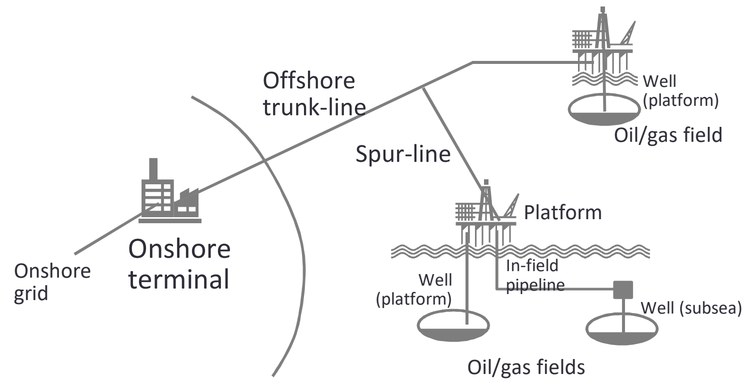
1) UK Industrial Strategy and Industrial Cluster Mission (BEIS, see appendix for references), CCS and blue hydrogen potential (EIP analysis)

CO_2 transport infrastructure

Oil & Gas Authority

CO_2 will be transported to offshore storage sites either as a gas or in dense phase. New CO_2 pipelines can be built according to established design standards. Selected existing O&G pipelines could be repurposed, subject to logistic and technical assessment

O&G infrastructure and potential for CCS reuse



Onshore terminals
Critical infrastructure already connected with both offshore pipelines and onshore grid. Could have strong case for repurposing, giving project timeline and Capex efficiencies.

Trunklines and spurlines (ca. 100 active on UKCS)
Connecting offshore platforms with terminals; transporting pre-conditioned fluids; could be good candidates for reuse:

- Location (connecting industrial clusters to main CO_2 storage areas)
- Original design: large diameters, high pressure

Intra-field pipelines (ca. 1000 on UKCS)
Tie nearby fields to main platforms. Less likely to be candidates for reuse, because of the smaller diameter and design characteristics

Platforms
Selected platforms could be considered for reuse, based on functional characteristics and integrity status

Technical assessment of O&G pipeline repurposing (illustrative)

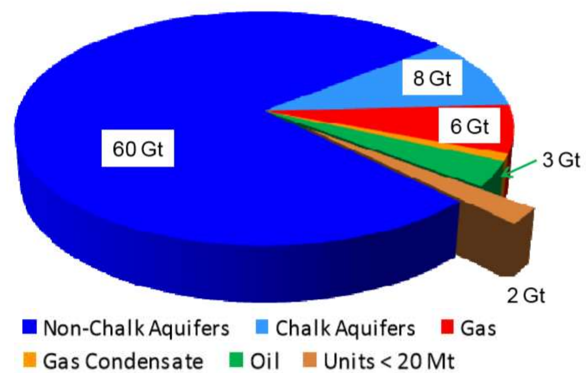
Criteria	Key considerations
Design parameters	• Original design compatible with CO_2 transport, and/or possible potential modification
Flow assurance	• Pipeline operations to ensure CO_2 is maintained in the same phase and free water not formed • Condensation of free-water would cause corrosion • Operating procedures and controls to be adequate
Internal corrosion	• Depending on the pipeline material and assurance against water condensation, verify that sufficient corrosion allowance is in place • Monitoring and control of water condensation, accurate detection of pipeline's earlier corrosion
External corrosion	• Integrity of external coatings (where exposed), absence of damage (eg trawlers), cathodic protection for intended operational life
Installation and seabed conditions	• Verify pipeline stability (including seabed loads, free spans, and buckling) due to the greater CO_2 fluid density and different temperature profiles
Other components and equipment	• Compatibility of other pipeline components with CO_2, including spools, risers, valves, pigging

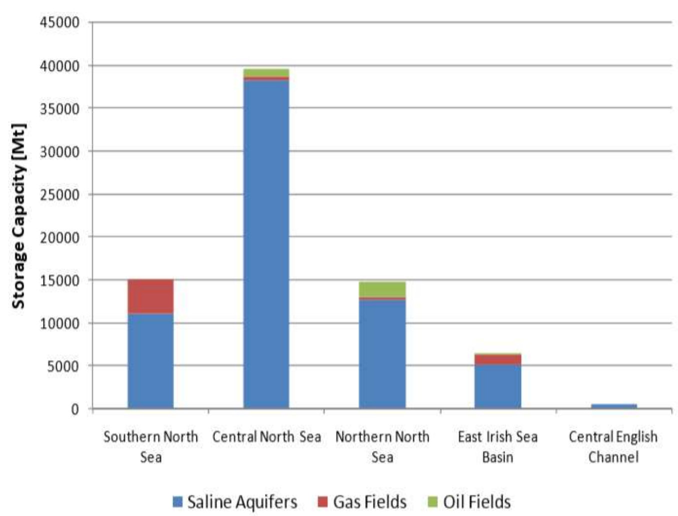
CO_2 subsurface storage

Oil & Gas Authority

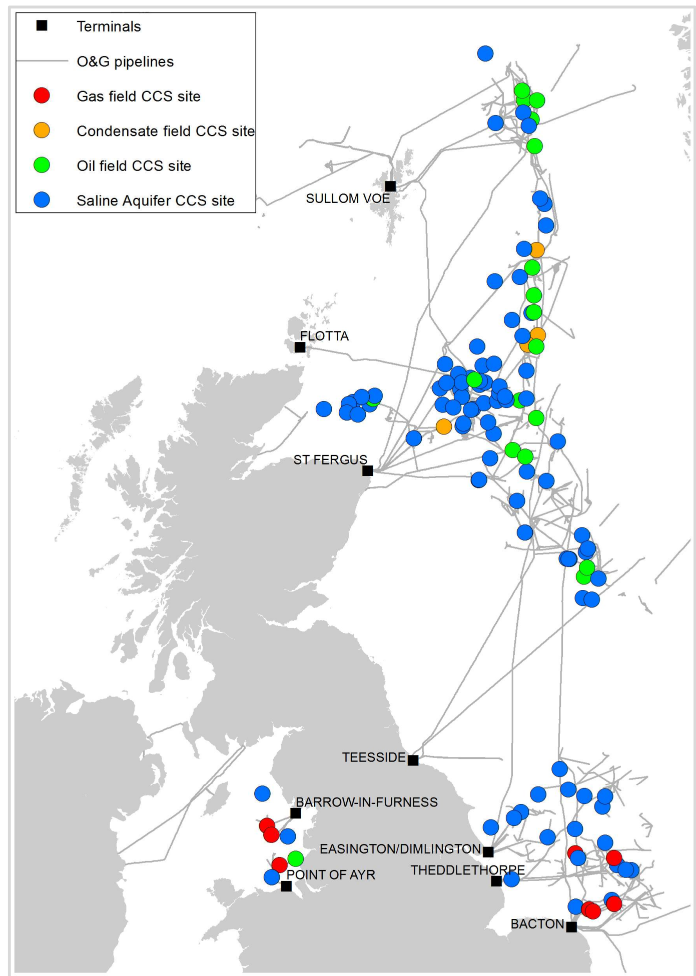
The UKCS is estimated to hold ~78Gt of potential CO_2 storage capacity, in over 560 subsurface stores[1]. This capacity could potentially cover UK needs for 100s of years. 87% of this capacity could be in saline aquifers, with about 9 $GtCO_2$ in potentially reused hydrocarbon fields. More work will be needed to mature the storage readiness level (SRL)[2] of individual stores, to qualify these as permanent storage sites for CO_2.

UKCS CO_2 potential storage capacity[1]





Store locations and O&G infrastructure



Main considerations for CO2 storage appraisal

Elements	Main criteria
Reservoir (All)	• Trapping mechanism • Seal competence • Store capacity • Injectability • Geomechanical effects • Geochemical compatibility
Reservoir (O&G repurposing)	• All of the above • Reservoir conditions at abandonment • Damage to seal formation as a result of O&G production • Formation damage which may affect injectability
Wells (P&A)	• P&A methodology • CO_2 resistant barriers • Verification • Long-term monitoring
Wells (Repurposing)	• Well trajectory • Casing and cementing • Side-tracking and re-completion options

1) ETI, BGS, et al. UK Storage Appraisal Project (2011)

BGS CO2stored.co.uk, and BGS/EIP analysis

EIP analysis

2) Axhurst, M, et al. Steps to achieve storage readiness for CO_2 source clusters; GHGT-14 Conference (2018)

Strong industry interest

Oil & Gas Authority

CCS initiatives and projects in the UK (partial list)

Caledonia Clean Energy

SUMMIT POWER

- CO_2 from Grangemouth cluster
- Re-use of existing pipeline to St Fergus
- Offshore CO2 storage

H21 North of England

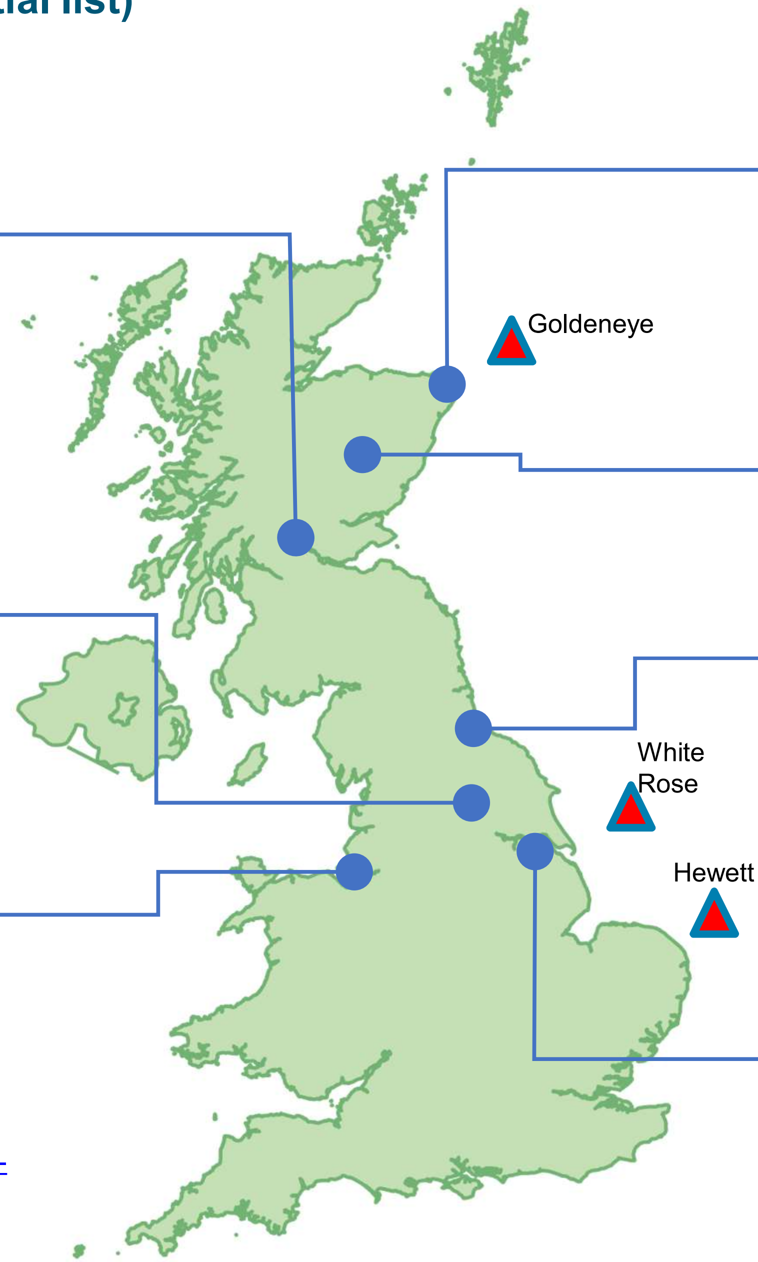
Northern Gas Networks, Cadent Your Gas Network, equinor

- Converting gas network to H_2
- 12GW blue H_2 production capacity discussed
- 8TWh of hydrogen storage
- CO_2 T&S infrastructure with capacity to sequester up to 20MtCO_2 pa by 2035

HyNet - Merseyside

Cadent Your Gas Network, eni, PROGRESSIVE ENERGY

- Industrial cluster
- Develop hydrogen economy
- Blue H_2 production
- Produced CO_2 to be stored offshore
- Plan to repurpose O&G facilities



Earlier CCS project studies
https://www.gov.uk/guidance/uk-carbon-capture-and-storage-government-funding-and-support#commissioned-ccs-reports

Project Acorn

Pale Blue Dot, Shell, TOTAL, CHRYSAOR

- Ongoing phase 1 feasibility
- Blue H_2 production
- CO_2 storage in offshore saline aquifer
- Targeting >2Mt/year in phase 1

NECCUS

https://www.neccus.co.uk/partners/

- Abate CO2 emissions from industrial sources in Scotland
- Deploy H2 and CCS technologies, developing markets and infrastructure

Net Zero Teesside

OGCI, bp, equinor, eni, Shell, TEES VALLEY COMBINED AUTHORITY, TOTAL

- Industrial cluster
- Targeting up to 10MtCO_2 pa. injection rate
- Storage targets in SNS

Zero Carbon Humber

drax, equinor, nationalgrid ventures

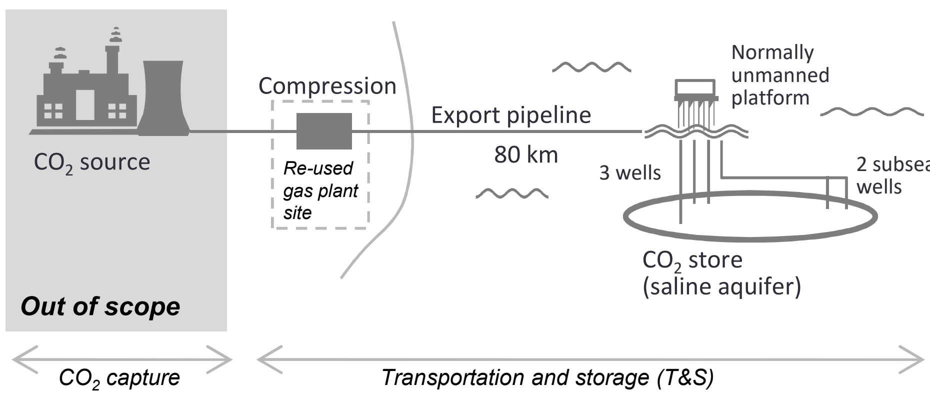
- Among largest UK industrial clusters
- CO_2 from combustion sources, BECCS and blue H_2
- Offshore storage target in large saline aquifer

Economic findings

Notional CCS project

Oil & Gas Authority

Notional CCS project



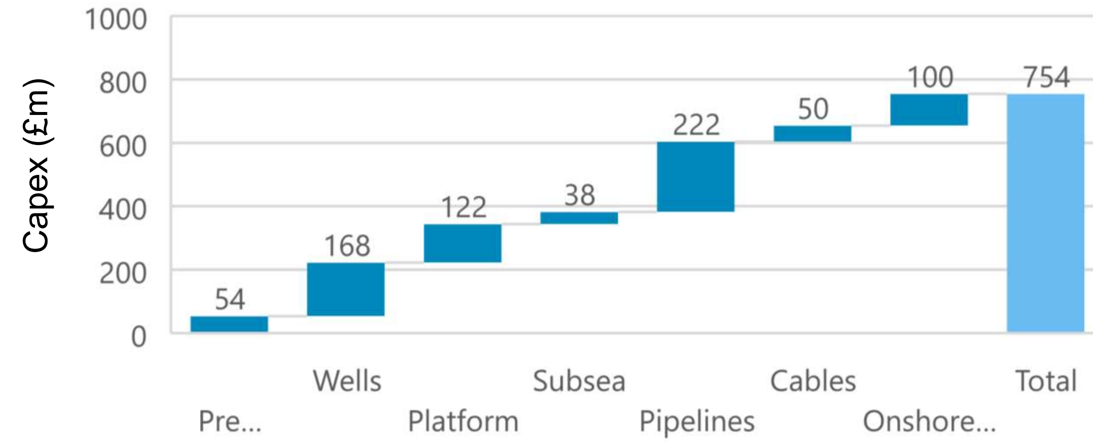
Transportation and storage scope

- CO2 store developed capacity: 150 $MtCO_2$
- Injection rate: 5 $MtCO_2$ p.a.

- 1 platform injection wells + 1 monitoring
- 3 subsea injection wells
- Wellhead platform (normally unmanned)
- Subsea injection centre (10km distance)
- Pipeline from shore (20 inch, 80 km)
- Power from shore – transmission cable
- Onshore compression (at re-purposed gas plant)

Source: EIP analysis, methodology described in appendix

Project costs and sensitivities



Other costs

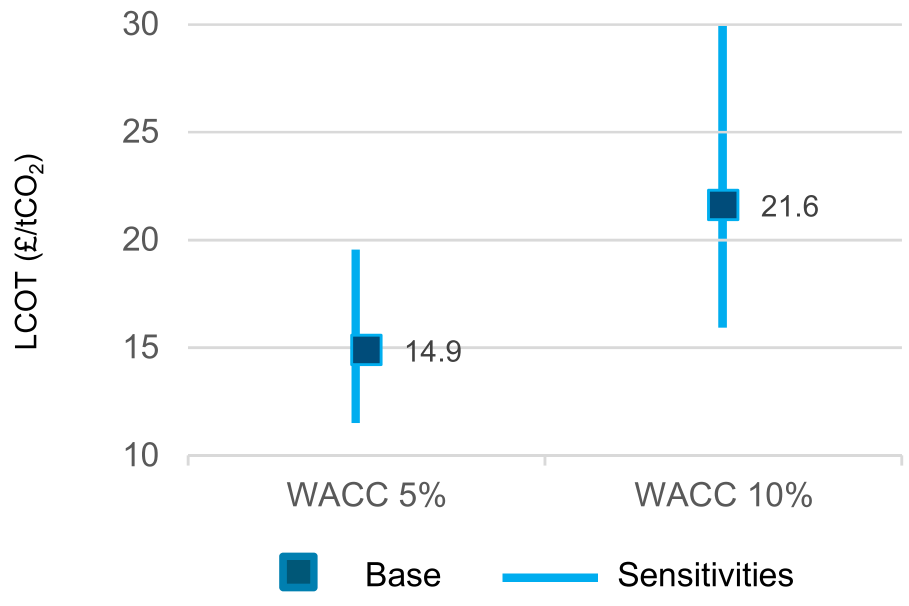
- Opex: £20m/yr
- Abex: £227m

Key sensitivities

- Reusing pipeline from shore: Capex saving £155m
- Reusing pipeline and platform: Capex saving £242m
- Project cost uncertainty: Capex +50%
- Operational risks: 20% annual downtime

CCS T&S economics

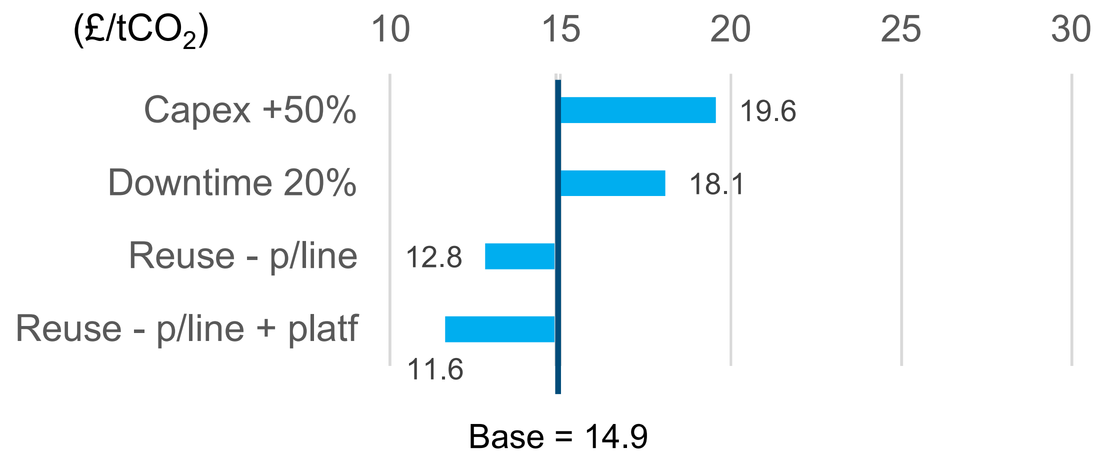
Levelized costs of Transportation & Storage (LCOT) £/tCO_2, notional project



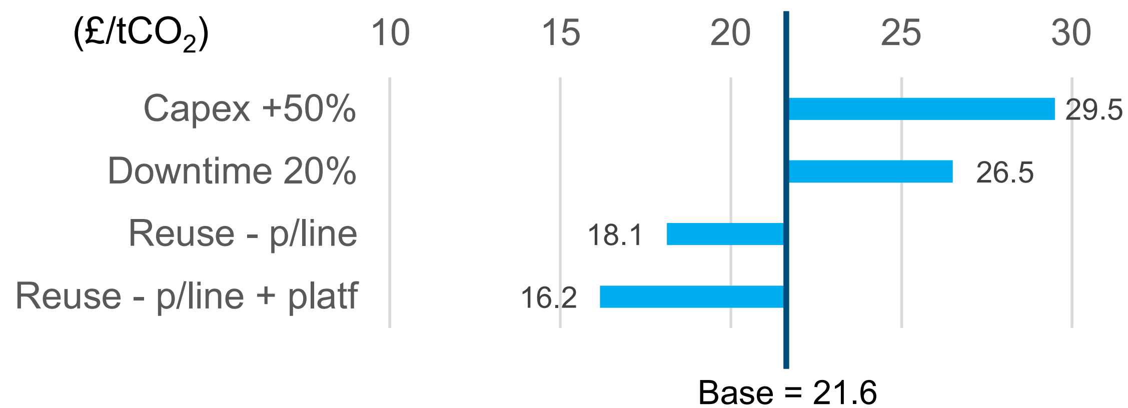
- For the purpose of estimating CO_2 T&S economics, we have assumed that CCS project will adopt a regulated business model with typical WACC values (real, pretax) of 5% to 10%.
- Investors' expected returns will be dependent on a range of factors including operational and financial risk, capital structure, incentives and taxation.
- BEIS is considering potential CCS business models and will publish further information in due course

Further notes on sources, methodology and assumptions in appendix

LCOT sensitivities (Case WACC 5%)



LCOT sensitivities (Case WACC 10%)



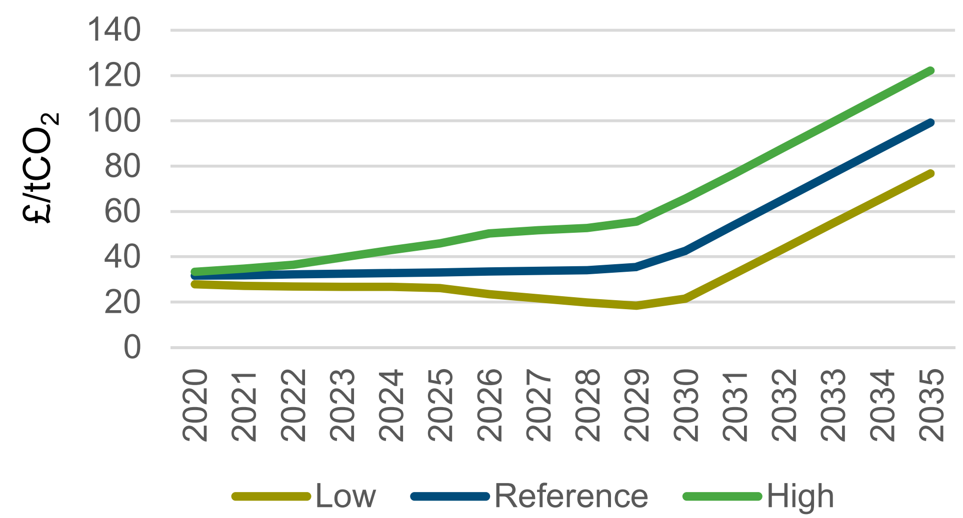
Economic findings

Oil & Gas Authority

- Under the assumptions employed, levelised costs of transporting and storing CO_2 offshore could be between £12 and £30/tCO_2
- Key sensitivities considered include:
  - Uncertainty in Capex, Opex and CO_2 injection performance due to limited deployment experience of this technology on a commercial scale
  - Ability to reuse O&G infrastructure which could reduce Capex costs by 20-30% on selected projects (subject to individual infrastructure assessment)
- Earlier estimates of levelised T&S cost from BEIS (£23/tCO2)[1] would be in the same range as this study

- Assuming an onshore carbon capture cost of £46/tCO_2[2] the overall CCS levelized cost would be in the range of £58-76/tCO2
- This is below BEIS long-term carbon price expectation[3] and carbon appraisal values, indicating that CCS could be economically attractive for net zero

Long-term carbon price expectation[3]
(energy supply sector, inclusive of EU ETS and UK CPS)



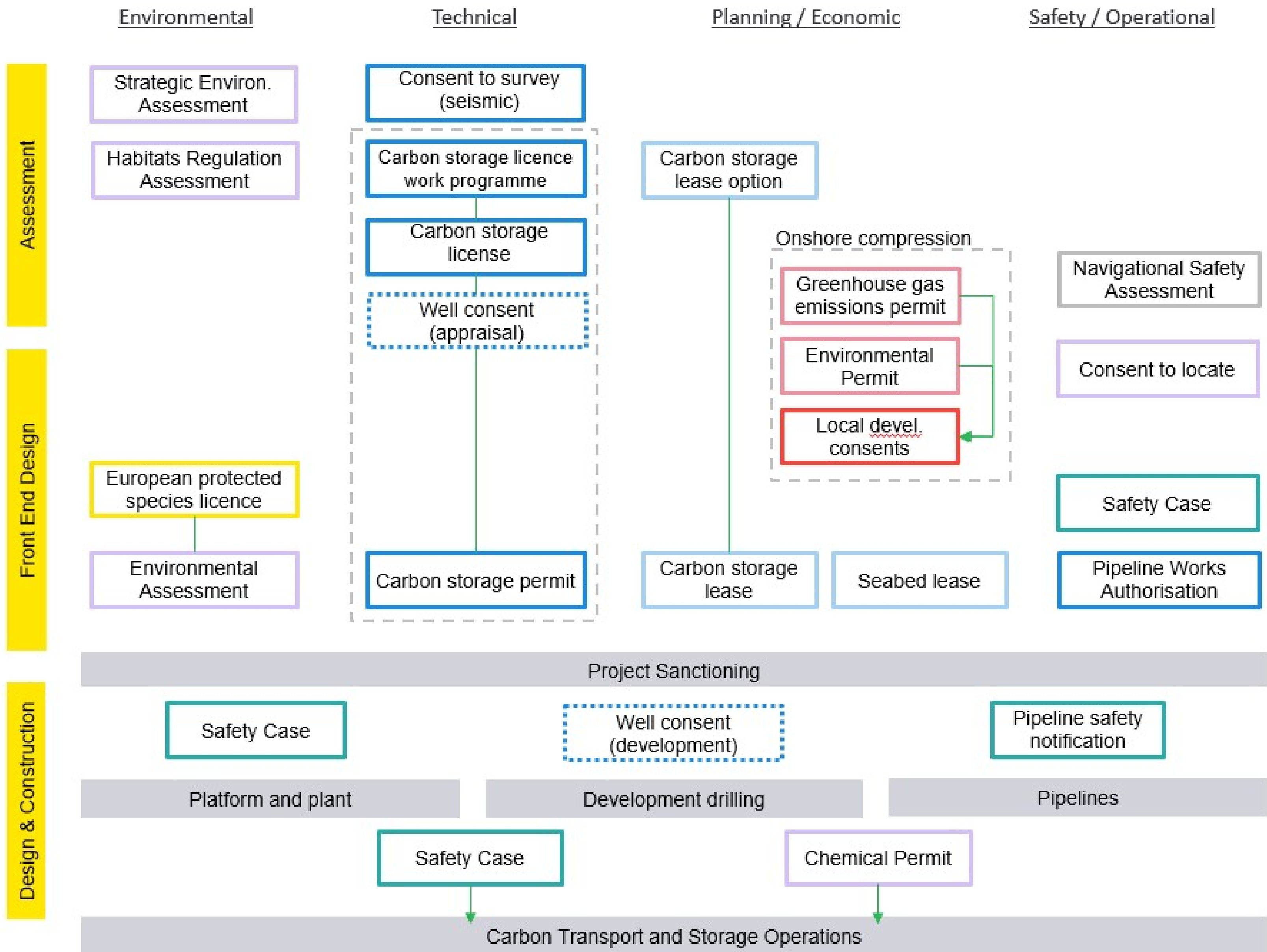
1) BEIS, CCUS Technical Advisory – Report On Assumptions, September 2018
2) Element Energy, Industrial carbon capture business models - report for BEIS, October 2018

3) BEIS 2018 Updated Energy & Emissions Projection - Annex M

Regulatory analysis

Regulatory map (transport & storage)

Oil & Gas Authority



Storage licensing framework progressed with good coordination among BEIS, the OGA and TCE/CES

Areas to be further clarified include consenting to later project phases, pipelines, operations, safety and decommissioning

	TCE / CES
	Marine Scotland / MMO / NRW
	BEIS / PINS
	Oil and Gas Authority
	Health and Safety Executive
	Local and Harbour Authorities
	Environment Agency / SEPA
	OPRED[2]

1) MMO – Marine Management Organisation, NRW – Natural Resources Wales, PINS – Planning Inspectorate National Schemes, SEPA – Scottish Environmental Protection Agency

2) OPRED (Offshore Petroleum Regulator for Environment and Decommissioning) is responsible for environmental consenting for offshore O&G operations

Other acronyms in appendix

Disclaimer: This map is illustrative of the process for consenting and licensing a notional CCS project, and as such it should not be relied upon.

Key findings

Oil & Gas Authority

Regulatory findings

- Storage licensing framework well under development with good coordination between OGA, TCE, CES and BEIS
- There are specific areas in the management of licences and leases which are being addressed
- In the development planning and consenting phases, not all regulatory powers may apply to CO_2 automatically, and may require clarification, eg:
    - Imposing terms on pipelines
    - Decommissioning plan requirement, as there may be no clear definition of “T&S operator”
    - Pipeline safety regulations may not automatically apply
- **The enhanced regulatory coordination, recommended on CCS and hydrogen, would facilitate the timely resolution of these and similar questions**

Policy framework – ongoing work

- The policy framework for CCUS is under consultation
- BEIS is proactively working on defining the most appropriate frame, including:
    - Business model
    - O&G infrastructure reuse
- Links to BEIS consultations are in appendix

Appendix

Appendix – References

Oil & Gas Authority

UK Industrial Strategy / Clean Growth Strategy

- Industrial Strategy the Grand Challenges: Clean Growth https://www.gov.uk/government/publications/industrial-strategy-the-grand-challenges/industrial-strategy-the-grand-challenges#clean-growth
- The UK Clean Growth Strategy https://www.gov.uk/government/publications/clean-growth-strategy
- The UK CCUS deployment pathway: an action plan https://www.gov.uk/government/publications/the-uk-carbon-capture-usage-and-storage-ccus-deployment-pathway-an-action-plan
- Industrial Strategy: Clean Growth – Industrial Clusters mission https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/803086/industrial-clusters-mission-infographic-2019.pdf
- Industrial Strategy Challenge Fund – Industrial Decarbonisation https://www.ukri.org/innovation/industrial-strategy-challenge-fund/industrial-decarbonisation/

Carbon Capture, Usage and Storage

- CCUS government guidance https://www.gov.uk/guidance/uk-carbon-capture-and-storage-government-funding-and-support
- CCUS business models consultation https://www.gov.uk/government/consultations/carbon-capture-usage-and-storage-ccus-business-models
- CCUS projects: reuse of oil and gas assets consultation https://www.gov.uk/government/consultations/carbon-capture-usage-and-storage-ccus-projects-re-use-of-oil-and-gas-assets

Facing page

Appendix

Oil & Gas Authority

Methodology, assumptions and sources

Carbon capture and storage growth

- CCC's report *Net Zero: The UK's contribution…* (2019) estimated up to 175 MtCO2 emissions p.a. to be abated through CCS by 2050, of which 125MtCO_2 from blue H_2 and combustion sources (power and industrial)
- NG FES *Two Degrees* case (2019) projects a conversion of 377 TWh of natural gas p.a. (or 28% of UK's demand today) to blue H_2 by 2050, a process which generates 70MtCO2 p.a. to CCS
- As a result we projected CO_2 injection rate growing to 130 MtCO2 p.a. by 2050, with a 70-60 CO_2 source split between blue-H_2 and post-combustion capture (power and industrial)
- The rate of growth reflects initial pilot-scale projects deployed in the 2020s, followed by a linear progression of commercial scale plants in the 2030/40s

Economic modelling

- Technologies are compared in terms of BCRs and levelised costs
- Model economics are real and pre-tax
- Offshore projects' scope is discounted at 10% (real)
- Hydrogen onshore processing is discounted at 5% (real)
- Electricity transmission infrastructure is discounted at 2.9% (real, from recent cases)

Energy parameters and conversion factors

- UK average power generation emissions 220 KgCO2/MWh (BEIS 2019)
- UK average power emissions excl renewables 330 KgCO2/MWh (BEIS 2019)
- UKCS offshore power generation emissions 460 KgCO2/MWh (typical OCGT)
- UK offshore windpower commercial load factors 39%-47% (2019 BEIS, DNV GL)
- Hydrogen energy density 39kWh/kg (HHV) and 33kWh/kg (LHV)
- Natural gas energy density 14.5kWh/kg (HHV) and 13.1kWh/kg (LHV)
- Blue hydrogen (methane reforming) energy efficiency 70-75% (NG FES)
- Green hydrogen (electrolysis) electricity efficiency 70-80% (Various)

Acronyms and abbreviations

BEIS	Department for Business, Energy and Industrial Strategy
BOE	Barrel of oil equivalent
BECCS	Bio-Energy Carbon Capture and Storage
CCC	Committee on Climate Change
CCS	Carbon Capture and Storage
CCUS	Carbon Capture Utilisation and Storage (in this report, same as CCS)
CES	Crown Estate Scotland
CO2e	Carbon Dioxide equivalent
EIP	Energy Integration Project
GHG	Green-house gases
HC	Hydrocarbon
HHV	High Heating Value = LHV + heat of products vaporisation
LCOT	Levelised Cost of Transport (CCS T&S)
LHV	Low Heating Value
NG ESO	National Grid Electricity System Operator
NG FES	National Grid ESO Future Energy Scenarios
OCGT	Open Cycle Gas Turbine generator
OGA	Oil and Gas Authority
OGTC	Oil and Gas Technology Centre
OGUK	Oil and Gas UK
PEM	Proton Exchange Membrane (electrolysis)
SG	Scottish Government
T&S	Transport and Storage (of CO2)
TCE[1]	The Crown Estate
tCO2	Tonnes of Carbon Dioxide
UKCS	UK Continental Shelf
UKRI	UK Research and Innovation
WACC	Weighted averaged cost of capital

1) The Crown Estate manages the seabed around England, Wales and Northern Ireland and provides leases/licences for offshore energy, marine aggregates and cables and pipelines. It is not a regulator, however, for the purpose of this report, it may be grouped together with regulators