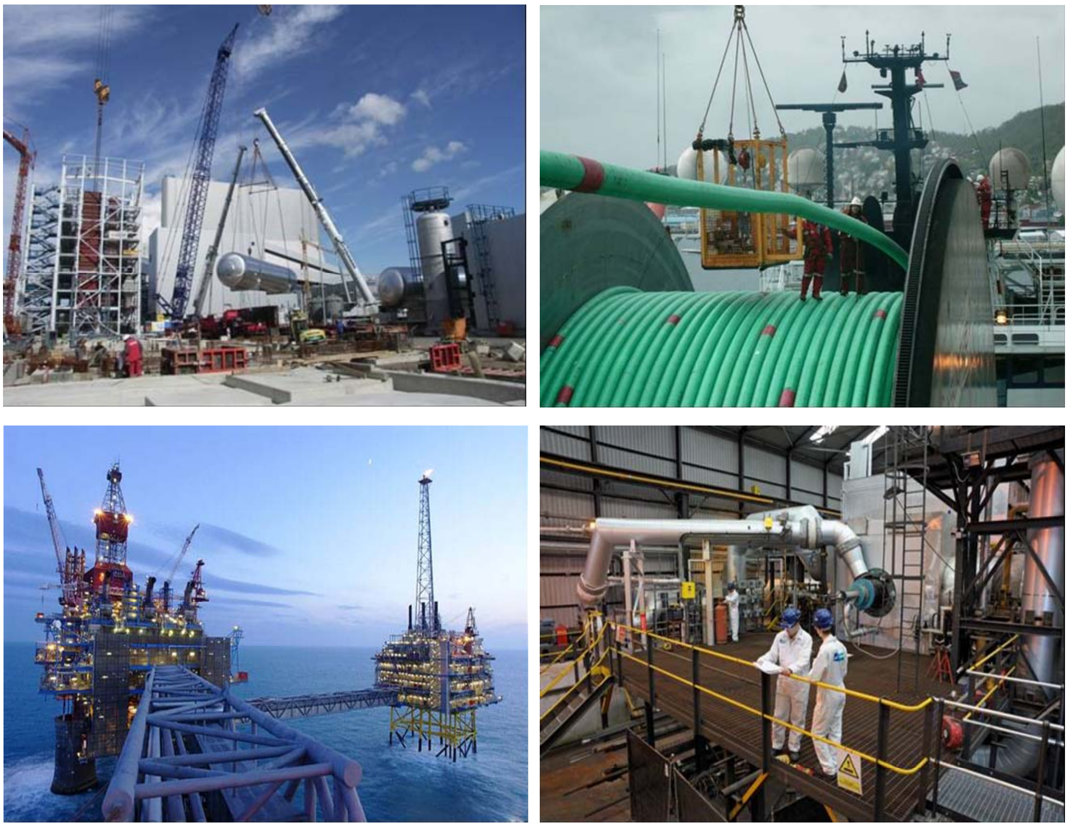
PÖYRY

CARBON CAPTURE AND STORAGE:

MILESTONES TO DELIVER LARGE SCALE DEPLOYMENT BY 2030 IN THE UK

Summary report

October 2009



Clockwise from top left: Construction of Vattenfall's Schwartz Pumpe CCS pilot plant, in Germany; laying CO2 pipeline to Snøhvit, Norway; Doosan Babcock oxfuel test rig at Renfrew, Scotland; Sleipner CO2 storage project, Norway.

MILESTONES FOR CCS DEPLOYMENT IN THE UK

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Our Carbon Capture and Storage practice is recognised as one of the leading consultancies in CCS. Recent projects include policy advice to Governments, economic assessment of several potential CCS projects and strategic advice to many leading industry participants.

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EXECUTIVE SUMMARY

The UK Government has a target to reduce greenhouse gas emissions to 80% below 1990 levels by 2050. Modelling undertaken for the Climate Change Committee (CCC) suggests that in order to achieve this radical decarbonisation the UK economy, the UK may need between 8 and 20GW of (predominantly coal-fired) carbon capture and storage (CCS) capacity by 2030. The exact requirement for CCS capacity will depend on the extent to which renewables and nuclear are deployed by that point and the evolution of electricity demand, but also the requirement for thermal plant on the system to balance these less flexible low-carbon generation options.

This report was commissioned by the CCC who asked Pöyry Energy Consulting to examine the challenges involved in the large scale deployment of Carbon Capture and Storage (CCS) in UK. It differs from most recent studies in that it focuses on the practical issues facing industry and suggests a number of policy and deployment construction milestones against which progress could be tracked, prompting government interventions, if required.

There is as yet no fully integrated, commercial scale, power generation scheme with CCS operating anywhere in the world but required elements of the value chain do exist at differing levels of technical and commercial maturity. Nonetheless, it is our view that deployment of significant levels (of the order of 10 to 20GW) of coal-fired power generation capacity with CCS in the UK by 2030 is feasible. However, for this to happen the Government needs to take immediate steps reduce regulatory and policy uncertainty and commit to provide sustained support for technology commercialisation. Key issues to be addressed follow below.

- A single phase of Government-supported demonstration projects is unlikely to be sufficient to establish the commerciality of CCS. It is likely that there will need to be two tranches of demonstration projects. The first will demonstrate that CCS projects can technically operate at scale. The second, building on the operational experience gained in the initial tranche will resolve technical issues and problems identified and provide the basis for the commercial guarantees expected of equipment suppliers.
- Progress towards commerciality needs to be monitored actively throughout the CCS demonstration phases. Requirement for further Government support is needed in the critical pre-commercial stage, the so called 'Technology Valley of Death'. This should be evaluated by 2013 with firm details proposed by 2015.
- CCS may struggle to be commercially viable in a market with high levels of intermittent wind generation and nuclear power. This needs to be recognised in future Government policy formulation.
- The storage capacity of deep saline aquifers needs to be assessed sooner, rather than later. There is likely to be insufficient suitable storage capacity in depleted UK oil and gas fields to support more than 10GW of power generation with CCS.
- There may be a lack of industry supply chain capacity to develop and construct CCS projects in the timescales required. CCS projects may well be competing for resources with other UK and international projects, not only in CCS but also other power sector projects such as wind and nuclear and the oil industry.
- Planning and consenting of CCS power plant and related infrastructure, particularly long distance pipelines may be subject to delay because of the large number of stakeholders who will need to be involved. Public concerns over the safety of

pipeline transportation of CO_2, even though unfounded, may prove to be a major stumbling block.

The nature of a report with this brief is bound to highlight the difficulties and risks involved in deploying a large amount of a new technology. There is a danger that the overall sentiment is one of problems to be overcome. Yet the potential for CCS to offer material amounts of carbon abatement continues to shine through. Large scale deployment of all low carbon technologies will encounter similar challenges, and the overwhelming conclusion from this report is the practicability of delivering CCS as a significant component of a low carbon electricity sector.

1. INTRODUCTION

In December 2008 the Committee on Climate Change (CCC) published its report '*Building a Low Carbon Economy'* in which it outlined its views by which the UK could lower its greenhouse gas emissions in the years up to 2050. Part of this report was devoted to the role which carbon capture and storage (CCS) might play in achieving the ambitious goals it proposed.

Pöyry is well placed to comment on these issues: the company has been involved in assessing the economics of CCS projects for many years, and as an international consultancy for the power generation and oil and gas industries it can draw on first hand experience of major engineering and project management challenges.

The CCC commissioned this report to examine the challenges involved in deploying significant power generation capacity with CCS in the UK through two scenarios – one of 10GW by 2030 and the second of 20GW by the same date.

It begins with a review of the current state of CCS development, the role and design of demonstration schemes and an overview of current demonstration initiatives. It then moves on to examine the practical time dimensions likely to be encountered by project developers and explores the plausibility of achieving the respective 10GW and 20GW deployments by 2030. An overview of the potential constraints that may impinge on the achievement of these indicative deployments is then provided. Finally, a set of policy and construction milestones are proposed that could be used to monitor progress towards the proposed levels of CCS deployment.

1.1 Acknowledgements

In the course of this project we have been able to draw on the views and experiences from clients and collaborators throughout the industry; we are grateful for their wisdom and advice.

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2. STATE OF CCS DEVELOPMENT

2.1 Introduction

While there are working examples of many of the elements of the carbon capture and storage process, there is yet no fully integrated, commercial scale, power generation scheme with CCS operating anywhere in the world. This section aims to provide a high level review of the current state of CCS development, the role and design of demonstration schemes and an overview of current demonstration initiatives as a precursor to our discussions about the future development and deployment of CCS.

2.2 Key projects

There have been a number of commercial and pilot projects that support each stage of the CCS process. CO_2 has been separated from oil and gas production and gasified syngas for many years, there are a number of oxyfuel pilot and test projects, CO_2 has been transported in pipes for decades in North America and more recently to the Snøhvit gas fields in Norway, and it has been used to enhance oil production and stored in saline aquifers for many years. Figure 1 shows the location of a selected number of significant projects and pilots that are relevant to CCS. This indicates that main areas of activity for CCS projects are North America and Europe, although there are also several projects in Australia.

Figure 1 – Location of selected project and pilots relevant to CCS

The projects and pilots shown in Figure 1 are referred to in the following discussion.

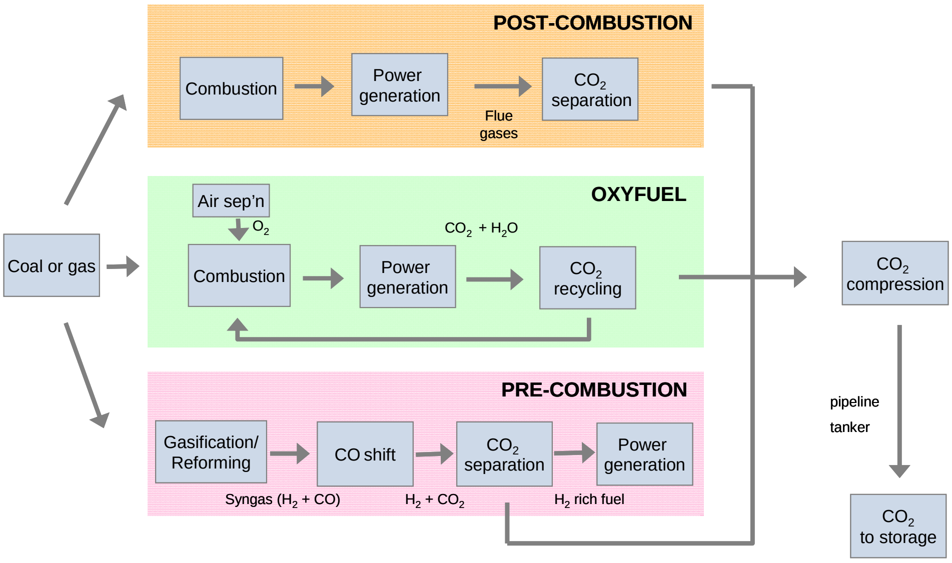
2.2.1 Capture

Three distinct groupings of the capture technologies for power stations have emerged:

- **post-combustion**, where the fuel is used in a standard thermal unit and the CO_2 is extracted from the flue gases, typically using a solvent;
- **oxyfuel combustion**, where the fuel is burnt in an oxygen rich environment, such that the CO_2 concentration increases which makes it easier to extract; and
- **pre-combustion**, where the molecules of the fuel are broken up under high heat and pressure, and a new gas fuel is produced that can be used in a combined cycle unit.

These approaches to carbon capture are shown schematically in Figure 2.

Figure 2 – Component processes of Carbon Capture and Storage



Post-combustion

Historically, CO_2 removal from combustion flue gases using chemical adsorption technologies has been carried out to supply CO_2 as either a chemical feedstock, or for the carbonated drinks industry. More recently the process has been incorporated into commercial power stations, where a slipstream of the flue gases has is passed through a separation unit: examples include FPL's Bellingham gas-fired plant in Massachusetts operates a 15% slipstream capture operation and AES's Warrior Run coal-fired plant has a 10% slipstream. With such a high value of the very pure CO_2 produced, the focus of these projects has been on quality, rather than on costs, and so while they provide valuable operating experience, they are only of limited relevance to CCS.

More recently several pilot projects have been more focused on capturing the CO_2 with the specific aim of storing the CO_2. Perhaps the longest standing project in Europe is at DONG Energy's Esbjerg Power station, where a capture system on a 0.5% slip steam has been in operation since 2006. Several other similar slipstream pilot projects have been developed since in Europe and the US, with the most recent at RWE's lignite-fired

Niederaussem power station in Germany which will be capable of capturing 300kg/hr, and a smaller unit at ScottishPower's Longannet station.

Considerable technological challenges have emerged, particularly in the areas of solvent performance and corrosion control, as well as the challenges of scaling up to the typical 300MW scale of a full commercial unit, clearly placing this technology at a pre-commercial stage.

Oxyfuel combustion

Although Oxyfuel is the youngest of the capture technologies, the early testing appears to show great promise. While in principle the idea of removing the diluting nitrogen from the combustion process and replacing it with CO_2 recycled from the flue gases is attractively simple, however, the technical challenges are large suggesting that managing the different behaviour of the flame in a different atmosphere; producing CO_2 of a suitable quality, and engineering a connected, integrated system at full scale will test developers.

Nevertheless, the technology has moved quickly from small 1MW test rigs, such as E.On's at Ratcliffe-on-Soar to a 30MW coal-fired unit attached to Vattenfall's Schwarze Pumpe power station near Berlin, and Total's gas-fired unit at Lacq in southern France. In 2009 Doosan Babcock opened a 40MW Oxycoal™ test rig at Renfrew in Scotland.

Given that the recent emergence from R&D scale, we would categorise oxyfuel combustion at a pre-commercial stage.

Pre-combustion

Technologies for converting solid fuels, such as coal, lignite, refinery residues and pet coke into gaseous forms, called gasification, date back to the nineteenth century. Coal, or other feedstock, is reacted at high temperatures with controlled amounts of oxygen and steam. The resulting mixture of largely carbon monoxide and hydrogen is referred to as synthetic gas, or syngas. Syngas has been used in the residential sector prior to the advent of natural gas, and in the refining sector as a chemical feedstock.

Syngas has also been used as a fuel for single and combined cycle gas turbines for the generation of power. Combining gasification and a combined cycle process is referred as an 'Integrated Gasification Combined Cycle' (IGCC). Over the years patents for different technical approaches have been developed, and a few main equipment suppliers for gasifiers are able to offer commercial terms, although they all recognise their limitations to particular specifications of feedstock.

There are now a few full scale IGCC units operating purely for power generation using coal as a fuel: the first was a 100MW unit at the Cool Water site in California, which ran from 1984 to 1988. More recently units ranging from 200 to 400MW have produced a significant amount of operating date: Buggenham in the Netherlands, Polk County and Wabash River in the US and Puertollano in Spain.

While the units running on syngas have enabled significant technological development, they burn carbon monoxide in the gas turbines. An additional intermediate process, known as a 'water shift' reaction, is required to convert the carbon monoxide to hydrogen and carbon dioxide: the CO_2 can all be removed, using well established gas processing technologies, to leave a fuel stream consisting only of hydrogen. Such a process happens, albeit not for power generation at the Great Plains Synfuels plant in North

Dakota, which has supplied CO_2 for Enhanced Oil Recovery (EOR) to oilfields 200 km distant in Canada.

Proposals for gas-fired analogues have been advanced by BP at Peterhead, and Hydrogen Energy in Abu Dhabi where the natural gas will be processed to produce a stream of hydrogen and CO_2. An IGCC with CO_2 separation (and storage) will need to run the gas turbines on hydrogen alone (so the only combustion product would be water). Such turbines are not available at the moment as hydrogen is a very different fuel from natural gas. There are technical solutions, such as diluting the hydrogen with nitrogen from the air separation unit, they impose significant efficiency penalties. Vendors have indicated that it is possible to burn up to 80% hydrogen in a mixture with natural gas in existing turbines without major modification.

Given the above, it would seem appropriate to classify the pre-combustion process as pre-commercial.

2.2.2 Transport

A coal-fired power station produces several million tonnes of CO_2 each year, posing a logistical challenge in transporting such sizable quantities to a suitable site for permanent storage. This can be made more manageable through transporting the CO_2 in dense rather than a gaseous phase – dense phase CO_2 takes up approximately 400 times less volume than it does in a gaseous state. This leads to transport being more economical, as the diameter of the pipes will be smaller and it is less costly to use pumps than compressors for boosters along the pipeline.

There is a long history of transporting a range of gases and liquids long distances in pipe networks. This expertise has been applied to transporting CO_2 from natural and industrial sources in North America for use in onshore enhanced oil recovery (EOR) since the 1970s. Currently there is approximately 2,400 km of pipelines transporting CO_2 to more than 70 EOR projects. Table 1 provides some details on some of these pipelines while Figure 3 indicates their location.

Table 1 – Selected CO_2 pipeline networks

Pipeline	Location	Operator	Capacity ($MtCO_2$/yr)	Length (km)	Diameter (inches)	Year finished	CO_2 source
Cortez	USA	Kinder Morgan	19.3	808	30	1984	McElmoe Dome
Sheep Mountain	USA	Occidental Permian	9.5	657	20 to 24	-	Sheep Mountain
Bravo	USA	BP	7.3	351	20	1984	Bravo Dome
Canyon Reef Carriers	USA	Kinder Morgan	5.2	225	16	1972	Terrell Gas Processing Plant
Weyburn	USA & Canada	North Dakota Gasification Co.	5.0	328	12 to 14	2000	Gasification Plant
Val Verde	USA	Petrosource	2.5	130	Up to 36	1998	Val Verde Gas Plants

Source: IPCC Special Report on CCS and Pöyry Energy Consulting

Figure 3 – CO_2 pipeline networks in the United States

Source: IPCC Special Report on CCS and Pöyry Energy Consulting

The pipelines typically transport the CO_2 in a dense phase, operating at pressures between 124 and 140 bar. Although this would suggest that the transport of CO_2 is well established, most of these pipelines are in sparsely located areas where they have not had to address a range of safety issues of public concern. One exception is the Cortez pipeline that traverses two built up areas in New Mexico.

In contrast to the US, there are only two significant CO_2 pipes in Europe. The small Lacq project involves 27 km of CO_2 pipe, but at much lower pressures than needed for dense phase operation. In 2008 StatoilHydro commissioned an 8 inch subsea pipe taking dense phase CO_2 from their LNG processing plant near Hammerfest in Northern Norway over 150 km to the Snøhvit gas field where it is injected into a saline aquifer adjacent to the gas field.

While the above discussion has been on using pipelines to transport CO_2, it is also possible to use tanker ships and cargo trucks, particularly for pilot projects or in the earlier phases of development. Tankers may also feature in the longer term as part of integrated complex networks, or in the event that CO_2 is required to be transported over long distances.

While it is technically possible to transport CO_2 a range of other issues that need to be addressed before large scale deployment in the UK, including:

- public acceptance of CO_2 transport networks;
- definition of pipeline design standards for CO_2 transportation;
- attaining the necessary permissions and consents to build the pipelines; and
- logistically managing CO_2 streams of differing qualities and variable flow rates from multiple sources.

2.2.3 Storage

Reaching conclusions on the state of development of technology for CO_2 storage is complicated by the diversity of different geological structures. There are also limitations on the inferences that can be drawn from the experience of CO_2 injection into oil and gas reservoirs for enhanced recovery programmes.

Key uncertainties range from the estimate of the likely storage capacity – in all types of geological storage regardless of whether they are depleted hydrocarbon reserves, to the behaviour of the CO_2 within the reservoir: permeability and containment probably rank amongst the most important parameters. Paradoxically, although saline aquifers offer the greater storage volumes in many parts of the world, including the UK, they are far less well characterised.

In this section we briefly review the many projects around the world that are providing a growing body of know-how on dedicated CO_2 storage – recognising that it builds on growing expertise developed in a plethora of EOR projects that first started in the 1970s.

Three flagship storage projects stand out – Sleipner, In Salah and Snøhvit are all running at injection volumes greater than 0.7Mt CO_2 pa and represent the closest experience of injecting into store the typical volumes from power stations. Even the largest of these, Sleipner, which has injected 1Mt CO_2 pa since 1996 is almost an order of magnitude smaller than a 1GW power station would require. As expected in early projects the level of monitoring for signs of migration and potential leakage has been high: there are no signs of leakage so far.

Canada's Weyburn EOR project is also an important reference point. From 2000 to 2004 it was the site of a world-scale research initiative, under the auspices of the IEA, which monitored the integrity of CO_2 storage in sub-surface formations.

Several European research projects have been investigating CO_2 storage in recent years, notably CO2REMOVE, CO2GEONET, CASTOR and CATO. Together these have added to the scientific skills required to characterise and operate potential storage sites, although the actual volumes injected are relatively small.

New plans recently announced to develop further large scale projects include the Altmark gasfield, near Berlin, which would provide the store for the previously mentioned Schwarze Pumpe capture project, and the licensing of the Otway Basin in Australia.

Over the life of a typical 1GW coal-fired power station it will be necessary to store over 200Mt of CO_2, and the storage volumes required for large scale deployment of CCS will be far in excess of current experience.

Evidence to date suggests that each geological formation, even if previously used for hydrocarbon extraction, is likely to have its own peculiar storage characteristics. This, coupled with the fact that many of the most promising aquifer formations have been relatively poorly characterised, suggests that considerable effort is required to quantify and evaluate storage capacity. Commercial unknowns exist regarding the effort required to evaluate potential storage sites; monitoring, mitigation and validation (MMV) obligations; storage operator liabilities; and potential hand-over criteria.

2.3 Role and design of CCS demonstration schemes

To commercially deploy CCS schemes it is first necessary to demonstrate that they can technically operate at scale and then take steps to improve their performance and resolve outstanding regulatory issues. A key aspect of a technology's transition from demonstration to commercial is the process in which knowledge and learning from one phase is used in the design of subsequent phases. While information gained in the design and construction of a project can be useful, it is the operational experience that provides the greatest benefits.

Consequently a number of leading commentators, including within industry, have argued that CCS will go through two phases, or tranches, of demonstration projects before it is likely to be deployed on a commercial basis, initially in lead countries, such as the UK, and afterwards globally. Figure 4 below show the framework that Jon Gibbins and Hannah Chalmers developed that distinguishes the various stages CCS technologies will progress through before being deployed on a commercial basis.

Figure 4 – Development of CCS from demonstration to commercial deployment

Source: Gibbins and Chalmers[1]

The second tranche of demonstration projects is an integral part of the evolution to full commercialisation, as in addition to resolving the technical issues and problems identified in the first tranche, it provides the basis on which business cases for CCS projects can be developed. Specifically:

- commercial guarantees will require examples, or cases, where CCS projects go into service on schedule and perform as expected;
- it needs to be shown that CCS projects involving multiple units and capacity in the order of 1GW can be built and operated successfully rather than single units with capacity below 400MW; and

1 Gibbins. J. and Chalmers, H. (2008). "Preparing for global rollout: a 'developed country first' demonstration programme for rapid CCS deployment". Energy Policy, Volume 36, pp 501-507.

- power stations using CCS technology will need to operate in a competitive market, suggesting there will need to be a significant reduction in costs, which is likely take several generations to materialise, and may require some fine tuning of market based incentives that could require time and experience.

Gibbins and Chalmers also distinguish between the first and later plants in the second demonstration tranche, in which the:

- first plants, which benefit from the operational experience of pilots and the lessons learnt in the design and construction of the first tranche of demonstrations plants; and
- later plants, which use information gained from the operation of the first tranche of demonstration plants and can be termed as ***pre-commercial***.

Below we review demonstration initiatives and discuss their potential impact on the transition of CCS to a commercial technology. It is not intended to be an exhaustive list.

2.4 Current demonstration initiatives

It is clear that full scale CCS technology is at a stage of development that significant effort is required before it can be deployed on a commercial basis. However, the potential of CCS to provide significant amounts of carbon abatement at competitive costs, while addressing energy security of supply concerns, has prompted governments around the world to encourage its development and deployment. For example:

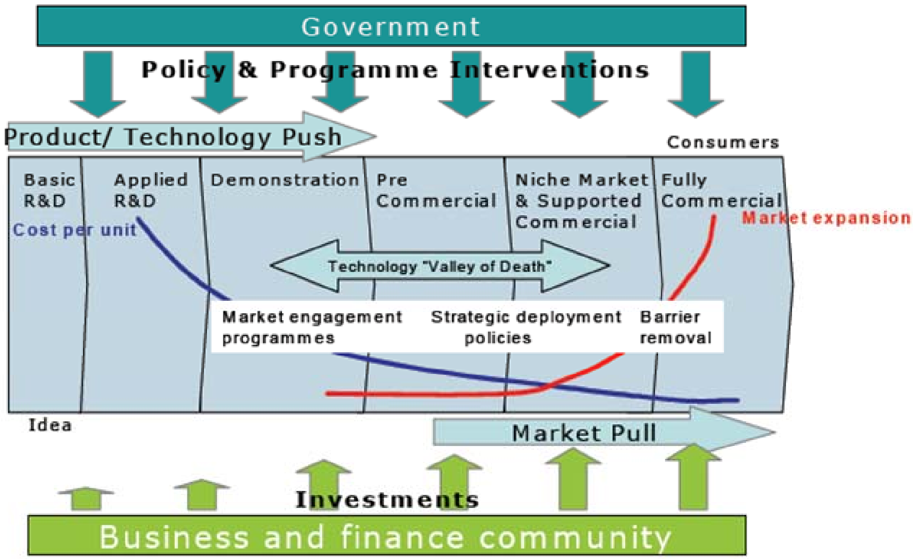
- In the UK a competition to fund a full scale post-combustion full CCS project has been running for some time, with the aim of delivering a project above 300MW by 2014. This was supplemented by a Government announcement of plans to provide funding support for up to four CCS projects and extended the scope to include oxyfuel and pre-combustion technologies.
- The European Union is supporting up to twelve full scale demonstration projects targeted to be operational by 2015, and funded by sale of EU ETS allowances.
- EU allocated €1 billion from the European Energy Programme for Recovery for CCS projects in seven EU Member States.
- US Government has recently provided:
  - $US1 billion to the FutureGen Alliance to support its IGCC project in Illinois;
  - $US100 million to Basin Electric to support its post-combustion Antelope Valley project in North Dakota; and
  - $US308 million to Hydrogen Energy to supports its IGCC project in California.
- The Canadian Government has set aside $C1 billion to support CCS, while the Alberta Government have set aside $C2 billion and has selected three projects which are expected to be operational by 2015.
- Australian Government has allocated $A2 billion for its CCS Flagship programme and established the Global Carbon Capture and Storage Institute (GCCSI) to support international co-operation in the development of CCS technology.

Figure 5 shows the location of selected proposed European CCS pilot projects. More detail on these projects is provided in Annex A.

Figure 5 – Location of selected proposed European CCS projects

While these initiatives will speed up the development of CCS, it remains to be seen whether they will be sufficient to bring CCS to the stage where it will be deployed on a commercial basis. There are a large numbers of cases where a technology has received support at the R&D and demonstration level only for it to drop away at the 'pre-commercial' stage before it is able to compete with other technologies. This has been called the 'Technology Valley of Death', which is illustrated in Figure 4 overleaf.

Figure 6 – Technology Valley of Death



Source: The Carbon Trust

Consequently it will be important to monitor how CCS develops under these initiatives and assess whether CCS:

- has become commercially viable;
- remains at a pre-commercial stage but is expected to become commercially viable; or
- is unlikely to be commercially viable in the foreseeable future.

Should CCS be showing signs of becoming fully commercial but not yet in a position to compete with other power generation technologies in the market, it may be necessary for Government to offer additional support. The current Renewables Obligation Scheme, where differentiated levels of support are provided to renewable technologies, depending on their commercial maturity is an obvious model.

2.5 Summary

There is as yet no fully integrated, commercial scale, power generation scheme with CCS operating anywhere in the world however, required elements of the value chain do exist at differing levels of technical and commercial maturity.

CO_2 has been separated from oil and gas production and gasified syngas for many years, but post-combustion, oxyfuel and pre-combustion separation technologies in a power generation context have so far been limited to small scale pilots and remain at a pre-commercial stage. CO_2 transportation by pipeline can be considered as commercially mature – the oil industry in North America has been transporting large volumes of CO_2 in pipelines since the early 1970s. Storage technologies are mature and three major projects exist in which significant volumes of CO_2, a by-product of natural gas production, are injected for sequestration into deep saline aquifers. Further, over the past three decades the oil and gas industry has gained considerable experience of injecting CO_2 into oil fields for the purpose of enhanced oil recovery.

It is likely that there will need to be two tranches of demonstration projects before power generation with CCS can be deployed on a commercial basis. The first will demonstrate that CCS projects can technically operate at scale. The second, building on the design, construction and operational experience gained in the initial stage, will improve performance and resolve outstanding regulatory issues and provide the basis for commercial guarantees expected of equipment suppliers and the first reference plant designs.

A number of demonstration initiatives have been established by the EU and the UK, US, Canadian and Australian governments but it is unclear whether they will be able to provide support at the critical pre-commercial stage, without which CCS is unlikely to be able to compete with rival power generation technologies.

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3. ASSEMBLING CCS PROJECTS

3.1 Introduction

While the previous section considered the generality of the evolution of CCS towards becoming an established commercial technology for electricity markets, this section examines the time dimensions likely to be encountered by project developers as we explore the practicability of reaching the 2030 indicative deployments set out by the CCC.

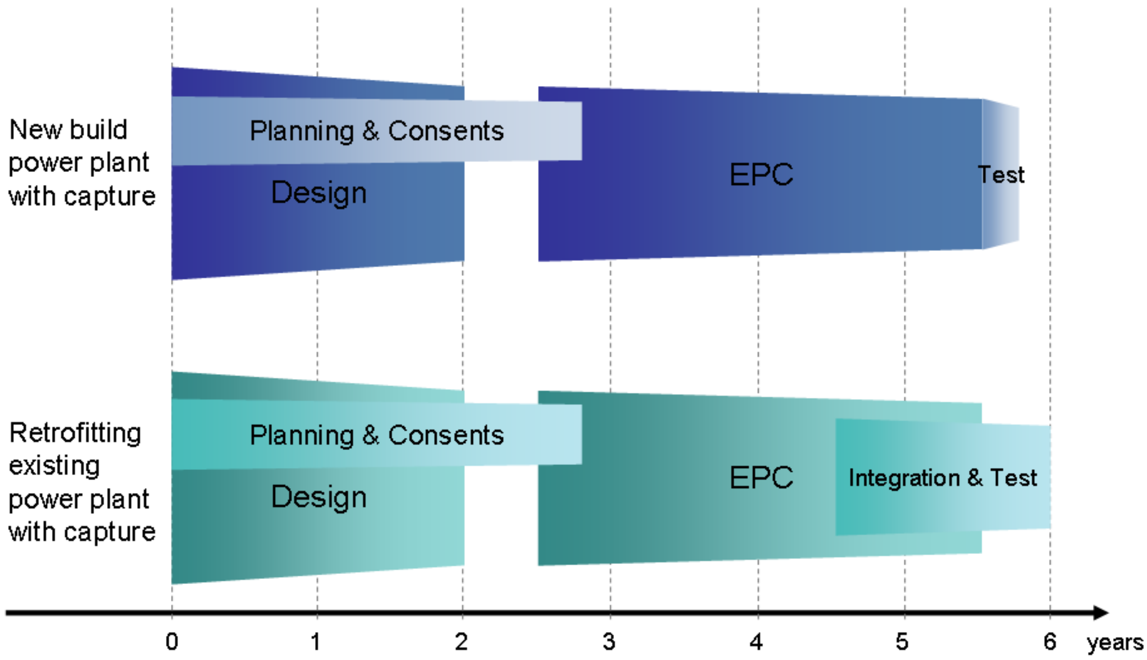
We first consider the timescales and risks associated with the individual components of a typical CCS project. We then examine the timelines for an integrated project and the implications for demonstration projects in the UK.

3.2 Project timescales and risks

3.2.1 Power station and capture plant

Figure 7 shows the likely timescales of the key components involved in delivering a typical power station and post-combustion capture plant, for both a new power station and the situation where an existing station is retrofitted with capture plant. Note, project timelines for power plants with pre-combustion and oxyfuel capture technologies are broadly similar.

Figure 7 – Timescales for power station and capture plant



Note: EPC refers to Engineering, Procurement & Construction

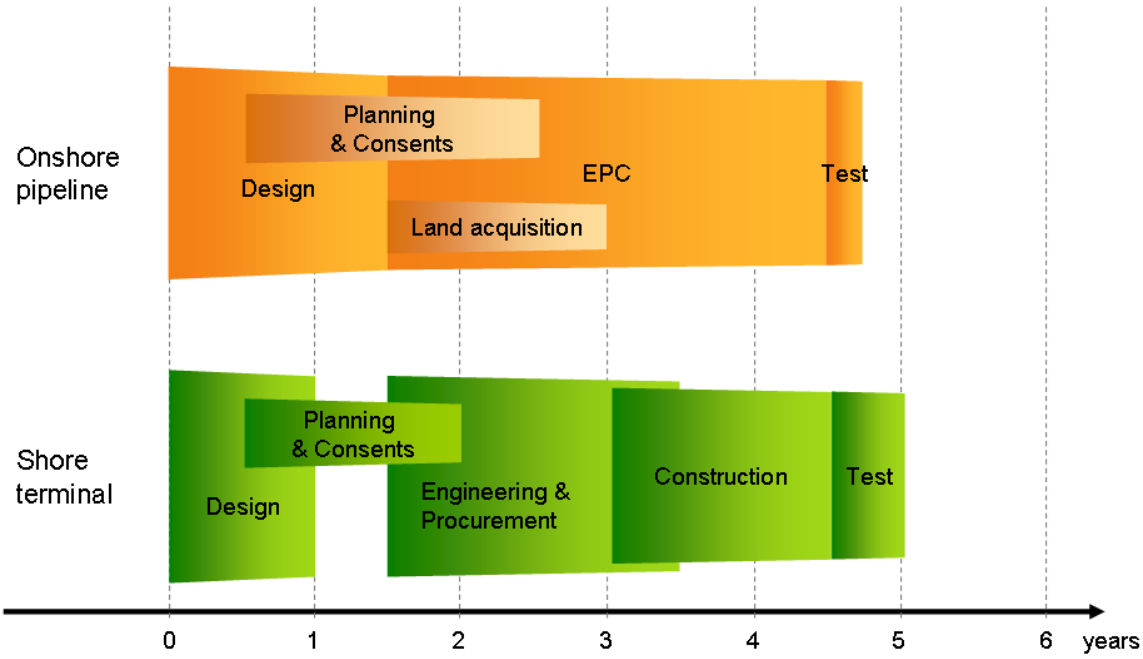
In both cases, the elapsed time from start to finish is likely to be at least six years and delays may extend the project into the seventh year. Historically, obtaining planning consents has caused considerable delay to projects – any lengthening of this part of the project cycle is unlikely to recoverable.

Contrary to general belief, the time taken for delivering a retrofit conversion of an existing power station is unlikely to be significantly shorter than for a complete new one. Retrofit will require similar activities, albeit of a more limited scope, compared with a new build but the critical path is effectively the same. However, timescales for retro-fit to 'capture-ready' coal plant could be significantly shorter.

3.2.2 Onshore infrastructure (pipelines)

Figure 8 outlines likely timelines for each of the steps involved in delivering the two key components of the onshore infrastructure: the pipeline and the shore terminal.

Figure 8 – Timescales for onshore infrastructure

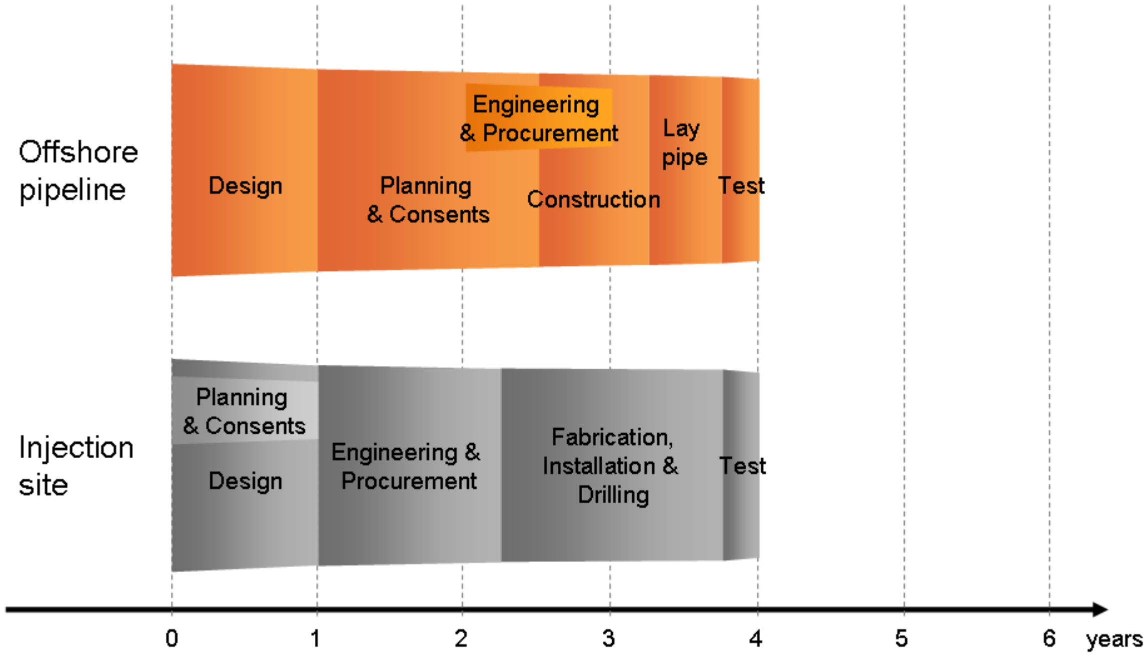


Both of these show that timescales of five years are feasible but that delays could extend these projects into the sixth year. However, there are some key risks to this in obtaining rights of way, consents and planning approval for the onshore pipeline. It is reasonable to assume that judicious choice of the pipeline route can mitigate this risk, but in some regions the choice of route will be limited.

3.2.3 Offshore infrastructure (pipelines and storage facility)

Figure 9 shows the timescales of the two principal components of the offshore infrastructure: the pipeline and the injection facilities.

Figure 9 – Timescales for offshore infrastructure



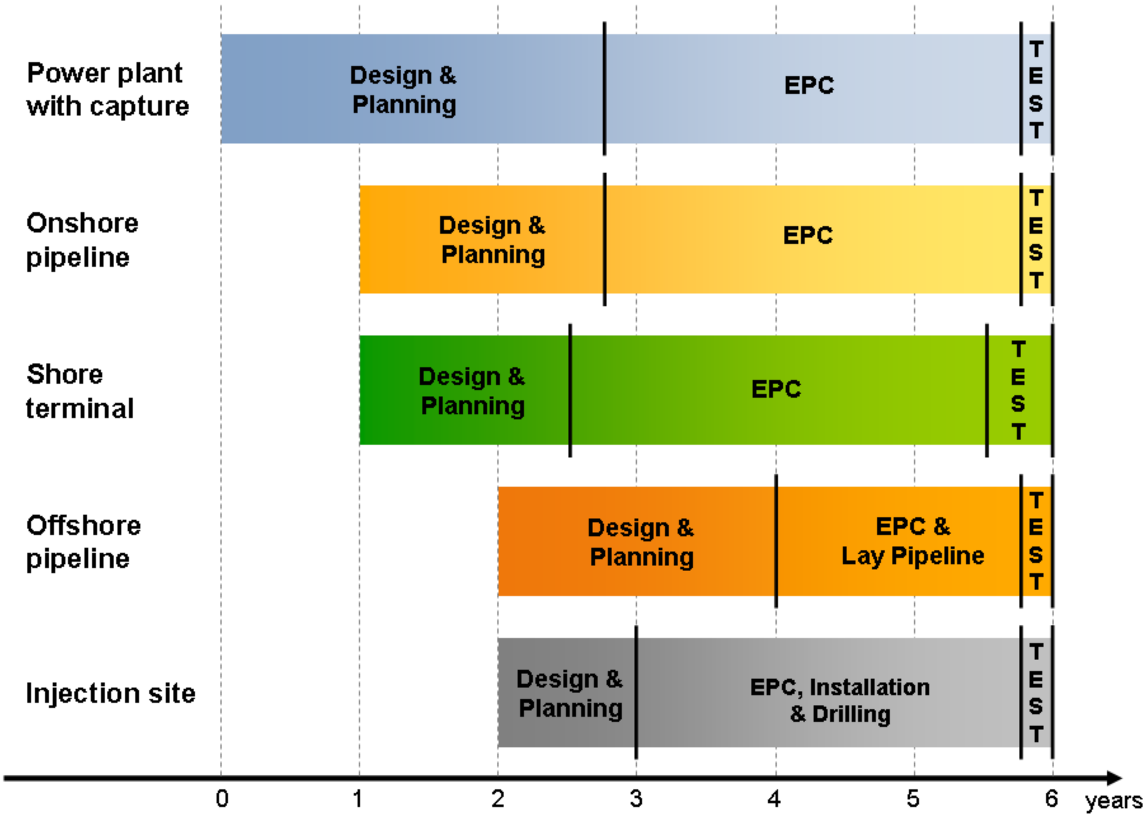
Our expectation is that it is reasonable to suggest a timescale of four years overall, once the storage site has been selected, which delays could extend to a fifth year. We believe that there may be possible to de-risk the pipeline component of the project if tanker supply chains were considered. There will also be a key design choice in the offshore infrastructure as to whether it is based on a subsea manifold. This would be slightly quicker and enable capex to be deferred because it enables the wells to be drilled while the manifold is installed. A platform approach would require the platform to be fabricated and installed before any drilling can take place.

3.2.4 Timescale for full chain CCS demonstration projects

We now examine the likely timescales for delivering a complete CCS project in the light of the above. In general the power station and capture plant are the longest component of the overall scheme, and set the time limit in which the overall project can be delivered.

Figure 10 shows our view on how the individual components would link together to give an overall timescale for a typical CCS project of six years.

Figure 10 – Generic timelines for a full scale CCS project



3.3 Timescale for the first tranche of demonstration projects

As mentioned above, the UK Government has announced it will run a competition to fund a full chain post-combustion CCS project of at least 300MW by 2014. Subsequently in April 2009 it announced that it will fund up to three additional demonstration CCS projects, and that projects with oxyfuel and pre-combustion technologies will be eligible for this funding. The Impact Assessment that accompanied the Government's consultation on CCS support mechanisms used a scenario of four projects in which the:

- first project starts operating in 2014, which would be the winner of the initial CCS demonstration project competition;
- second starts operating in 2015; and
- final two start operating in 2018.

Given that any projects that commence operation in 2018 could gain from the experience and knowledge acquired in the design and construction of the earlier projects, such projects could be considered to be the early projects in the second tranche of demonstration projects. Consequently, we have assumed in the latter analysis that the first tranche of demonstration projects in the UK will consist of two projects of between 300 and 400MW that commence operation by the very end of 2014 and 2015.

The start of operation dates of 2014 and 2015 appear to be challenging given the discussion above concludes that it will take approximately six years to deliver a CCS project. However, in the case of the initial UK demonstration competition, a significant amount of work has already been carried out and there is a reasonable expectation that these could be shortened by up to a year. Bearing this in mind, we consider that it is only possible for the demonstration project to be completed by late 2014 if:

- the Front End Engineering Design (FEED) studies are carried out during 2010 and the winning bidder notified before the end of 2010;
- discussions with commercial partners are significantly advanced, and there are no serious delays in the project obtaining planning and authorisation approval, acquiring the necessary land and testing the storage site; and
- construction starts before Q4 in 2011 such that testing will be completed within 2014.

With regard to the subsequent first tranche demonstration project due to begin operating in 2015, expanding eligibility beyond those considered in the initial competition implies that the design work and discussions with commercial partners will be at a less advanced stage than for the initial project. Consequently while there is an additional year before this project may be operational, the risk may be greater that this project is not completed on time than there is with the initial project.

3.4 Timescale for the second tranche of demonstration projects

As mentioned above, the UK Government has announced it will fund up to four demonstration projects, and has released an Impact Assessment that used scenarios in which the third and fourth begin operating in 2018.

We envisage that projects that begin operating in 2018 will benefit from the knowledge gained in the design and construction of the earlier demonstration projects, but there will be limited operational experience that feeds into their design. Consequently, if we use the classifications that Gibbins and Chalmers developed, these projects can be considered as the earlier projects in the second tranche of demonstration projects. While such projects will enhance the development of CCS technology, it remains to be seen whether they will demonstrate the successful construction and operation of multiple CCS units on a single site.

In addition, if the UK demonstration funding is allocated across different capture technologies in the proposed timescales, CCS commercialisation would require information to be shared from commercial-scale demonstrations in other countries. This implies that some sort of international co-ordination of demonstration of projects would be required and that information disclosure and knowledge sharing should be a pre-requisite for funding.

In our subsequent analysis we have assumed that the second tranche of demonstration projects will consist of a total of four projects of which two begin operating in:

- 2018 and benefit from the knowledge gained in the design and construction of earlier demonstration projects; and
- 2021 and benefit from the knowledge gained in the design, construction and operation of earlier demonstration projects and are called pre-commercial.

3.5 Summary

The elapsed time required to deliver a typical post-combustion CCS project, as envisaged in the UK demonstration competition, including design, planning consents, land acquisition, engineering procurement, construction and testing is likely to be of the order of six years. This raises significant challenges for the UK Government to meet its objectives of having one project operating in 2014 and its possible objective of another project operating by 2015.

We have undertaken some analysis that assumes a total of six CCS demonstration projects, made up of two:

- first tranche demonstration projects stating operation in 2014 and 2015;
- early second tranche demonstration projects stating operation in 2018; and
- two pre-commercial projects stating operation in 2021.

4. SUGGESTED TIMELINES

4.1 Introduction

The information discussed in the previous section has allowed us to develop indicative timelines for the deployment of 10 and 20GW of CCS capacity in the UK by 2030. We discuss this in two distinct phases:

- first, the rollout of the demonstration projects; and
- second, the subsequent commercial deployment of CCS.

We conclude by considering the impact of delays in the delivery of demonstration projects.

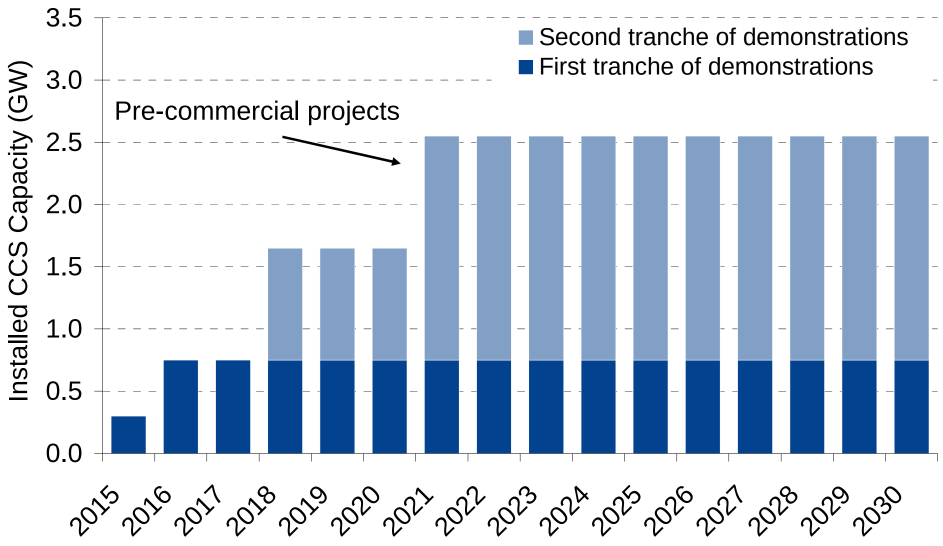
4.2 Rollout of demonstration projects

In considering the rollout of the demonstration projects we make the following assumptions:

- the first four demonstration projects will be implemented as suggested in the Government's consultation on CCS support mechanisms – but we assume a year's slippage on the first 'tranche' given delays in the current demonstration competition;
- demonstration projects will not be restricted to one specific capture technology;
- knowledge acquired will be shared with pilots and demonstrations being conducted contemporaneously in other countries; and
- Government financial support for demonstration projects continues for 15 years.

Figure 11 shows how the installed CCS capacity could evolve under this scenario – one plant of 300MW in operation in 2015, one of 450MW in 2016 and two of 450MW in 2018, resulting in some 1.7GW of operational CCS plant by 2018. These early demonstration plants would be followed by the role out of two, 450MW pre-commercial increasing total CCS capacity to about 2.6GW by 2021 plants by 2021.

Figure 11 – Demonstration project rollout

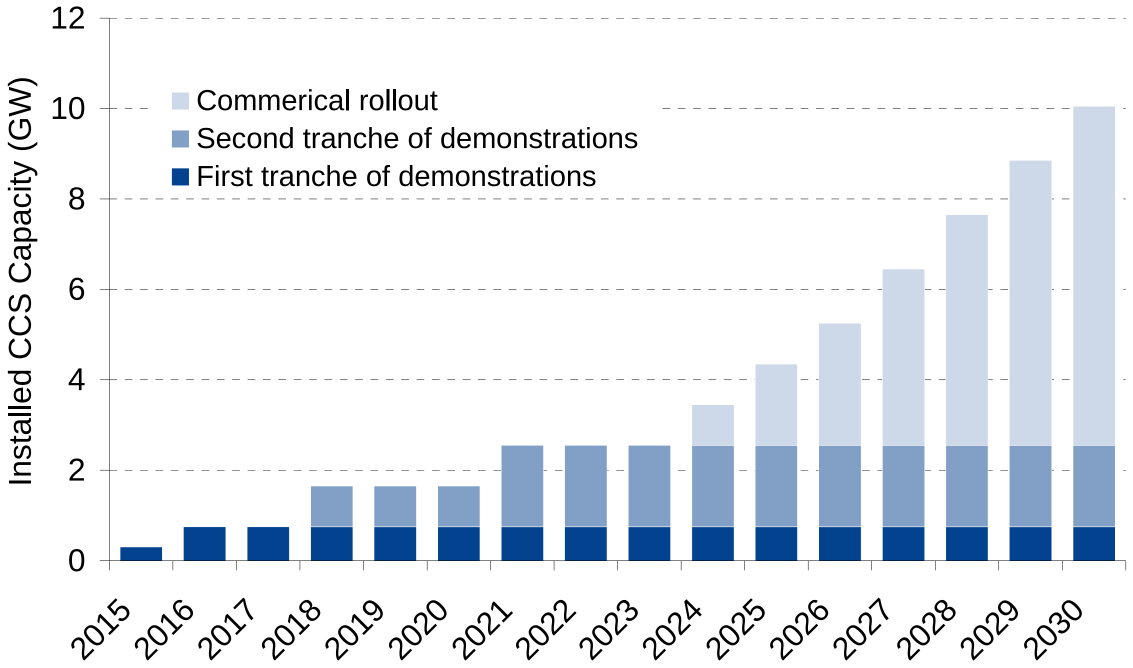


We would expect that the only operational experience feeding into the early demonstration projects would be from various small-scale pilot projects. However, development of the two pre-commercial demonstrations would be informed by operation of the early full-scale demonstration projects.

4.3 Commercial deployment of CCS: 10GW by 2030

Figure 12 shows how the commercial deployment after the initial two tranches of demonstration might achieve 10GW in operation by 2030. In this scenario, a further 7.4GW of commercial capacity is needed to supplement the 2.6GW of capacity developed in the demonstration projects.

Figure 12 – CCS commercial rollout to 10GW by 2030

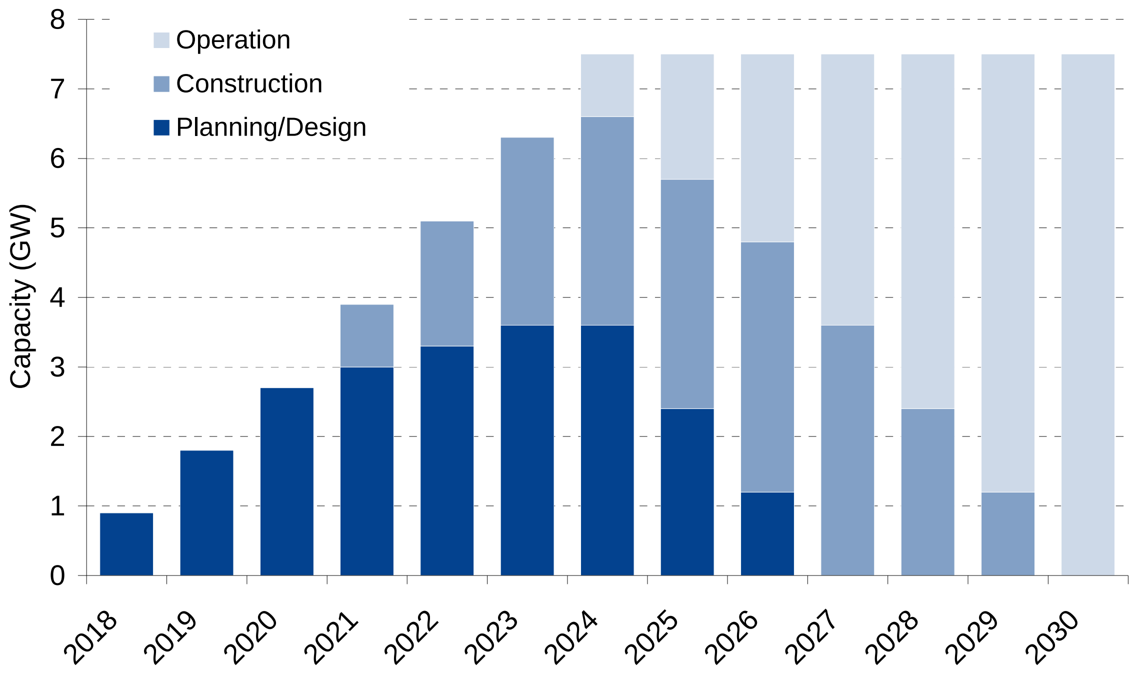


We have assumed that the commercial deployment would begin six years after plants in the second demonstration tranche start operation, with a design and build time for each project of six years. This timeline assumes that capacity amounting to approximately 1GW per annum begins construction in the years 2021 to 2023, increasing to 1.5GW per annum between 2024 and 2027.

Over the course of the decade we assume that the size of individual projects grows from about 1GW each to up to 1.5GW in line with greater commercial viability and general growing confidence in CCS operations. In total seven 'commercial' projects would be required to meet the 10GW level of deployment by 2030.

Figure 13 shows the commercial deployment phase in more detail, breaking it down into the three key stages of development i.e. planning and design, construction and operational start-up.

Figure 13 – CCS commercial rollout to 10GW by 2030: key development stages

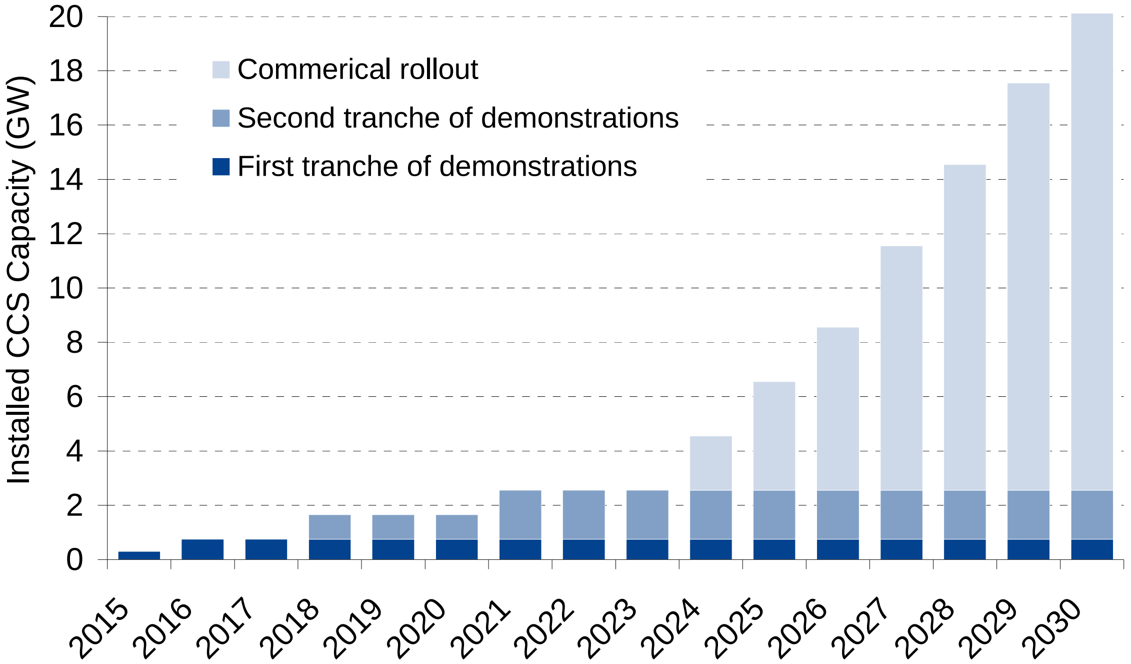


This shows that some 3.5GW of CCS capacity would need to be in the planning and design phase in 2023 and 2024 and under construction in 2026 and 2027. While it is reasonable to expect sufficient capacity from the equipment manufacturers and construction industry, we recognise that the seven projects may well be competing for resources with other UK and international projects not only in CCS but also other power sector projects such as wind and nuclear. Further, CCS projects will also be competing for resources with the oil industry, where activity tends to be strongly cyclical. It is possible that there could be constraints arising from the availability of vessels to lay the pipes during periods of high demand. Similar constraints could arise from the availability of drilling rigs.

4.4 Commercial deployment of CCS: 20GW by 2030

As might be expected, the timeline towards the higher scenario poses considerably more challenges. Figure 14 shows how 20GW of installed capacity might be achieved, maintaining the second demonstration phase, but with very high rates of subsequent commercial deployment – we believe that the alternative way of meeting the 20GW scenario by 'skipping' the second tranche of demonstrations is not realistic.

Figure 14 – CCS commercial rollout to 20GW by 2030

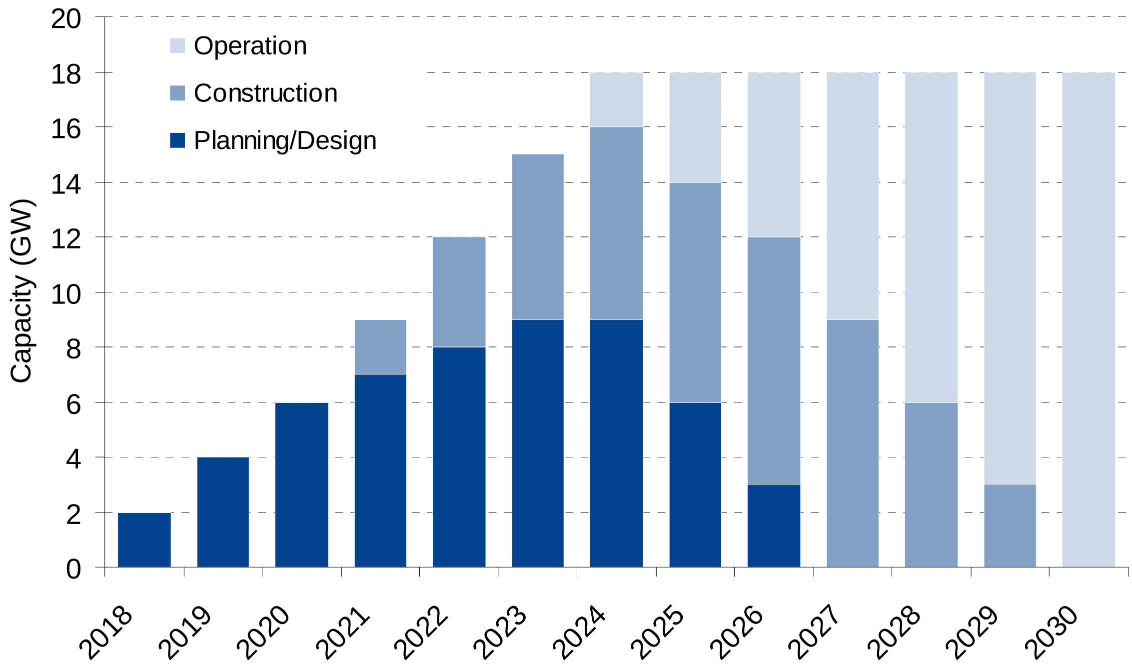


To achieve 20GW, 17.4GW of commercial build would be required. We have kept the start date and individual project length identical to the 10GW scenario, but have needed to assume that the construction rate doubles to two, 1GW plants per annum between 2021 and 2023 and two, 1.5GW plants per annum between 2024 and 2027.

This appears to be only just plausible, especially when the 'dash for gas' delivered 2.8GW per annum of CCGT capacity at its peak. We recognise that there are also additional complications from delivering the transport and storage systems, but have allowed for these components in individual projects' timelines.

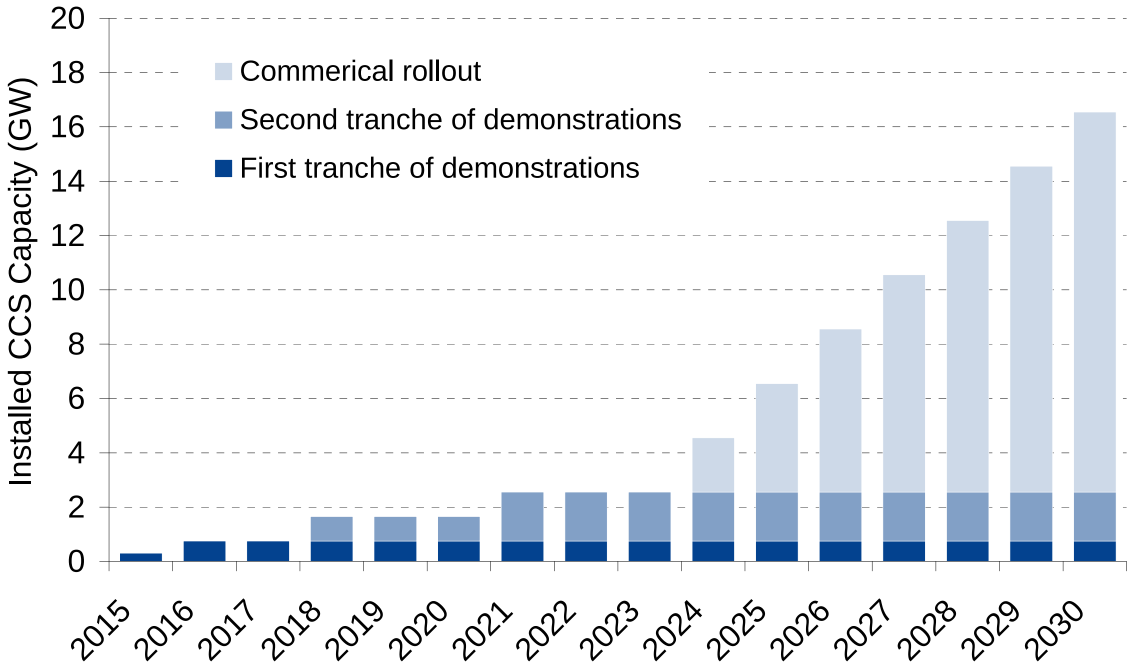
In total fourteen 'commercial' projects would be required, and as shown in Figure 15 which means that at its peak, simultaneously six projects will be in the design phase and six in construction with a total capacity of 9GW.

Figure 15 – CCS commercial rollout to 20GW by 2030: key development stages



We recognise that this rate of CCS development is unrealistic and propose a more realistic high deployment scenario of two, 1GW plants per annum under construction in the period 2021 to 2027. As is illustrated in Figure 16 under this scenario, installed CCS capacity reaches about 16.5GW by 2030.

Figure 16 – CCS commercial rollout: realistic maximum high deployment path



4.5 Dependency on timely delivery of the demonstration projects

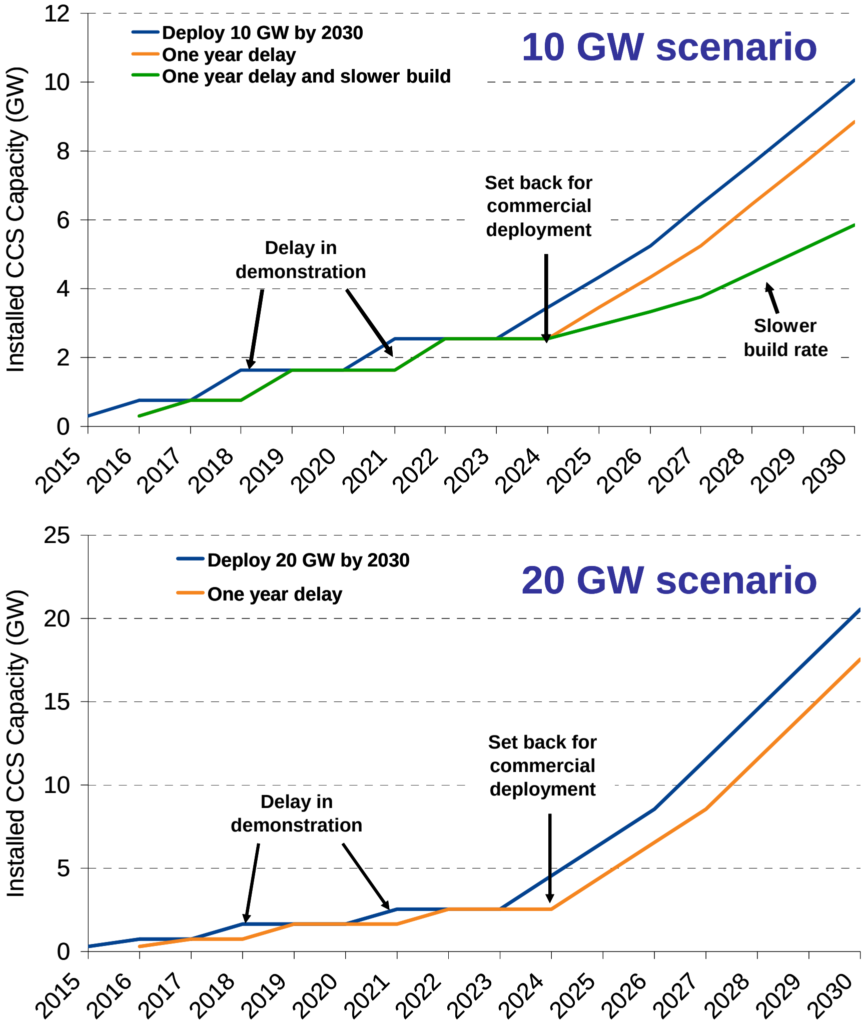
While this report is being written in the second half of 2009, there appears to be a significant likelihood of the target date for first operation of these projects in 2014 and 2015 slipping somewhat.

Delays have three main consequences:

- putting back the timescale on which their operational experience can feed into design and development of the 'pre-commercial' demonstrations;
- delays in the development of a local engineering and manufacturing capacity and skills base; and,
- potentially affecting and reducing investor and public confidence in CCS as a plausible low-carbon technology.

Figure 17 shows our estimate of the potential impact of delays on the 10GW and 20GW scenarios.

Figure 17 – Impact of delays



As can be anticipated a year's delay in delivery of the demonstration phase has a limited impact on the two scenarios and the deployments could be achieved by an accelerated commercial rollout – although in the case of the 20GW scenario, this would imply a build rate in excess of that achieved at the peak of the 'dash for gas'. However, if, as is likely, these delays are a symptom of a more general uncertainty over the CCS regulatory framework and support schemes then we would expect much lower deployment rates, as illustrated by our 'slower build rate' path in the 10GW scenario. In this case we estimate deployment levels could be as low as 6GW by 2030.

4.6 Summary

In the timelines we have developed for deployment of significant levels of CCS capacity are built on a common foundation of a four demonstration plants having been delivered by 2018 and two pre-commercial plants by 2021.

Of the two scenarios explored, the 10GW scenario is the more realistic, requiring commercial investment in a further 7 to 8GW of capacity by 2030, comprising an estimated seven projects. The 20GW scenario requires deployment rates of generation capacity last seen at the peak of the 'dash for gas' in the 1990s. Even under the 10GW scenario project timelines suggest that some 3.5GW of CCS capacity would need to be under construction in 2023 and 2024 which could represent a considerable challenge for the current industry supply chain.

The impact of delays in the delivery of the demonstration phase of projects could be overcome by an accelerated commercial rollout, at least in the 10GW scenario. However, if, as is likely, these delays are a symptom of a more general uncertainty over the CCS regulatory framework and support schemes then we would expect much lower commercial deployment rates.

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5. CONSTRAINTS

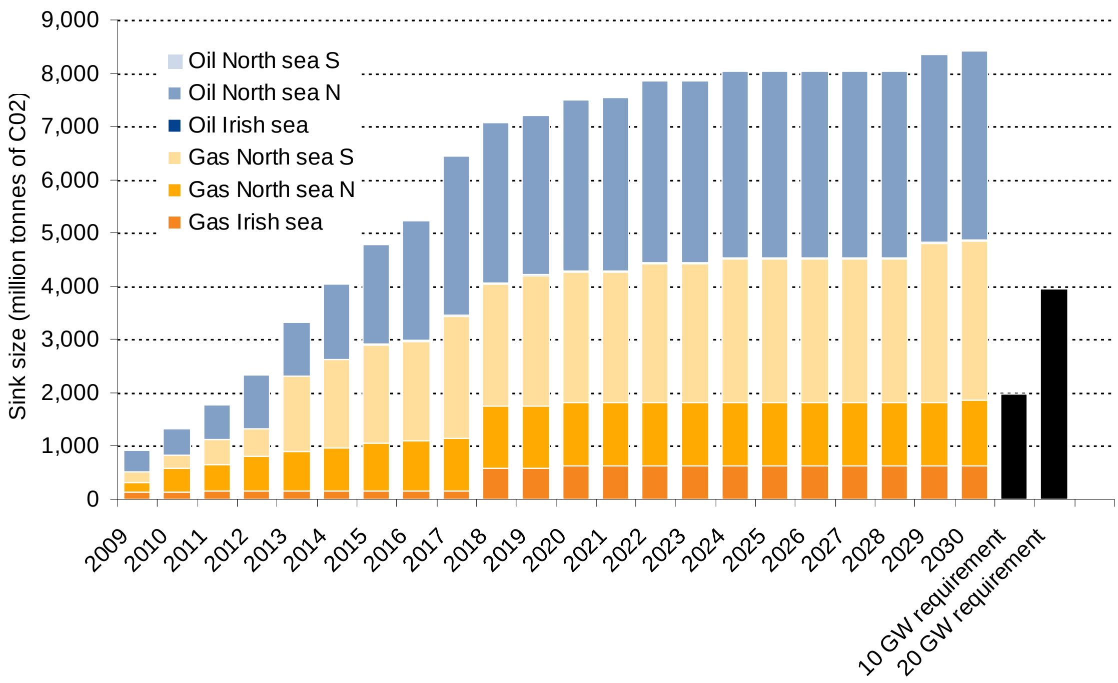
5.1 Introduction

In the course of considering the roll out of the demonstration projects and subsequent progress towards 10 and 20GW by 2030, we have identified a number of factors, or constraints, that may impinge on the achievement of these levels of CCS deployment. At best, these represent a risk, and at worse a major constraining factor in delivering significant amounts of CCS capacity in the UK.

5.2 Storage capacity

The existence of a large number of oil and gas fields in the UK sectors of the North Sea and Irish Sea suggests that there is likely to be an abundance of storage capacity well suited to large scale deployment of CCS. Figure 18 shows the timing of cumulative sink availability between now and 2030 in depleted oil and gas fields. It illustrates that the theoretical capacity available in such reservoirs is more than adequate to meet the likely CO_2 storage requirement arising from the 10 and 20GW scenarios.

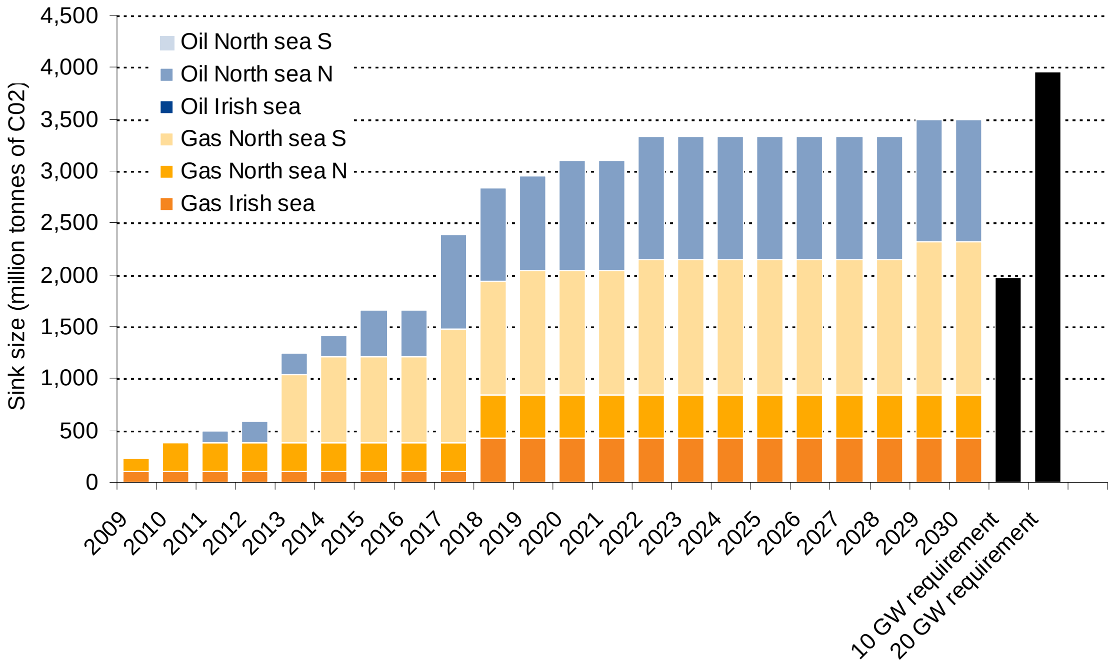
Figure 18 – Availability of carbon sinks in UK depleted oil and gas fields



Source: BGS data and Pöyry analysis

However, much of this capacity is unlikely to be well suited to CO_2 storage from large scale, coal-fired power CCS projects. Once factors such as field size, reservoir pressure, residual water and hydrocarbon production history are taken into account, the impact is to significantly reduce the headline figures. A picture emerges (see Figure 19) that 10GW of CCS plant would use more than half the available capacity in depleted oil and gas fields, and that storage in deep saline aquifers will be essential under a 20GW scenario. Note, this analysis ignores any practical and commercial considerations that are likely to reduce capacity in depleted oil and gas fields even further.

Figure 19 – UK carbon sink availability in depleted oil and gas fields after constraints applied



Source: BGS data and Pöyry analysis

Undoubtedly the UK is geologically favoured and has a huge sink potential. A recent study by the Scottish Centre for Carbon Storage estimates total UK offshore storage capacity at between 60 and 150 bn tonnes of CO_2. However, most of this is in deep saline aquifers which have been poorly characterised to date.

In the evaluation of storage capacity, several issues need to be considered, namely:

- how can the technical uncertainties concerning aquifer storage be lessened;
- what sort of storage is best suited to the early CCS projects, where an emphasis on lowering project risks will be important;
- what is the proximity of potential storage reservoirs to major power projects or clusters;
- what is the potential for oil and gas infrastructure re-use;
- can storage outside the UKCS be considered, for example on the Norwegian Continental Shelf, and if so on what access terms;
- how to cater for uncertainty in the likely storage requirements – which may be higher if capture from industrial sources becomes significant?

5.3 Planning and Consenting

In our experience the planning and consenting components of large projects have potential to become a significant constraint on the deployment of individual CCS projects, which are large, complex and require approvals in many different dimensions. Table 2 summarises the main requirements.

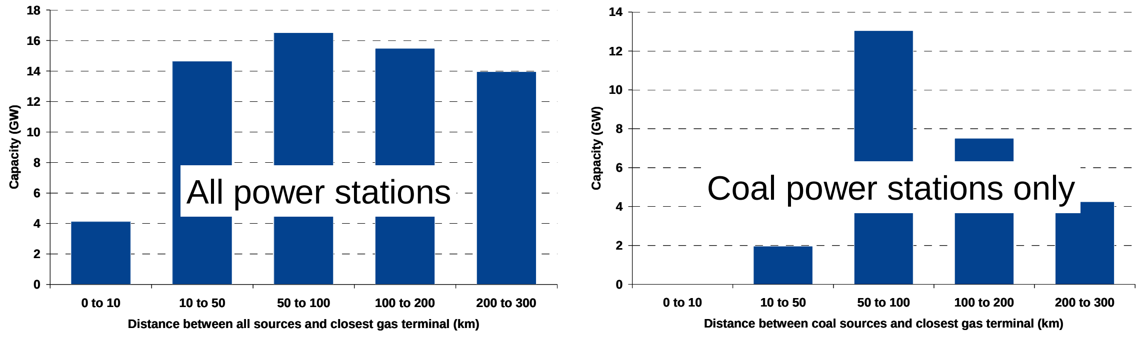
Table 2 – Principal planning and consent requirements

Requirement	Description	Capture facilities	On shore pipeline	Offshore pipeline	Storage site
Section 6 of Electricity Act 1990	Generation licence	✓	-	-	-
Section 36 of Electricity Act 1990	Consent to construct power station above 50 MW, including Enviromental Statement	✓	-	-	-
Construction Design Management (CDM) Regulations 2007	Construction health and safety regulations	✓	✓	-	-
Environmental Permitting Regulations 2008	Environmental permit	✓	-	-	-
Section 7 of GHG Trading Scheme Regulations 2003	EU ETS permit	✓	-	-	-
Consents from:	• Land owners • Network Rail • British Waterway	-	✓	-	-
Water Resources Act 1991	Flood Defence Consent	-	✓	-	-
Section 1 of Pipelines Act 1962	Onshore pipelines more than 16 km long require a Pipeline Construction Authorisation (PCA)	-	✓	-	-
Pipeline Safety Regulations 1996	Covers treatment of hazardous material; HSE is considering of treatment of pressurised CO_2	-	✓	✓	-
Section 15 of Petroleum Act 1998	Pipeline works authorisations (PWA's), including Enviromental Statement	-	-	✓	-
Offshore Petroleum Activities (Oil Pollution Prevention and Control) Regulations 2005	Various Petroluem Operations Notices (PON)	-	-	✓	✓
Section 18 Energy Act 2008	Licence to store CO_2 offshore,	-	-	-	✓
Crown Estate	Right to use sea bed	-	-	-	✓

Although many of the consents are procedural, they can not only take a long time, but they also add considerably to the uncertainty involved. A key area is the need to obtain rights of way to build pipelines, either by land acquisition or by gaining consents from landowners, such as Network Rail and British Waterways. As a guideline, any onshore pipeline which is longer than 100 km in length can be regarded as problematic because of the potential number of landowners and organisations – and the consequent effort to evaluate several route options to mitigate difficulties.

Our analysis of the likelihood of pipeline planning issues becoming and important constraint has therefore examined the location of current power station sites in relation to existing natural gas terminals. It makes the assumption that coal fired generation with CCS will be developed at existing coal plant sites (as coal transportation and power transmission infrastructure already exists for these sites) and that gas terminals are the most likely transit points to offshore storage sites. Figure 20 illustrates distance of all current UK power stations and separately, coal-fired power stations, in relation to their closest gas terminals.

Figure 20 – Distance of current UK power station sites to closest gas terminal



As can be seem approximately 15GW of coal-fired capacity is less than 100 km from a gas terminal. This suggests that pipeline planning issues should not be a major concern under the 10GW scenario. An option to reduce the need for long onshore pipelines under the 20GW scenario would be to build increased CCS generation capacity at existing sites, or the development of CCS clusters at coastal sites. It should be noted that the Government has stated that CCS demonstration plants will be developed in clusters in order to share the infrastructure used for transportation and storage of CO_2 in the North Sea.

A further issue that needs to be taken into account is the potential impact of public concerns over the safety of pipeline transportation of CO_2. These concerns, although unfounded, may prove to be a major stumbling block to obtaining planning permits.

The Infrastructure Planning Commission (IPC) was set up in 2008 to address delays in the planning system in England and Wales. The experience of the initial CCS demonstration projects, as they navigate the new planning processes should be closely monitored by Government, and corrective actions taken if necessary.

5.4 Industrial Emissions Directive

Although it is expected that a large proportion of coal-fired generation capacity in the UK will close as a result of the Large Combustion Plant Directive (LCPD), the Industrial Emissions Directive (IED) may have even greater consequences for the deployment of fossil-fired capacity in the UK.

The IED is still being negotiated and is expected to be approved in 2010 and will significantly tighten the emission levels of NOx, SO_2, carbon monoxide, and particulates from 2023. Older plants will be allowed to 'opt out' and operate with restricted running hours for a fixed period in a similar fashion to the LCPD: the current proposal is for 20,000 hours from 2016 to 2023.

It is envisage that most of the current coal fleet will close by 2023, leaving a significant capacity shortfall. Given the lead times, the decisions on what type of capacity that will need to be built to fill this gap are likely to be made in the mid 2010s. Concerns at this point over the viability of CCS compared to other forms of generation, such as renewables, nuclear and gas-fired generation, could lead to investors choosing not to build plants that require CCS, inhibiting the development and deployment of this technology. It may be appropriate for the Government to monitor this and assess whether additional support for CCS will be required.

5.5 Carbon market price

Historically carbon market prices have been far below the estimated €60-110/tonne of CO_2 we believe are required to allow 'first-of a-kind', or early commercial-scale, CCS projects to be competitive with other generation technologies. The early phase of 'commercialisation' is therefore unlikely to happen unless there is a reasonable certainty that this level of support will be present either directly in the market or indirectly through other support mechanisms.

If the carbon market does not deliver the required carbon support, then Government will have to make up the difference at the demonstration and pre-commercial stages. CCS is far more complex and involves many more delivery risks than a super critical coal plant or simple CCGT, so it is likely that it will need even higher levels of support.

Currently the Government is consulting on the form of a support mechanism for the first round of demonstrations. If, as we suggest, a further tranche of demonstration plants is necessary for commercialisation it will need to give due consideration to the associated support mechanisms well in advance of the early 2020s.

5.6 CCS in the future UK generation mix

Coal plants with carbon capture facilities will be seeking to sell power into a market that involves a range of other types of generators. If this market is characterised by high levels of intermittent wind generation (the current Government target is for 28GW of installed capacity by 2028) and price insensitive nuclear and, then plants with CCS could face the challenges of needing to operate:

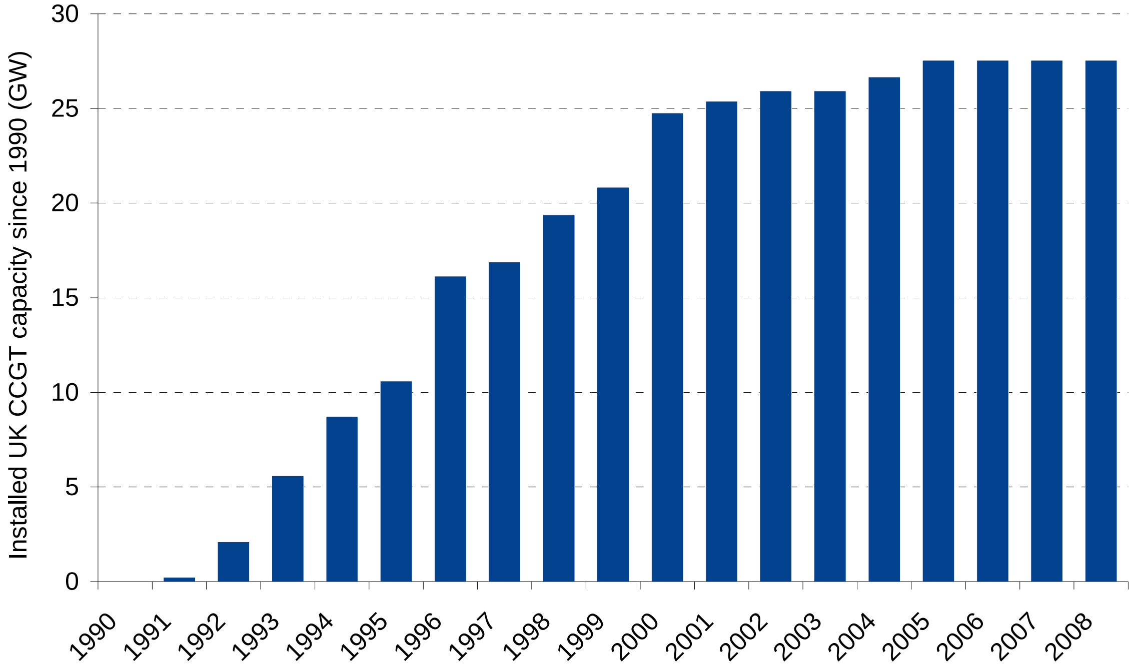
- for sufficient hours to recover their, significant, capital costs; and
- with the flexibility required to respond to the fluctuations in the supply from intermittent sources.

Concerns over these issues may deter investment in CCS under the current market structure. This needs to be recognised in future Government policy formulation.

5.7 Industry-wide deployment limitations

The ability of the industry to rapidly develop and build new power stations is well evidenced by the build rates of CCGTs achieved during the so-called 'dash for gas' in the 1990s, when there were clear commercial drivers.

Figure 21 – CCGT build during the 'dash for gas' in the UK



As discussed in Section 4, CCS projects may well be competing for resources with other UK and international projects, not only in CCS but also other power sector projects such as wind and nuclear and there may be a lack of supply chain capacity to deliver the large amount of power generation, capture, offshore storage equipment and infrastructure required.

The scope of this project requires a view of likely industry constraints in the 2020s in particular. While this is likely to be subject to considerable influence from global events, we believe it is reasonable to infer that given the additional complexity of CCS projects, compared to CCGT, their deployment rate is likely to be below those achieved in the 1990s in the UK.

5.8 Summary

There are a number of factors that may impinge on the successful deployment of significant levels of CCS capacity in the UK by 2030.

- Suitable storage capacity in depleted UK oil and gas fields may be limited, particularly in the 20GW scenario, which may require the utilisation of deep saline aquifers.
- Planning and consenting of CCS power plant and infrastructure, particularly long distance pipelines may be subject to delay because of the large number of stakeholders who will need to be involved.
- The Industrial Emissions Directive (expected to be approved in 2010) may further skew the investment case for new power plant towards CCGTs and nuclear, at a time when CCS plant have just become commercial.

- The carbon market price may not be high enough (€60-110/tonne) to enable early commercial-scale CCS projects to be competitive with other generation technologies. If this is the case early commercialisation of CCS will not happen unless the Government provides the necessary levels of support.
- CCS may struggle to be commercially viable in a market with high levels of intermittent wind generation and nuclear power.
- There may be a lack of supply chain capacity to deliver the large amount of power generation, capture, offshore storage equipment and infrastructure required.

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6. MILESTONES FOR CCS DEPLOYMENT

6.1 Introduction

The final part of this report addresses how a set of policy and construction milestones could be put in place to monitor progress towards the 10GW and 20GW levels of deployment. Such milestones could provide a framework by which progress would be monitored and key uncertainties reduced or eliminated.

We first detail potential key milestones for the demonstration and pre-commercial projects before moving on to consider the commercial deployment phase for the power and capture plant, the transportation network and the storage sites.

6.2 Demonstration projects

Given the strong dependence on the subsequent delivery of projects, these are milestones which will need to be very closely monitored, and we have therefore suggested a set which provide greater scrutiny so that any possible corrective actions could be initiated earlier.

- suitable storage sites are identified and made available by 2010;
- publication of details on the number and funding mechanism for the remaining demonstration projects as soon as possible and no later than 2010;
- for projects scheduled to start operation in 2015, construction must start on the power station site and pipeline network by 2012 and on the storage site by 2013; and
- for projects scheduled to start operation in 2018, construction must start on both the power station site and on the pipeline network by 2015 and on the storage site by 2016.

We believe that there is some scope to use experience from CCS demonstration projects outside the UK, but as the UK competition for a demonstration plant is amongst the most advanced proposal for a commercial scale post-combustion project, it should provide early, easily accessible information.

6.3 Pre-commercial projects

Currently there is no arrangement to support CCS projects beyond that for the initial demonstration projects from the UK government and the European Commission. At this stage it is not clear whether the initial demonstration projects will create sufficient momentum for companies to develop ‘pre-commercial’ projects without further support. Such support would be expected to be at lower levels than the initial demonstration projects.

Nevertheless, we view the pre-commercial projects are a key step in the development of fully commercial technology. We therefore suggest the following framework:

- If a support mechanism is deemed necessary, we believe that project developers will need a clear indication that support will be available from 2013, with sufficient details being available from mid-2015 to enable developers to build business models.
- Delivery of a reference demonstration CCS project by 2018.

- Regular monitoring of developments at other demonstration projects elsewhere in the EU and outside it, particularly Australia, Canada, China and the United States.

6.4 Commercial deployment

Our focus in developing milestones for the commercial phase of CCS deployment falls on two main areas. Firstly, to ensure that clear investment signals are provided to industry in a timely manner; and secondly, to reduce the uncertainty over the availability of storage capacity. Consequently, we suggest the following milestones.

- By 2016 confirmation of confidence in the returns for CCS projects, allowing for confidence in, and the level of support from either specific support mechanisms or the EU ETS.
- Identification of suitable storage capacity to the extent that by 2016 power station operators can develop appropriate commercial arrangements with storage counterparties.

The next section considers milestones to track project development progress to meeting the 10GW and 20GW scenarios.

6.4.1 Power and capture plant

To monitor the deployment of power and capture plant along the tracks discussed earlier in this report, the following milestones would be appropriate for:

- 10GW by 2030, 3.5GW will need to be under design in 2024 and 2025 and under construction in 2027 and 2028; while
- 20GW by 2030, the corresponding number is 9GW for the same timelines.

However, given our concern about industry capacity to deliver such a large number of projects under such challenging timescales we also suggest that suitable monitoring processes are developed. These could include lead times for delivery of key power and capture plant equipment, manufacturers' prices and levels of relevant EPC activity.

6.4.2 Transportation network

Confidence in there being a suitable transportation network will be a crucial part of investment in capture plant in this commercial deployment phase. Our focus here is on onshore pipeline systems.

The transportation network will face important decisions, for example the extent to which the network is over-specified to ensure sufficient capacity over the longer term and how this is funded, and the design for a network which will need to manage the flows of CO_2 from various sources in a manner which optimises its delivery to several storage sites.

A key issue is how the permitting and consenting processes will work under the new Infrastructure Planning Act. Progress of the first projects will need to be monitored closely to understand whether additional measures are required to expedite planning decisions.

Our suggestions for suitable milestones for the transportation network in the commercial deployment phase are the start of the construction on sufficient pipelines for:

- 2024 projects by 2021; and
- 2027 projects by 2024.

Note, if there is continued uncertainty arising from consenting and planning processes, there may be a need to consider additional leading milestones.

6.4.3 Storage sites

Confidence in sufficient and appropriate storage will be a requisite for both investors in capture plant as well as the public.

The earlier discussions about storage capacity suggested that deep saline aquifers will be needed if more than 10GW of CCS capacity is to be deployed but that relatively little was known about their potential. Therefore, proving the suitability of sufficient storage capacity is one of the most important barriers to be overcome, and we believe that early steps should be taken to make their potential less of an unknown. Furthermore, due consideration ought to be given to the order in which the different types of storage are exploited in order to balance the clear need to use the best characterised sites in early projects to reduce risk with the need to advance understanding of the aquifers.

In terms of delivery of storage facilities, we suggest specific milestones For CCS projects scheduled to start operating in:

- 2024 the construction of facilities at the storage sites should have commenced by 2022; and
- 2027 the construction of facilities at the storage sites should have commenced by 2025.

6.5 Summary

Commercialisation and the development of significant capacity of power generation with CCS, as set out in the 10GW and 20GW scenarios will challenge both industry and government. The UK Government needs to set clear and realistic timelines for delivering the required regulatory and licensing framework and defining a robust and sustained support mechanism for demonstration and pre-commercial projects. It should provide industry with confidence that it will put measure in place to recognise and, potentially, intervene to alleviate potential supply chain bottlenecks. Further, where necessary, it should support the development of the industry by sponsoring targeted R&D initiatives such as an evaluation of the storage potential and ensuring that channels exist to share information from other demonstration projects elsewhere in the EU and outside it.

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7. CONCLUDING REMARKS

There is as yet no fully integrated, commercial scale, power generation scheme with CCS operating anywhere in the world but required elements of the value chain do exist at differing levels of technical and commercial maturity. Nonetheless, it is our view that deployment of significant levels (of the order of 10 to 20GW) of coal-fired power generation capacity with CCS in the UK by 2030 is feasible. However, for this to happen the Government needs to take immediate steps reduce regulatory and policy uncertainty and commit to provide sustained support for technology commercialisation. Key issues to be addressed include the following:

- A single phase of Government-supported demonstration projects is unlikely to be sufficient to establish the commerciality of CCS. It is likely that there will need to be two tranches of demonstration projects. The first will demonstrate that CCS projects can technically operate at scale. The second, building on the operational experience gained in the initial tranche will resolve technical issues and problems identified and provide the basis for the commercial guarantees expected of equipment suppliers.
- Progress towards commerciality needs to be monitored actively throughout the CCS demonstration phases. Requirement for further Government support is needed in the critical pre-commercial stage, the so called ‘technology valley of death’. This should be evaluated by 2013 with firm details proposed by 2015.
- CCS may struggle to be commercially viable in a market with high levels of intermittent wind generation and nuclear power. This needs to be recognised in future Government policy formulation.
- The storage capacity of deep saline aquifers needs to be assessed sooner, rather than later. There is likely to be insufficient suitable storage capacity in depleted UK oil and gas fields to support more than 10GW of power generation with CCS.
- There may be a lack of industry supply chain capacity to develop and construct CCS projects in the timescales required. CCS projects may well be competing for resources with other UK and international projects, not only in CCS but also other power sector projects such as wind and nuclear and the oil industry.
- Planning and consenting of CCS power plant and related infrastructure, particularly long distance pipelines may be subject to delay because of the large number of stakeholders who will need to be involved. Public concerns over the safety of pipeline transportation of CO_2, even though unfounded, may prove to be a major stumbling block.

It is clear that the commercialisation and large scale deployment of CCS will challenge both industry and government. The UK Government needs to set clear and realistic timelines for delivering the required regulatory and licensing framework and defining a robust and sustained support mechanism for demonstration and pre-commercial projects. It should provide industry with confidence that it will put measures in place to recognise and, potentially, intervene to alleviate, potential supply chain bottlenecks. Further, where necessary, it should support the development of the industry by sponsoring targeted R&D initiatives such as an evaluation of the UK’s storage potential and ensuring that channels exist to share information from other demonstration projects elsewhere in the EU and outside it.

The following table sets out suggested policy and deployment milestones against which progress to delivering significant volumes CCS generation capacity by 2030 could be tracked, prompting government interventions, if required.

Table 23 Key milestones for deployment of UK CCS projects

	Confidence in adequate		Construction start year		Start year for capture facilities		
	Carbon price & support	Storage capacity	Transport network	Storage site	Design	Construction	Operation
First demonstration projects	2010	2010	2012	2013	Underway	2012	**2015**
Initial second demonstration projects	2010	2010	2015	2016	2012	2015	**2018**
Pre-commercial projects	2013	2013	2018	2019	2015	2018	**2021**
Initial commercial deployment	2016	2016	2021	2022	2018	2021	**2024**
Global commercial deployment	2019	2019	2024	2025	2021	2024	**2027**

The nature of a report with this brief is bound to highlight the difficulties and risks involved in deploying a large amount of a new technology. There is a danger that the overall sentiment is one of problems to be overcome. Yet the potential for CCS to offer very significant amounts of carbon abatement continues to shine through. Large scale deployment of all low carbon technologies will encounter similar challenges, and the overwhelming conclusion from this report is the practicability of delivering CCS as a significant component of a low carbon electricity sector.

ANNEX A – POTENTIAL FULL SCALE PROJECTS

A.1 Introduction

As might be expected, the commercial nature of projects under development and associated commercial sensitivity of releasing information prematurely means that any list will become out of date almost as soon as it is printed. In our experience, as well, many announced projects CCS have been abandoned with little progress – this is inevitable as project economics evolve, support mechanisms moderate and the strategies of partners develop. In this Annex, we describe a sample of current projects in many parts of the world to illustrate the current level of activity.

A.2 UK projects

The UK Government is running a competition to fund an end to end commercial scale post-combustion scale project. Initially four bidders were selected to progress through to the next stage of the process. One of these withdrew from the process, leaving the following three bidders.

- E.ON, who has proposed to retrofit capture facilities to one units at its proposed supercritical coal-fired station at Kingsnorth in Kent, and transport the CO_2 to the Hewitt gas field for storage.
- Scottish Power has proposed retrofitting capture facilities to one unit at its Longannet power plant in Scotland, and transporting CO_2 to saline aquifer in the North Sea. Shell and National Grid have recently joined the consortium working on this project.
- A consortium comprising Peel and DONG were expected to propose a new coal fired station with capture facilities at Hunterston in Scotland, but following RWE joining the consortium at the end of 2008, it is expected that they will now propose to incorporate capture facilities in the new supercritical coal-fired plant at Tilbury in Essex.

A number of other pilot and demonstration projects have been proposed. RWE proposed to build a 1MW post-combustion pilot at its Aberthaw plant in south Wales. At the beginning of 2009, RWE indicated it would increase the size of the pilot of 3MW, which is expected to be operational by 2010.

A number of IGCCs have been proposed, but these appear to be on hold due to their high upfront cost. These include:

- Powerfuels has received its Section 36 consent to build a 900MW power station at Hatfield in Yorkshire, where it intends to build an 800MW CCGT and convert it to a 900MW IGCC;
- ConocoPhillips has examined building a gasifier to convert coal and petcoke to a fuel for its Immingham CHP plant in Humberside;
- E.ON announced that it would undertake a feasibility study for a 450MW IGCC next to its existing Killingholme plant; and
- Centrica and Progressive Energy announced an agreement to build an 850MW IGCC at Teesside in November 2006. Centrica has subsequently pulled out, selling its equity stake in the project to Progressive Energy.

A.3 EU projects excluding the UK

Following is a brief summary of the CCS projects considered for EU funding under the European Energy Programme for Recovery that have not been outlined above.

RWE has announced its intention to build a 450MW IGCC with capture facilities at Hürth near Cologne in Germany. Vattenfall have announced its intention to replace one of its 250MW units at its lignite fired plant at Jänschwalde Germany with an oxyfuel unit and refit another with post-combustion capture facilities. Following its acquisition of Nuon, Vattenfall intends to build a 1,200MW IGCC plant at Eemshaven near Groningen in the Netherlands. It is envisaged that it will use gas, coal and biomass as a fuel stock.

E.ON has announced its intention to fit capture facilities to its 1,100MW Maasvlakte power station in Rotterdam in conjunction with the Rotterdam Climate Initiative (RCI). EnecoGEN have proposed to use a cryogenic process to separate CO_2 from its 870MW CCGT unit in Rotterdam.

PGE has proposed to retrofit post-combustion technology to one of its units at its Belchatow heat and power plant in central Poland. Endessa have proposed to build a 500MW circulating fluidized bed (CFB) coal fired oxyfuel unit at Compostilla near Leon in Spain. Enel are undertaking a feasibility study to retrofit a 660MW coal-fired unit in Porto Tolle in Italy. ArcelorMittal have announced its intention to fit capture facilities at its Florange Steelworks in France.

A.4 Projects outside the EU

Beyond the EU there are a large number of proposed CCS demonstration projects, and some of the key ones are summarised below.

A.4.1 Australia

Australia has an abundance of accessible coal and it is the fuel for in the order of 80% of Australia's power generation. This has lead to a significant interest in developing CCS technologies, and there have been a number of research studies and proposed pilot and demonstration projects. In addition to the Otway storage project, CO2CRC, International Power, Loy Yang Power, and CSIRO are conducting a post-combustion capture pilot project in the Latrobe Valley Victoria while CO2CRC and HRL are studying capturing carbon from an integrated drying gasification combined cycle (IDGCC) in Melbourne Victoria. In addition, CS Energy is retrofitting oxyfuel technology to a 30MW unit at its Callide Power Station in central Queensland which is scheduled to being operating in 2010. They are examining storage sites and expect to begin injecting the CO_2 into geological structures in 2011.

The Queensland Government is seeking to develop a commercial scale 530MW IGCC with carbon capture by 2015 through its ZeroGen project. It is envisaged that the carbon will be transported approximately 220 kilometres for injection into reservoirs in the Northern Denison Trough in Central Queensland.

In mid 2009 the Australian and Western Australian Governments jointly agreed to accept long term liability from the storage of CO_2 in geological formations under Barrow Island as part of the Gorgon LNG project. This project seeks to inject CO_2 separated during the production of natural gas.

A.4.2 Canada

Canada has a strong interest in CCS, due to its heavy use of coal in some provinces, increasing greenhouse gas emissions, management of emissions from its energy-intensive tar sands projects and interest in using CO_2 for enhanced oil recovery.

The Bow City project involves building two 500MW supercritical coal-fired units 180 km southeast of Calgary, Alberta, which will involve fitting carbon capture facilities. This project is scheduled to be operational in 2014 and the captured CO_2 is expected to be used to enhance oil recover.

TransCanada Energy have submitted a description of its 300MW Belle Plaine IGCC project. The fuel would be petcoke and the captured CO_2 would be used to enhance oil recovery. The FEED is scheduled for 2009 and the project is expected to be operational in 2013.

SaskPower has proposed a 100MW post-combustion unit at its Boundary Dam Power Station in Estevan, Saskatchewan. It is expected to capture approximately 1Mt CO_2 per year from 2015 which will be used to enhance oil recover.

TransAlta announced that it had started the FEED for its Pioneer CCS project in 2008, which will retrofit Alstom's chilled ammonia post-combustion capture process to an existing coal plants west of Edmonton. Construction is planned to begin in 2010 with operation commencing by late 2012. TransAlta are exploring options for storing the expected 1Mt CO_2 captured per year in the Wabamum area in Alberta.

In mid 2009 the Alberta Government announced that it had completed its evaluation of CCS projects that had applied for funding and was pursing letters of intent with proponents of the three following projects:

- the Alberta Carbon Trunk Line, which is a 240 km pipeline that Enhance Energy is building to transport CO_2 from industrial sources to oil fields for EOR;
- a 270MW IGCC that EPCOR has proposed to build next to its Genesee power plant, west of Edmonton, which his currently at the FEED stage and is expected to be operational in 2015; and
- capturing carbon from Shell's Scotford Upgrader near Fort Saskatchewan Alberta, which processes bitumen from the Athabasca oil sands into synthetic crude oil, and perminantley storing it 2,000 to 2,500 metres below the surface in the Basal Cambrian Sands.

A.4.3 China

In recent years China has significantly increased its use of coal and has become a leading emitter of greenhouse gases. China is developing a strong interest in CCS so it can moderate its CO_2 emissions while using coal. One significant CCS project in process is GreenGen, in which the China Huaneng Group plans to build a IGCC plant in three phases:

- Phase 1 involves building a 250MW IGCC by 2010 that will involve a 2MW pilot to test hydrogen production and CCS;
- Phase 2 increases the IGCC to 400MW by 2016, from which a quarter of the syngas will be processed into hydrogen and CO_2, which should enable the capture of approximately 1Mt CO_2 per year; and

- Phase 3 increases the IGCC to 650MW by 2020 where all of the syngas will be processed into hydrogen and CO_2.

A.4.4 United States

A significant number of CCS projects have been proposed, particularly for IGCC plants, which are summarised below. In August 2004 AEP announced its intentions to construct two 629MW IGCC plants, one in Ohio and the other in West Virginia – progress on these plants has been limited due because of a lack of support from regulators and legislators. In August 2009 AEP announced plans for post-combustion retro-fit to 235MW of its 1.3GW Mountaineer coal-fired plant in West Virginia, scheduled for deployment in 2015.

The FutureGen project involves building a 275MW IGCC in Illinois and storing the captured CO_2 in a geological structure. The project was first considered in 2005, and during 2008 it was decided to restructure the project. In 2009 the Department of Energy announced that it would proceed with the project and make $1 billion available. The project is scheduled to begin operations in 2013.

In 2007 BP and Rio Tinto formed a consortium called Hydrogen Energy, which sought to explore options for exploiting carbon capture and storage technologies. In 2008 Hydrogen Energy submitted an application to the California Energy Commission to build a 390MW IGCC in Carson, Kern County. The project would capture approximately 2Mt CO_2 per year, which would be stored in underground geological formations and used for EOR. The project is expected to use petcoke and coal. The project was put on hold, but is expected to resume following funding from the Department of Energy of $308 million, and is scheduled to begin operation in 2015.

In 2007 Wallula Energy Resource Center proposed to build a 600 to 700MW IGCC, coupled with carbon capture in the south east of the state of Washington. The plant is scheduled to be commissioned in 2014, and the captured CO_2 is expected to be injected into basalt formations more than 2,000 metres under the surface.

In 2008 Cash Creek Generation announced that it had commissioned Burns & McDonnell to perform EPC engineering design services and entered an MOU with Kiewit Energy to provide the engineering, procurement and construction services for a 720MW IGCC project with carbon capture in Kentucky. The project is expected to be completed in 2012 and that the CO_2 will be used to enhance oil recovery.

In 2009 SCS Energy announced plans to build a 500MW PurGen IGCC plant in New Jersey. The projects is scheduled to be operational in 2014, and is expected to capture up to 10Mt CO_2 per year, which will be transported for storage in an offshore site in the Atlantic Ocean.

Basin Electric Power Cooperative has proposed a post-combustion carbon capture project of a 120MW slipstream at its lignite-fired 450MW Antelope Valley Station in North Dakota. The project will use Powerspan's ECO2® ammonia based capture technology. In mid 2009 the US Department of Energy announced it would provide $100 million to support this project.

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