A summary insights report by the
Energy Technologies Institute

Carbon Capture and Storage
Potential for CCS in the UK

Why Carbon Capture and Storage?

When addressing long term emissions reductions targets, Carbon Capture and Storage (CCS) is one of two critical levers (alongside bioenergy) in delivering an affordable, secure and sustainable UK energy system.

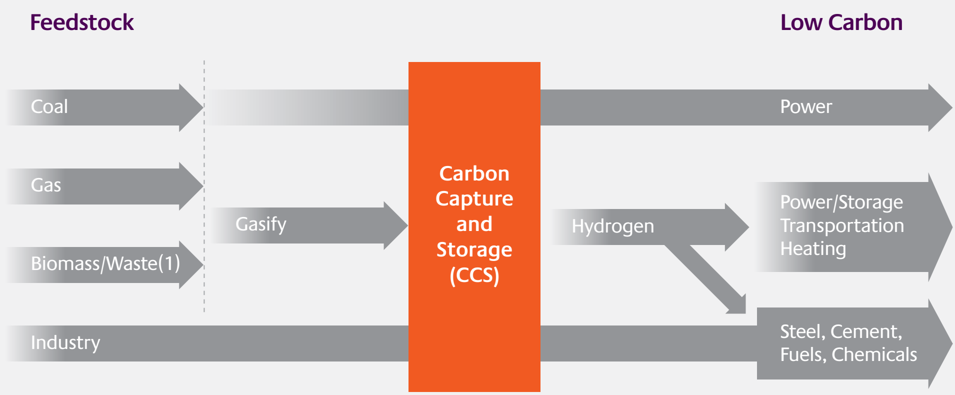
We have modelled the UK energy system out to 2050. Without a national CCS infrastructure, the cost of reaching UK Climate Change targets will double from a minimum of around £30bn per year in 2050. This is the equivalent of an additional 2p per kWh on all UK energy use in 2050. Therefore the economic prize of CCS to the UK is potentially considerable. Our calculations show that each five years of delay in implementing CCS until 2030 will add the equivalent of £4bn per annum to the total cost of the compliant UK energy system.

The importance of CCS lies in its capability and flexibility to reduce carbon emissions from a large range of activities. It also has relatively low costs when practiced at scale. For example in the power sector, a fossil fuel sector fitted with CCS can not only provide clean electricity at an attractive baseload price, but it can also alternatively operate in a role which offers the lowest cost additional power when peaks in demand occur.

Whilst there are other potential affordable ways of power generation, CCS might be the only practical option for avoiding industrial emissions.

CCS allows for the capture and storage of greenhouse gases from the use of bioenergy, which result in a net reduction in the greenhouse gases in the air, or “negative emissions”. This could reduce the need to decarbonise other activities which are much more expensive to tackle.

System wide value of CCS – Low carbon energy on consumer's demand
(1) Biomass with CCS produces negative emissions, offsetting other emitting activities



CCS also allows for the production of clean hydrogen to be used as a decarbonised storable energy source.

The most effective way to implement CCS is through a national infrastructure comprising a handful of shared transport and storage networks because this captures economies of scale and drives asset utilisation. Initially these networks would reduce power generation emissions, but then extend to meet industry needs and also allow the clean production of hydrogen from biomass, waste and fossil fuels. We believe the development of this national infrastructure is vital for any future CCS industry in the UK.

Planning, developing and proving the national infrastructure is now on the critical path for future success because of the long timescales involved, especially for the technical and regulatory processes involved in CO_2 store appraisal.

We should not delay the demonstration of the CCS chain at full commercial scale in the UK, since the benefits of scale, supply chain development and reduced cost of finance from demonstrating the end-to-end model early, is over time more important than technology development.

Of equal importance is the need to develop business and regulatory models to reduce market uncertainty and attract private sector investment.

CCS is a critical global technology. The development of technological capability and capacity can provide the UK with a major business opportunity.

Energy Technologies Institute
Carbon Capture and Storage Projects

CCS Performance Analysis

A project to provide an objective view of the performance of a range of next generation carbon capture technologies.

Project partners

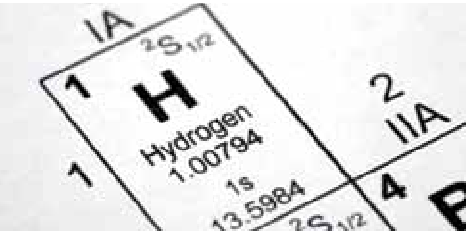
Foster Wheeler

Mineralisation

A research project into the availability and distribution of mineral deposits across the UK and the technologies needed to economically capture and permanently store CO_2 emissions from distributed services.

Project partners

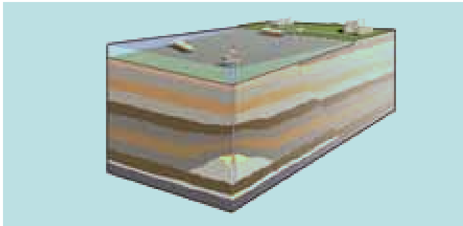
Caterpillar | British Geological Survey – Natural Environment Research Council | The University of Nottingham



High Hydrogen

A project investigating the safe design and operation of high efficiency combined cycle gas turbine and combined heat and power systems to increase the range of fuels that can safely be used in power and heat generating plant.

Project partners



CCS System Modelling Toolkit

The creation of a modelling toolkit capable of simulating the operation of all aspects of the CCS chain from capture and transport to storage and maintenance.

Project partners

Energy Technologies Institute
Carbon Capture and Storage Projects

Drilling offshore for CCS

National Grid and the ETI is undertaking the UK's first drilling assessment of a saline formation site for the storage of CO_2, 70km off Flamborough Head in Yorkshire.

Project partners

nationalgrid

Flexible Power Generation Systems

A research project seeking to increase the understanding of the economics and potential use of energy systems involving low carbon hydrogen production, storage and flexible turbine technology.

Project partners

FOSTER WHEELER

British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

CCS Next Generation Coal Capture Technology Distribution

A front end engineering design study of a carbon capture pilot plant (based on pre-combustion) capable of capturing 95% of carbon dioxide emissions.

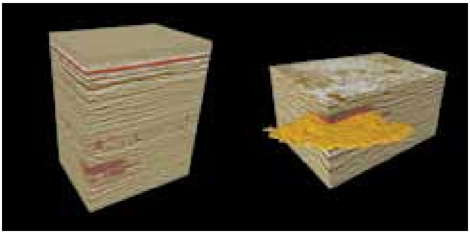
Project partners

Advanced Carbon Capture Technology for Gas Power Stations

A project to develop, demonstrate and verify advanced carbon capture technology (focused on post combustion) to be used on new build or retro fitted onto Combined Cycle Gas Turbine power stations.

Project partners

Energy Technologies Institute
Carbon Capture and Storage Projects



UK Storage Appraisal

The UK's first comprehensive assessment and database of national CO_2 storage capacity, reviewing potential sites suitable for storing CO_2 offshore.

Project partners

senergy

British Geological Survey

Heriot Watt

Durham University

GRL

Imperial College London Consultants

RPS Energy

elementenergy

Market Confidence

A report published in conjunction with the Ecofin Research Foundation that explores the challenges that both the public and private sectors need to overcome to help build CCS into a viable low carbon industry that is economically competitive.

Project partners

Insights
Focusing on the UK

The Role of CCS

The future power mix will likely consist of an appropriate combination of nuclear, CCS (including biomass) and other renewable generation.

Looking towards 2030

Fossil fuels will continue to play an important role in UK power generation:

- Fossil fuel power generation will occupy the gap in cost-effective base-load generation that new nuclear capacity does not fill, should the nuclear build remain slow. Unabated gas will provide the flexible generation required for periods of high demand and to support the intermittency of renewables.
- The capture of carbon from the power sector by 2030 is a key feature of the lowest cost pathway to meeting 2050 climate change targets, and CCS if fitted and run at full load will reduce emissions at a cost of £45-£85/Te.
- Over a wide range of scenarios explored using our modelling the CO_2 storage rate needs to be ramped up to c.100Mt/a by 2030. Early store appraisal and infrastructure planning are key to minimise costs and risks in the use of geological storage.
- In addition to assessing the security of the stores, projects will have to consider ease of expansion and interfaces with the oil and gas industry.
- Clean power will assist in decarbonising sectors such as domestic heating, for example through heat pumps, also accelerating the requirement for flexible low carbon generation, due to the extraordinary peakiness of heat demand.

- The currently anticipated rate of renewables growth will require significant flexible generation capacity.
- CCS systems can operate at high load AND provide flexible power by producing and storing hydrogen in salt caverns. The hydrogen can be manufactured from gas, coal or biomass and stored when power is not required. When power is demanded the hydrogen will be drawn from the store and burned in flexible turbines and these are likely to be the only system components in part load use. The gasifiers and CCS equipment may operate at high load. Hydrogen may also find use decarbonising other sectors – transport and industrial applications.
- Biomass coupled with CCS (for example using gasification) to generate electricity and/or make hydrogen can produce negative emissions allowing us to tolerate CO_2 emitting activities which are substantially more costly to mitigate.
- Overall, fossil fuel generation is likely to fall in absolute terms. Substantial numbers of coal firing stations that have not fitted pollution abatement equipment will close, and be replaced by gas and later other clean technologies in the new mix, including new energy storage options for short term needs and nuclear for baseload needs.
- To be economic early transport and storage networks must build off the platform of the DECC competition.

£5bn

We believe deploying CCS at this level will involve developing no more than six shoreline hubs and 20 stores. The offshore infrastructure having a net present cost of less than £5bn.

Insights
Focusing on the UK

Looking beyond 2030 to 2050

- CCS should grow rapidly in the 2030's and 2040's and by 2050 CCS applications should be split between industry, hydrogen production (as an energy vector), direct power generation and production of liquid bio-fuels and bio-SNG (Synthetic Natural Gas). It seems that some form of post-combustion CCS, use of hydrogen (e.g. in Direct Reduction of iron ore) and use of biomass will compete to be the economic routes to greenhouse gas reduction in heavy industry.
- Requirements for hydrogen storage will grow, if it penetrates other intermittent markets, such as transport and industry.
- Sustaining 100MTe/a of CO_2 storage will mean larger individual stores will be needed with good injectivity and low levels of compartmentalisation to sustain high fill rates economically. Spatial conflicts with operating hydrocarbon fields will decrease as they reach close of production.
- A few selected CO_2 networks are likely to dominate. Choice of location for industry will move away from today's preference for the benefits of a brown field power station towards coastal locations with CO_2 or hydrogen infrastructure.
- Depending on the capacity of newly built nuclear plant, the fossil fuel component in the power sector will likely fall further.

> “Without a national CCS infrastructure, the cost of reaching UK Climate Change targets will double from a minimum of around £30bn per year in 2050.”

Scope of CCS

- Deploying CCS at this level would involve the development of not more than six shoreline hubs and 20 stores, the offshore infrastructure having a net present cost of less than £5bn.

Challenges

- Climate change is a truly global issue, but there is no global international agreement which includes all major nations and sets coherent targets fair to all. Nor have EU carbon tax schemes yet succeeded in providing effective incentives for those abating emissions. Individual nations with deregulated electricity markets like the UK largely have to “go-it-alone”, reforming their electricity markets and developing difficult contracts in which power costs exceed what their electorate currently pays.
- There is no generic framework giving the investor confidence in remuneration for CCS, and UK Emission Performance Standards currently do not enforce CCS for gas or established coal stations, so private sector investor commitment to investment is minimal. Early full chain CCS project investments could cost in excess of £1bn, involve many different companies and will have long lead times and the high level of risk associated with storage appraisal.
- New policy and institutional frameworks which facilitate CCS commercialisation are needed, focusing on bankable approaches to managing risk, developing long term investor confidence, efficiently aligning rewards to impact (especially for bio-CCS) and new regulations.
- The immediate challenge is to plan the rollout of a large de-risked, intrinsically low cost storage and transmission system. This will require costly appraisal of large saline aquifers, which have a lead time of up to six years. 2 GTe of storage will need to be appraised and found suitable for storage by 2025 to cost effectively meet targets.
- Since CCS is a lowest cost solution any reduction in cost relative to other technologies will increase deployment and lower overall UK costs. The cost of capture in terms of capital and energy penalty is severe and technology development is required to reduce these.
- New system designs are needed to ensure that the additional complexity of CCS does not detract from reliability or operability and maximises use of the assets deployed.

Background Information

Storage

- Given the critical economic importance of CCS to the UK, we are fortunate in having a large potential offshore storage capacity, including depleted oil and gas fields and saline aquifers in various types of geological formations. The ETI UK Storage Appraisal Project (UKSAP) studied the potential of over six hundred storage sites and identified 78GTe of possible storage. 9GTe of this has reasonable quality data and appears low risk and a further 5GTe has less data but also appears relatively low risk.
- There are a number of operating saline aquifer stores operating around 1MTe/a, including Sleipner, Snohvit and In Salah. There is relatively little experience with Depleted Oil and Gas Reservoirs, although using reservoirs for gas storage is a well understood operation and involves repressurisation.
- The International Energy Agency also identifies saline aquifers as the major storage formations for CO_2, with Enhanced Oil Recovery (EOR) providing a niche for early demonstrations with potentially improved economics (albeit at the risk of more complex business and regulatory models).
- The risks and costs of building a national strategy on Depleted Oil and Gas Reservoir fields alone are unacceptable. Saline aquifers will be important from the very beginning, partly due to their availability, partly due to their scale and economics and partly in order to mitigate technical and other cluster issues associated with clusters of Depleted Oil and Gas Reservoirs. Given that it can take six years to bring an aquifer project through appraisal to the point of starting construction, this work needs to have started already. Both the ETI and National Grid independently identified a promising aquifer in the Southern North Sea and the ETI is now involved in a National Grid project to appraise that store. The store forms part of the White Rose Project, which is one of the preferred bidders in DECC's £1bn CCS competition.
- In scenarios where CCS is exploited effectively in the UK, our modelling leads us to anticipate that around 3 to 4GTe will have been injected into stores by 2050. More may be required if other technologies fail to deliver their promise (or are not deployed at the optimal rate) and less may be possible if business models for CCS do not progress. Final Investment Decisions (FID) on capture projects will depend on a significant degree of confidence and commitment to specific storage sites. Based on

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this modelling and the need to have sufficient storage in place ahead of FID we anticipate that final appraisal will be required for 2GTe by 2025, 4GTe by 2030 and 5GTe by 2050.

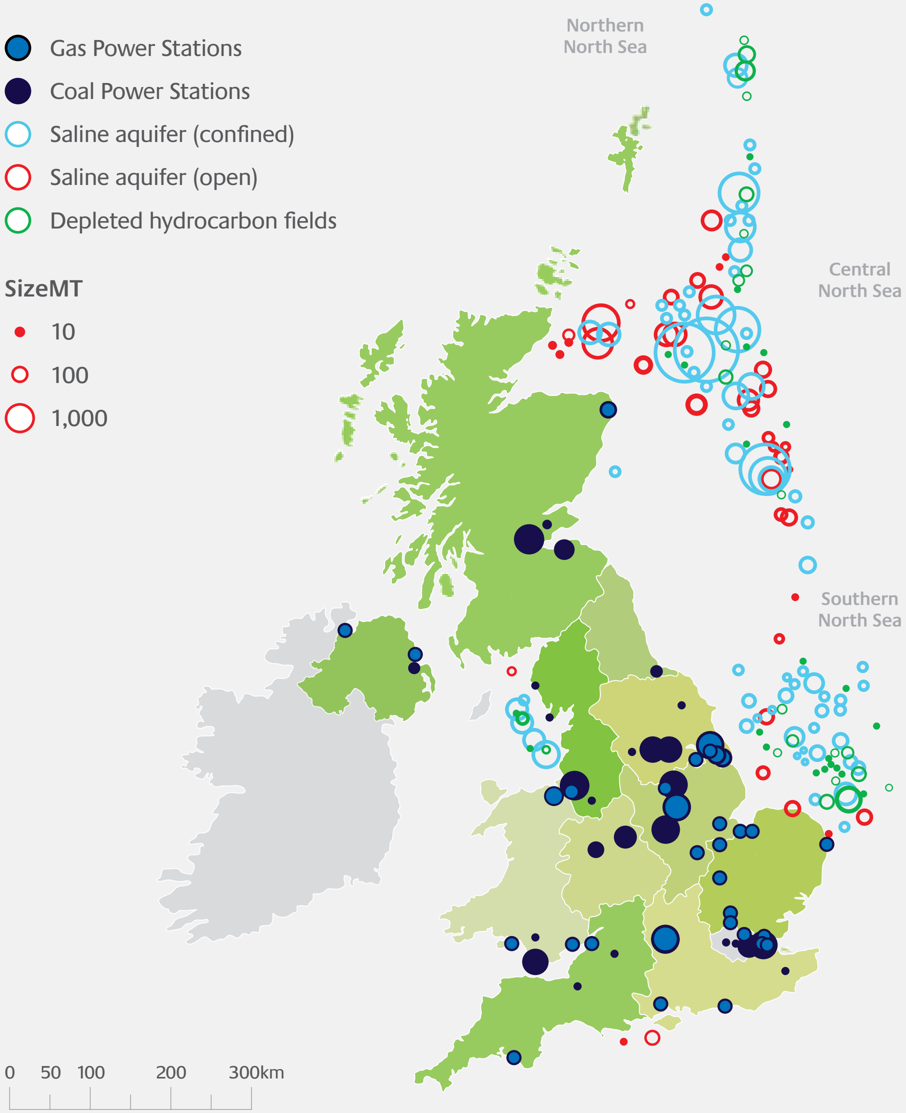
- There will inevitably be a significant funnelling-down of attractive capacity as the risks and economics of the most promising sites are appraised in more detail. Over time technology developments and increasing confidence will bring more capacity into the economically feasible range. Saline aquifers and depleted gas fields will form a large part of the capacity, with some contribution from depleted oil fields and Enhanced Oil Recovery. UKSAP results indicate that there will be sufficient storage available with a transport (from shoreline station) and storage cost in the range £7-25/Te, with a realistic typical cost of £15/Te for base load connections (assuming financing costs for an established business model).
- The Southern North Sea offers the most attractive combination of capacity and cost. There are also potentially economic networks in the Central North Sea, based on some large individual structures that deserve further study. There is also storage in the East Irish Sea. The ETI has developed a storage cluster and network planning tool, which can be used to compare different schemes for building storage clusters. Economic networks are likely to be focusing on larger stores (of several 100MTe capacity), with smaller ones (20-100 MTe) attached as required. Once CCS is fully launched the national fill rate is likely to be in the range 50-150MTe/year out to 2050.
- Operating CO_2 transport networks for industrial purposes is well established in the USA, but application in more built-up environments will require further engineering development.

Background Information

Flexible Generation

- Assuming renewables are rolled out at expected rates, and nuclear occupies the base-load role, flexibility in generation will be at a premium.
- By some time early in the 2030's, we would anticipate a cost-effective UK energy system having at least 50GWh of fast response pumped or compressed air storage (compared to half that today), 45GWh of cost-effective daily storage embedded in the distribution system, 100GWh of hot water storage in buildings and 450GWh of reserve hydrogen in geological stores (for comparison the Rough gas store holds 30,000GWh of natural gas).
- We would anticipate an economic electricity system would have a significant increase in interconnection to take advantage of arbitrage opportunities, but the investment is likely to be determined strategically, due to market unpredictability.

Capturing carbon from the power sector by 2030 is a key feature of low cost pathways to meeting 2050 climate change targets.


Gas Power Stations
Coal Power Stations
Saline aquifer (confined)
Saline aquifer (open)
Depleted hydrocarbon fields
SizeMT
10
100
1,000
Northern North Sea
Central North Sea
Southern North Sea
0 50 100 200 300km

Background Information

Economics

- When comparing the techno-economic value of different power generation technologies, it is common practise to compare their levelised costs i.e. identify a notional average cost over the life of the unit. Levelised costs alone are not an appropriate method of comparing different generating technologies as they do not recognise the energy system-wide economic of flexible generation in response to needs. The extent of base load power generation from CCS in future will depend on the development of nuclear and bio-mass to power capacity. Since capture, transport and storage fixed costs are higher than variable costs, the economics of CCS plants will depend on the anticipated capacity utilisation. Typical transportation and storage costs almost double for 50% utilisation due to the very high capital element of the cost structure.
- The “carbon price” required to incentivise future CCS adoption for new base-load coal plants is around £45/Te CO_2 and for gas £85/Te CO_2 (note that because coal emits twice as much CO_2 as gas powered generation per kilowatt produced, the cost of abatement are not dissimilar). The first plants will require additional support to compensate for the strategic risks of operating in an unproven market, sub-scale supply chains and some residual technology risk. Early 2013 European Trading Scheme (ETS) prices were as low as €5/Te CO_2 (£4.22 equivalent).
- ETI estimates that effective CO_2 prices of over £200/Te will be required to meet the 2050 targets and drive technology adoption outside power generation and CCS (for example deep penetration of non-fossil vehicle fuels), demonstrating why generation decarbonises earlier on the pathway and justifying capture rates of 90% for gas and up to 95% for coal applications.
- At current UK Renewable Obligation Certificate (ROC) buy-out prices of £41, the effective carbon price for offshore wind is around £200/Te CO_2, given that it is displacing gas generation in today’s market. Clearly part of that relates to early added scale up costs that CCS will also face.

Global Application

- The global market for CCS technologies is at an early stage of development. The International Energy Agency estimates that CCS is the third most important global technology to address climate change, after efficiency and all renewables technologies added together. Outside the UK, the balance of applications will be marginally towards industry, although the pattern of the initial anchor points for the networks being power generation seems to apply widely.

Key facts and figures

2 p/kWH

Additional cost on all UK energy use in 2050 by not deploying CCS

£45/Te

CO_2 'carbon price' required to incentivise future CCS adoption for new baseload coal plants

£4bn

The cost per annum each five years of delay adds to the annual total cost of the compliant UK energy system

3GTe

Anticipated levels of CO_2 injected into stores by 2050

2 GTe

2 GTe of storage will need to be successfully appraised by 2025

6

Shoreline hubs and 20 stores required to deploy CCS in the UK

£85/Te

CO_2 'carbon price' required to incentivise future CCS adoption for new baseload gas plants

£30bn

Without a national CCS infrastructure, the cost of reaching UK Climate Change targets will double from a minimum of around £30bn per year in 2050

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