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Executive Summary

Why CCS
Carbon Capture and Storage (CCS) is a technology that can capture 90% or more of the carbon dioxide (CO2) emissions produced from the use of fossil fuels in electricity generation. The captured CO2 is then transported for permanent storage in depleted oil and gas fields or deep saline formations. CCS can also be applied to industrial processes such as chemical processing and steel and cement manufacture, preventing CO2 from entering the atmosphere and contributing to climate change.

The value of CCS as an important CO2 abatement tool is already recognised by multiple authoritative organisations, including the UK Committee on Climate Change (CCC), the Intergovernmental Panel on Climate Change (IPCC) and the International Energy Agency (IEA). The IEA asserts that the cost of reducing emissions to 2005 levels by 2050 will increase by 70% if CCS is not deployed. For many large industrial emitters, CCS is seen as the only viable long term solution to mitigating the future costs of CO2 emissions.

Recent studies have shown that the levelised cost of power generation with CCS incorporated compares well with other low carbon generation technologies such as offshore wind and marine renewables as a competitive low carbon electricity option. CCS has the advantages of reliability and flexibility and is thus able to complement other fuel types in a balanced generation mix.

A study by Parsons Brinckerhoff showed that the use of CCS causes less of an increase on overall system costs (grid, interconnectors and back-up) than alternatives. The UK Committee on Climate Change quote investment costs (levelised) for CCS in the range £1-2 Bn/GW which compares well with estimated costs for other sources. Because of its lower capital costs, a reduced load factor impacts upon CCS less than nuclear, hence CCS will be useful as ‘in-fill’ to compensate for the intermittency associated with increased wind power generation.

Scotland and CCS
The IEA CCS Roadmap indicates that OECD Europe will need to deploy around 100 CCS projects by 2030, storing over 300 Mt of CO2 annually. Scotland has significant CO2 storage assets and existing infrastructure to make it a comparatively low risk option for early demonstration and deployment of Carbon Capture and Storage within both the power generation and industrial sectors. Under a “High CCS Deployment” scenario, Scotland could provide a large proportion of the storage space required for the wider UK and European Union with up to 50% of the available offshore storage space across the EU27 member states.

The economic opportunities associated with development of CCS are considerable; it is estimated that cumulative spend in Scotland on CCS demonstration projects could be more than £2 billion by 2020 and £4 billion by 2025. Around a quarter of the value of these projects is expected to go to Scottish firms and another £1 billion could be earned by Scottish firms from the global CCS market by 2025. The development of CCS has the potential to generate more than £2 billion in retained GVA and create more than 13,000 jobs in Scotland by 2025. There is also the bigger prize of export opportunities in a global market expected to be worth around £450 billion by 2050.

Enhanced Oil Recovery
There is significant opportunity for the use of captured CO2 in enhanced oil recovery (EOR) applications in North Sea fields. Industry estimates suggest the potential for additional oil recovered through CO2-EOR is approximately 3 billion barrels and that the associated storage of CO2 could be in the region of 1,000 Mt.

The presence of existing infrastructure makes CO2-EOR in the North Sea a credible proposition although there are a number of challenges which remain to be addressed including the technical challenges of EOR in deepwater conditions as well as the price of oil required to make EOR economic. Studies suggest a minimum $100 per barrel would be required.

Transport and Storage Options
This report sets out three scenarios for deployment of CCS covering the periods to 2020, 2030 and 2040. They each examine the extent of infrastructure associated...
with a “high CCS deployment” situation which includes a number of assumptions:

1. Construction of three demonstration projects in Scotland with full carbon capture retrofitted on those plants
2. Construction of additional gas-fired generation with carbon capture fitted
3. Capture plant fitted to major industrial emitters in Scotland
4. Import of captured CO₂ from major emission sources in North East England
5. Import of captured CO₂ from other member states within the EU (initially Netherlands and Germany).

The inclusion of industrial emitters around the Forth estuary along with the construction of capture plant at the proposed new Cockenzie gas station would see the development of a Forth CCS Cluster which could attract investment from power intensive industries by providing a ready route for their carbon emissions.

In order to maximise the potential storage assets in the North Sea, it is likely that shipping would play a role in the early stage of CCS roll out across the EU. The development of facilities at Peterhead port and the St Fergus gas terminal would facilitate the creation of a CO₂ hub for import and dispatch of CO₂ from emission sources outside of Scotland.

The level of capital investment required to achieve the vision of a CO₂ storage hub for Scotland and the creation of a Scottish CCS cluster is likely to be in the region of £4.5 billion by 2040. Early investment in CCS infrastructure could place Scotland at the forefront of the development of a global CO₂ storage industry of the future.

The development of a suitable network of CO₂ infrastructure could see Scotland transporting and storing in excess of 70 million tonnes of captured CO₂ annually by 2040, making an important contribution towards the decarbonisation targets for the power and industrial sectors in the European Union.

Issues and Barriers
Most industrial organisations involved with developing CCS agree that most of the technical challenges associated with integrating capture, transport and storage have been overcome or would be easily surmountable; the greatest challenge facing the development of CCS is the establishment of appropriate policy incentives that provide sufficient return on capital investment with a manageable risk profile.

Barriers to investment will need to be overcome by further demonstration and de-risking of the transport and storage options available. With a supportive approach by the UK and Scottish Government and public sector agencies, incentives could be developed which demonstrate the attractiveness of Scotland as a location for the demonstration and deployment of CCS projects. The detail of the mechanisms adopted when the proposed Electricity Market Reform (EMR) comes into effect in 2013 will influence the ability of the UK and Scotland to deliver CCS projects. The outcome of the EMR process is therefore vital to the long-term future of CCS.

With the skills, infrastructure and experience gained from 40 years of offshore oil & gas activity alongside strong governmental support, Scotland is well placed to play a leading role in the delivery of CCS going forward.

Next Steps
Scottish Enterprise recognises the need to examine in detail the technical constraints, cost implications, regulatory requirements and funding support necessary to deliver the vision of a CCS cluster in Scotland. Scottish Enterprise is committed to working with partners in government, academia and industry to promote the development of CCS infrastructure in Scotland, making the case for investment in order to realise the benefits associated with the longer term opportunity which CCS presents. This will require further development of infrastructure options including detailed assessment of costs, technical evaluation of proposed networks, identification of funding sources and potential commercial barriers as well as the evaluation of business models which can facilitate delivery.
Introduction and Vision

This report examines the infrastructure requirements for progress to be made on developing a Carbon Capture and Storage (CCS) network solution linking emission points in Scotland and further afield with storage opportunities in the North Sea.

The report describes:
- Why CCS is important
- Where key emitters are located in Scotland
- A range of transport network options based on future development scenarios
- Issues and barriers that need to be considered as progress is made towards the development of a transport network for captured CO₂.

The purpose of this report is to support and stimulate further collaborative discussion about the steps towards a network solution to transporting captured CO₂ in Scotland.

Scotland and CCS
Scotland is currently taking a world leading role in the development of CCS technologies which offers significant economic opportunities:
- In Scotland - the potential to support more than 13,000 jobs in the next 10 to 15 years
- Across the UK – the potential to support more than 70,000 jobs in the next 10 to 15 years
- Export potential - an estimated 23,000 thermal generation plants around the world represent a huge market opportunity to the Scottish CCS supply chain.

There are several key factors which mean that Scotland is ideally placed to become a global leader in CCS technology:
- The North Sea offers huge capacity for the safe storage of captured CO₂ in depleted hydrocarbon reservoirs and saline aquifers
- Over 40 years supply chain experience serving the oil and gas industry in Scotland means that much of the skill set and supply chain capabilities for this new sector is already in place
- The historical development of hydrocarbon fields in the North Sea means that opportunities exist to reuse some of the existing offshore and onshore infrastructure for the transportation of CO₂ associated with CCS
- With a number of large emitters within a relatively small geographic concentration, existing suitable transport and handling facilities and ready access to some of Europe’s largest storage sites (potentially in excess of 50% of EU offshore storage capacity), Scotland is well placed to demonstrate a hub and cluster approach to CCS network development
- Scotland has world leading industrial research and academic institutions at the leading edge of CCS research and technology development
- Scottish Enterprise along with other public agencies have supported the development of the CCS sector since 2005 and are continuing to drive it forward as a priority area to help Scottish companies capitalise on the global opportunities CCS presents.

The vision for CCS in Scotland
The Thermal Generation and CCS Industry Advisory Group which includes representatives from Government, Industry and Academia provides advice on the strategic direction and supporting actions required to help Scottish industry realise its CCS ambitions and has set a number of short and long term ambitions for Scotland in relation to the development of CCS:
- To become a leader in the demonstration and deployment of CCS technology, capitalising on the advantages and strengths the nation possesses
- Ensure the experience and knowledge gained is shared for the benefit of Scottish businesses and academics
- Develop a number of CCS demonstration projects in Scotland along with their ancillary and support services
- Secure a significant share of the global CCS business.
**Why CCS is Important**

Carbon Capture and Storage (CCS) has a significant role to play in addressing the global challenge of climate change. Analysis by the International Energy Agency (IEA) suggests that the cost of reducing emissions to 2005 levels by 2050 will increase by 70% if CCS is not deployed. The IEA’s Blue Map scenario - which aims to halve global energy-related CO₂ emissions by 2050 (compared to 2005 levels) - shows that CCS could contribute a 19% reduction in emissions, and account for more than a third of emission reductions in the power generation sector.

Electricity produced by coal, oil and gas currently accounts for more than 40% of the world’s energy-related CO₂ emissions. A further 25% comes from large-scale industrial processes such as iron and steel production, cement making, natural gas processing and petroleum refining.

CO₂ emissions are a major contributing factor to:
- Global warming which is causing severe weather events
- Ocean acidification which threatens all sea life and ecosystems and ultimately the human food chain.

With world energy demand projected to grow by more than 40% over the next two decades, fossil fuels will continue to be required. However, carbon reductions are also necessary. Therefore reducing emissions is a significant challenge. Fossil fuels are currently vital for the UK’s energy supply - three quarters of the UK’s current primary energy demand is met by oil and gas – and they will remain so for decades to come. Coal and gas reserves are relatively cheap and abundant in many countries including the US, China and India. Developing effective CCS systems will allow the continued use of these fuels but without 90% of the damaging CO₂ emissions.

The Scottish Government / Scottish Enterprise CCS Roadmap (2010) shows that without CCS Scotland is likely to produce cumulatively between 300 and 700 million tonnes of CO₂ between 2010 and 2050.

Effective CCS technologies can deliver a significant reduction in the emission of CO₂ on a global scale. Nearly all developed economies will remain reliant on fossil fuel power for the foreseeable future and demand from developing countries is increasing rapidly. It is clear that limiting global CO₂ levels cannot be addressed without technologies such as CCS which has the potential to bring emissions from power plants and factories to almost zero.

CCS will allow the production of low carbon electricity while ensuring that fossil fuels remain part of a diverse power generation portfolio. It may also be the only option for reducing emissions in energy intensive industrial sectors such as cement, iron and steel production as well as petrochemicals, pulp and paper manufacture.

With the Scottish Government committed to world-leading greenhouse gas emission reduction targets, Scotland has an outstanding economic and environmental opportunity to develop a new industry
sector to tackle climate change while offering a secure, cleaner energy supply. This commitment by government will help provide regulators with certainty and investors with confidence. A clear aspiration exists for Scotland to become the European hub for offshore storage of CO₂ and decisions and targets set by government will reflect this.

The economic opportunities associated with development of CCS are considerable. For example, it is estimated the cumulative spend in Scotland on CCS demonstration projects could be more than £2 billion by 2020 and £4 billion by 2025. Around a quarter of the value of these projects, up to £1 billion is expected to go to Scottish firms and another £1 billion could be earned by Scottish firms from the global CCS market opportunities by 2025. The CCS market therefore has the potential to generate more than £2 billion in retained GVA and create more than 13,000 jobs in Scotland by 2025. There is also the bigger prize of export opportunities in a global market expected to be worth around £450 billion by midway through this century.

Recent studies have shown that the levelised cost of power generation with CCS incorporated compares well with other low carbon generation technologies such as offshore wind and marine renewables. Work carried out by Mott MacDonald for the Committee on Climate Change for example shows CCS with gas or coal to be a competitive low carbon electricity option. Industry associations point out that CCS has advantages of reliability and flexibility, and is thus able to complement other sources of electricity generation in a balanced generation mix.

Another study by Parsons Brinckerhoff shows that CCS causes much less of an increase on Overall system costs (grid, interconnectors, and back-up) than alternatives. The Committee on Climate Change quote investment costs (levelised) for CCS in the range £1-2 Bn/GW which compares favourably with costs for nuclear and offshore wind. Because of its lower capital costs, a reduced load factor impacts upon CCS less than nuclear, hence CCS can be used to complement other low carbon generation in a balanced mix.

Meeting the challenge of climate change means new approaches are required. CCS is one of these approaches and it is one where Scotland has a number of comparative advantages to help ensure that this emerging new sector materialises.

“CCS could play an important role in maintaining the diversity of the low-carbon mix in the UK, and is likely to be of key importance internationally.”

The UK Committee on Climate Change
Emission Points

Scotland’s total CO₂ emissions in 2008 were estimated to be 44 million tonnes (Mt), around 8% of the total UK emissions of an estimated 557 Mt. The majority of the large fixed sources of CO₂ are power generation plants, which produced approximately 15 Mt (34% of the Scottish total); cement manufacturing, oil refinery/petrochemical complexes and other large industrial facilities are further significant sources. The table below lists the largest fixed emission sources exceeding 0.25 Mt during the year 2008.

<table>
<thead>
<tr>
<th>Rank</th>
<th>Facility</th>
<th>CO₂ Emissions (Tonnes) in 2008</th>
<th>Total Emissions (Scotland)</th>
<th>% Total Emissions (Scotland)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Longannet Power Station</td>
<td>5,960,000</td>
<td></td>
<td>13.5</td>
</tr>
<tr>
<td>2</td>
<td>Cockenzie Power Station</td>
<td>4,430,000</td>
<td></td>
<td>10.1</td>
</tr>
<tr>
<td>3</td>
<td>Peterhead Power Station</td>
<td>3,660,000</td>
<td></td>
<td>8.3</td>
</tr>
<tr>
<td>4</td>
<td>Ineos Manufacturing Scotland</td>
<td>3,440,000</td>
<td></td>
<td>7.8</td>
</tr>
<tr>
<td>5</td>
<td>Fife Ethylene Plant</td>
<td>744,000</td>
<td></td>
<td>1.7</td>
</tr>
<tr>
<td>6</td>
<td>Grangemouth CHP Plant</td>
<td>647,000</td>
<td></td>
<td>1.5</td>
</tr>
<tr>
<td>7</td>
<td>Dunbar Cement Works</td>
<td>628,000</td>
<td></td>
<td>1.4</td>
</tr>
<tr>
<td>8</td>
<td>BP Forties Pipeline Plant</td>
<td>388,000</td>
<td></td>
<td>0.9</td>
</tr>
<tr>
<td>9</td>
<td>St Fergus Gas Terminal</td>
<td>329,000</td>
<td></td>
<td>0.7</td>
</tr>
<tr>
<td>10</td>
<td>Stevens Croft Power Station</td>
<td>301,000</td>
<td></td>
<td>0.7</td>
</tr>
<tr>
<td>11</td>
<td>Norbord Pulp and Board Plant</td>
<td>264,000</td>
<td></td>
<td>0.6</td>
</tr>
<tr>
<td>12</td>
<td>Markinch Papermill</td>
<td>260,000</td>
<td></td>
<td>0.6</td>
</tr>
<tr>
<td></td>
<td>TOTAL</td>
<td>21,051,000</td>
<td></td>
<td>47.8</td>
</tr>
</tbody>
</table>

For Scotland over a 40-year period from 2010 to 2050, total output from electricity generation alone is forecast to produce CO₂ emissions ranging from approximately 700 Mt (17.5 Mt/year) under a high CO₂-output scenario to 320 Mt (8 Mt/year) under a low CO₂-output scenario assuming no new nuclear power and no CCS.

Additional major point sources in North East England produced around 50 Mt CO₂ in 2006. Thus, if outputs from both regions are included, over the period to 2050, up to 3,000 Mt CO₂ is potentially available for capture and storage from large emission sources. This is equivalent to 75 Mt CO₂ per year under the high-case scenario. It is likely that carbon capture technology would be installed on power generation assets initially with large industrial emitters following once the technical and economic case can be demonstrated.

Future emissions may differ significantly from those of today and the development of any transport and storage infrastructure should consider the possibility of increased levels of CO₂ captured from power generation and industrial emitters of the future as well as potential new sources of CO₂ such as unconventional gas projects e.g. Underground Coal Gasification and design network routes and capacity accordingly.

Enhanced Oil Recovery

Creation of a CO₂ pipeline network would also provide the potential for captured CO₂ to be used in producing greater volumes of oil from fields in the North Sea through the application of CO₂-Enhanced Oil Recovery (EOR). CO₂-EOR is a tried and tested technology which has been deployed in the USA for thirty years. The application of EOR could provide a financial catalyst for investment in a CO₂ pipeline network if an economic value can be attached to the captured CO₂ used in the process. EOR has been extensively used on a large commercial scale by oil companies in the USA and under the right circumstances it has been shown to be a profitable business; it has already financed 4,000 miles...
of CO₂ pipeline onshore in the USA. There are a number of differences with deploying the technology in the North Sea such as the challenges of deepwater operations and the use of captured CO₂ from industrial emissions as opposed to naturally occurring CO₂ which has been the catalyst for EOR in the USA. This is likely to have some impact on the design of transmission pipelines.

Recent studies evaluating the potential for EOR in the North Sea have concluded:

- If CO₂ is not a cost to the project, CO₂-EOR could be economic in North Sea oil fields at an oil price of US $70 per barrel.
- If CO₂ is a cost to EOR projects in the £20–£40 per tonne range (i.e. the EOR operator pays for the supply of CO₂), an oil price of US $80–$110 per barrel will be required to break even.
- If a subsidy is available for the CO₂ stored then the project could be economic at an oil price significantly lower than US $70 per barrel.
- Taking risks into account, it is unlikely that CO₂-EOR will be commercially viable in North Sea fields at an oil price less than US $100 per barrel.
- The total CO₂ storage capacity of all North Sea fields to which CO₂-EOR might be applied is approximately 1,000 Mt.
- Projected additional oil recovered through CO₂-EOR in the North Sea is estimated at approximately 3 billion barrels).

In order for CO₂ emitters to realise any economic opportunities associated with development of EOR in the North Sea, the creation of a suitable network of CO₂ pipelines and supporting infrastructure is essential. With a substantial network of offshore pipeline infrastructure already in place, there are likely to be opportunities to re-use pipelines for CO₂ injection although it is generally thought that oil pipelines will be more technically challenging to convert.

2CO Energy are currently developing plans to utilise CO₂ captured from their proposed Don Valley Power Plant CCS project for Enhanced Oil Recovery within two Central North Sea fields whilst retaining an option for saline aquifer storage. The CO₂-EOR operations are anticipated to result in additional production of circa 200 MMB oil.

Another potential attraction for oil companies to utilise the captured CO₂ from CCS projects comes from the fact that they need to inject gas into oilfields anyway to maintain pressure; if they can use CO₂ instead of natural gas, then the natural gas currently being used for this purpose could be be treated as a commodity to generate revenue.

The deployment of CO₂-EOR activity in the North Sea has the potential to provide significant economic value to Scotland through the extended use of existing assets, contract opportunities for the oil & gas supply chain and increased revenue from additional oil extraction.


Schematic showing elements of CCS infrastructure and relationship with geographical structure.
Transport Storage options and scenarios

Scotland already has well developed oil & gas pipeline infrastructure which has served the sector for several decades and offers significant potential for re-use in the development of CCS. A large number of potential storage sites have already been subject to high level examination including 29 hydrocarbon fields and 10 saline aquifers with more detailed modelling completed on the Captain sandstone aquifer in the Moray Firth.

Consequently there are a number of transport and storage options for CCS deployment in Scotland. Whilst there is approximately 11,000 km of existing pipeline infrastructure in the North Sea it is likely that only a small proportion of that will be suitable for CO₂ transportation. Detailed engineering and technical feasibility studies will be required to accurately estimate the extended life expectancy of oil & gas pipelines with factors such as location, geology, water depth, diameter, length and accessibility all having an impact. The type of service the pipeline has seen will be of high importance; in general, natural gas pipelines are better suited for transportation of CO₂ than crude oil pipelines because they do not require substantial cleaning. Additionally, sour gas pipelines containing significant amounts of highly corrosive hydrogen sulphide (H₂S) will be better suited to CO₂ transportation than sweet gas pipelines.

A 2007 study for the North Sea Basin Task Force identified 28 pipelines in the UK sector of the North Sea with a capacity in the range of 10 to 50 Mt CO₂/year.

This section will set out a range of possible scenarios for the development of CCS transport infrastructure and storage assets which will allow Scotland to fully realise the benefits available from CCS through the utilisation of existing infrastructure and the comparatively large scale of suitable CO₂ storage assets within Scottish offshore locations.

The scenarios examined reflect a “high CCS deployment” situation based on the best available information from industry and government sources regarding the likely scale and timing of CCS deployment across the EU. The envisaged roll out of CCS will start with the demonstration projects which are expected to lead to the installation of full capture systems on existing and new fossil-fuel power stations followed by the inclusion of large industrial emitters.

Although it is expected that pipeline transport of CO₂ will be the most economical option, the transportation of CO₂ by ship is included as an alternative option for longer distances. Ship transport may also be appropriate for some storage locations in the relative short term if pipelines are not yet available or the storage capacity has not been proven.

Several high level statements have been made by the EU and individual member states about their commitment to the development of CCS, along with some funding allocations. However there are still no fully integrated CCS demonstration projects in operation of sufficient scale to prove the commercial viability of CCS. If CCS is to move to a commercial scale and a regional cluster approach is to be pursued, then development of appropriate transport networks must be investigated and assessed. The first Scottish CCS Joint Study identified a number of potential routes for CO₂ transport depending on a number of different options with the assumption that developing transport options on a single emitter to a single store basis will be less efficient over the long term than a cluster approach.

Studies elsewhere have also concluded that networks offer economies of scale leading to lower overall transport and potentially storage costs e.g. the CO₂ Sense initiative in Yorkshire estimated cost savings of 33 per cent over the longer term by developing an integrated network compared to individual source to sink pipelines. As well as reducing costs, a coordinated regional effort to establish a network can also reduce risks for both initial and future projects by reducing the barriers of entry for subsequent projects with access to existing infrastructure as well as establishing technical expertise along with lower risk business and financing models.

The development of a significant integrated CO₂ transport network in Scotland is critical to its role in the deployment of CCS.
transport network in Scotland will require the upgrading and expansion of several existing facilities such as the gas terminal at St Fergus to facilitate the receipt, compression and dispatch of CO2 to offshore storage locations as well as the development of appropriate handling facilities at Peterhead port if the shipping option is to be utilised.

“CO2 transport via pipeline has been proven; the challenge for the future of transport technology is to develop long-term strategies for CO2 source clusters and CO2 pipeline networks that optimise source-to-sink transmission of CO2. To address this challenge, governments need to initiate regional planning exercises and develop incentives for the creation of CO2 transport hubs.”

IEA CCS Roadmap 2009

This development scenario looks at the CO2 transport infrastructure requirements associated with deployment of the proposed CCS demonstration projects in Scotland. Whilst the delivery of the individual projects is dependent on numerous factors such as planning permission, funding decisions, technical and financial evaluations, the scenario depicts the infrastructure required if all three demonstration proposals are built in Scotland under a “high CCS deployment” scenario.

It is likely that the Longannet demonstration project will be the first to be developed and the transport infrastructure requirements for this project are well understood. It is anticipated that the project will capture approximately 2.2 million tonnes of CO2 at the plant which will then be transported via a new pipeline of around 17km in length to the National Grid operated Avonbridge gas compression facility. From there, the compressed gas will be transported 284km via an existing gas import pipeline to the St. Fergus gas terminal in Aberdeenshire where it will be further treated for dispatch through an existing offshore pipeline to the depleted gas field at Goldeneye within the Captain sandstone aquifer.

Given the location and quantity of emissions anticipated from the Peterhead CCS demonstration project, the requirement for new transport infrastructure is limited to a CO2 pipeline running from Peterhead Gas Station to
the St Fergus gas terminal, a distance of approximately 16km. As with the Longannet project, the developers of the Peterhead project currently envisage compressed CO₂ in dense phase being dispatched offshore via the same existing pipeline as Longannet to the Goldeneye field for injection and storage. This will provide significant useful learning for future projects in relation to the potential technical challenges associated with the mixing of CO₂ from different emission sources in a single transport pipeline and storage site.

The proposal for a CCS demonstration project at Hunterston in Ayrshire includes the construction of a 340km pipeline transporting the captured CO₂ from the plant to a depleted gas field in the Irish Sea off the coast of Morecambe. It should be noted that the delivery of the Hunterston CCS demonstration is dependent on planning approval for the construction of a full coal fired (capture ready) power station at that location. Whilst it is recognised that the current plan is for offshore dispatch of captured CO₂ to the West of Hunterston, the scenario map includes an alternative option which routes the captured CO₂ via a shorter offshore pipeline to the Finnart oil terminal on the west coast and then via a new West-East pipeline laid alongside existing oil pipeline to Grangemouth; this could potentially make use of existing wayleaves for the oil pipeline. From Grangemouth, a short tie-in to Longannet would allow the CO₂ to be transported to an offshore storage site via St Fergus using existing pipelines being developed for other CCS demonstration projects.

It is assumed that the existing onshore and offshore pipeline routes proposed for the Longannet and Peterhead demonstration projects would have sufficient capacity to also transport captured CO₂ from the Hunterston demonstration if required and that Goldeneye would have sufficient capacity to store all of the emissions for the duration of the demonstration projects. However it is likely that additional storage sites will be characterised and developed in this scenario and these could provide test cases for the licensing, monitoring and verification of CO₂ storage assets whilst showcasing the potential of the North Sea to provide storage capacity far beyond this phase of CCS deployment. It is understood that the Goldeneye field is fully connected to the Captain formation and could therefore feasibly provide an entry point to the Captain Sandstone aquifer for additional CO₂ storage capacity which is estimated to be sufficient for many decades of Scotland’s CO₂ emissions. Other hydrocarbon fields within the Captain formation and within licence blocks adjacent to Goldeneye may also be suitable for CO₂ storage; however detailed information on availability and suitability of infrastructure is required to determine when these could be incorporated into a CCS transport and storage network.

The 2020 Scenario Summary table provides an overview of the pipeline capacities, estimated flows, and investment figures for the existing and new pipeline systems. The table includes columns for Offshore and Onshore distances, capacity in Mt/yr, estimated flow in Mt/yr, and investment in £M for both existing and new pipeline systems.

<table>
<thead>
<tr>
<th>Existing Pipeline (km)</th>
<th>New Pipeline (km)</th>
<th>System Capacity (Mt/yr)</th>
<th>Estimated Flow (Mt/yr)</th>
<th>Investment (£M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Offshore</td>
<td>Offshore</td>
<td>Onshore</td>
<td>Offshore</td>
<td></td>
</tr>
<tr>
<td>284</td>
<td>100</td>
<td>111</td>
<td>55</td>
<td>10</td>
</tr>
</tbody>
</table>
2030 Scenario

This scenario assumes successful completion of the earlier demonstration projects which then moves CCS into the deployment phase. The map illustrates the potential CO₂ transport and storage network associated with power stations in Scotland operating with full carbon capture and large industrial emitters capturing CO₂ and feeding into the system, forming the beginnings of the Scottish CCS Cluster, largely concentrated around the Forth estuary.

Under this scenario, full CCS would be fitted to new stations constructed at Longannet and Peterhead along with the proposed new power stations at Hunterston and Cockenzie incorporating full CCS. The industrial facilities included in this scenario are those in Scotland currently emitting more than 0.5 MtCO₂/yr as it is assumed that carbon capture would only be economically viable for the largest emitters in the first phase of CCS implementation to industrial plants. It should be noted here that some industrial emitters envisage the incorporation of carbon capture plant to their facilities well ahead of 2030 although this will largely be driven by the price of carbon going forward. This scenario includes the development of gas receiver and compression facilities at the Cockenzie site to receive and process CO₂ from industrial emitters and feed into the wider transport network via an offshore pipeline/shipping route to Peterhead/St Fergus.

Also included under this scenario is a cluster of emitters over 1 MtCO₂/yr from the Tees Valley area of North East England which is currently promoting proposals to develop a CCS Cluster linking the largest CO₂ emitters in the region via a common transport network. It is assumed that the offshore route for the captured CO₂ would be via an offshore pipeline/shipping route directly to depleted hydrocarbon reservoirs or proven aquifer storage sites in the northern North Sea whilst retaining flexibility through the development of a CO₂ shipping route to Peterhead. It is assumed that further storage assets will have been developed by 2030 to allow for the injection of the increased quantities of captured CO₂ being sequestered and there will be a corresponding requirement for additional offshore pipeline to be utilised.
In order for the CO₂ to be handled and treated appropriately, an import facility is envisaged at Peterhead port incorporating the necessary gas compression facilities to ensure the CO₂ is in the correct phase for onward transport via pipeline to St Fergus terminal. The infrastructure requirement at Peterhead would include facilities to handle CO₂ arriving by pipeline or from ship transfer and may also need to include interim storage capacity.

<table>
<thead>
<tr>
<th>2030 Scenario Summary</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Existing Pipeline (km)</td>
<td>New Pipeline (km)</td>
</tr>
<tr>
<td>Onshore</td>
<td>Offshore</td>
</tr>
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<th>Shipping Routes</th>
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<tr>
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<td>Capacity (MTpa)</td>
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</table>
2040+ Scenario

The longer term scenario envisaged here includes the import of captured CO₂ from other parts of the European Union. In this scenario, the imported CO₂ comes from emitters in the Netherlands and Germany; these two member states are considered because of recent developments which suggest that onshore storage of CO₂ is unlikely to be permitted meaning that offshore storage locations will need to be identified and utilised for any CCS projects developed over the longer term in those countries.

Whilst it is recognised that storage capacity exists elsewhere in the southern North Sea, these are predominantly in depleted hydrocarbon fields which may not have the required storage capacity to accommodate the level of captured CO₂ envisaged by 2040 and beyond.

Plans are well developed for a CCS cluster in Rotterdam and this scenario envisages CO₂ being gathered at a hub location in Rotterdam before onward transport into the European transport and storage network, either by offshore pipeline, shipping or a combination of both. The option of shipping to Peterhead is included in this scenario although shipping directly to injection sites in the North Sea may also be an option by this time with storage facilities having been further characterised and developed to allow CO₂ injection directly from vessels.
## Scenario Options Summary

<table>
<thead>
<tr>
<th>Scenario (PHASE)</th>
<th>Emission source (Existing and potential)</th>
<th>CO₂ Volume (Mt/yr)</th>
<th>Infrastructure Requirement</th>
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<td>Cockenzie Gas Power Station¹³</td>
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<td>Netherlands</td>
<td>8.5</td>
<td>Note¹⁹</td>
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</tbody>
</table>

3. Existing offshore infrastructure shared with Longannet demonstration
4. Section 36 application submitted in June 2010, awaiting decision
5. Based on alternative onshore West-East route for captured CO₂ and injection into Goldeneye field
6. Assumes existing onshore pipeline capacity utilised for demonstration phase will be sufficient for full capture phase
7. Assumes development of multiple storage locations to provide back-up for injection activities
8. Based on alternative route from West to East, tying in to network at Cockenzie and construction of new offshore pipeline to Peterhead/St Fergus
9. Assumes pipeline feeding into network at Avonbridge Compressor Station
10. Offshore CO₂ transport via new pipeline from Cockenzie to Peterhead/St Fergus
11. Assumes tie-in to network at Cockenzie Gas Power Station
12. Section 36 application submitted in December 2019, awaiting determination
13. Gathering facility at Cockenzie taking CO₂ from industrial emitters and feeding into new offshore pipeline to Peterhead/St Fergus
14. Based on ‘Medium’ scenario as outlined in Element Energy report “Developing a CCS network in the Tees Valley Region”
15. Assumes pipeline transporting CO₂ from Teesside directly to proven storage sites in North Sea
16. Shipping route could be to Peterhead or directly to proven storage sites in North Sea
17. Assumes pipeline from Rotterdam directly to proven storage sites in North Sea as part of European CCS network
18. Shipping of CO₂ from Rotterdam to Peterhead or directly to proven storage sites in North Sea
19. Assumes use of same offshore pipeline and shipping routes utilised for captured CO₂ from Germany
Clustering
A number of responses to the DECC consultation on A framework for the development of clean coal suggested that clustering of businesses around capture demonstrations would be advantageous. Whilst the development of a robust CO₂ transport infrastructure is essential to the successful deployment of CCS in Scotland, there are advantages and disadvantages to the clustering of emitters which should be considered in taking forward infrastructure plans. These apply to the short-term development of CCS demonstration projects as well as over the longer term and the roll-out of CCS on a wider scale.

Advantages of clustering during the demonstration phase include:

• Enablement of future development through the creation of a general purpose entry specification for others
• Reduction in overall cost to those funding the demonstration projects by realising a return on the transport asset from future users
• Provides an attractor to any new industrial investment considering where to locate if they require to capture CO₂ from their activities
• Allows projects to share the cost of investment in transport and storage assets.

Disadvantages associated with clustering during the demonstration phase include:

• DECC competition rules do not allow funding for the design and construction of common oversized infrastructure
• Absence of sufficient long term financial incentives for developers to invest in oversized infrastructure due to lack of certainty over future use and return on capital
• Lack of clarity around third party access arrangements
• Lack of certainty on ownership of CO₂ in transit
• Additional expense at demonstration phase for technology as yet unproven at required scale.

Whilst the construction of a “point-to-point” transport solution addresses the needs of an individual CCS project, the question of design capacity should be examined to determine potential future sharing of infrastructure; increasing capacity of a pipeline in the initial development phase results in a much lower marginal cost than adding a parallel pipeline at a later date. Extra land use for additional pipelines adds huge costs, which is why oversizing pipelines onshore appears even more attractive than for offshore pipelines. The extra capacity could be offered for greater CCS potential from the same site, sold to emitters on the same route, or the establishment of a network solution with a spine and feeder layout. Proponents of clusters also argue that the existence of a network with spare capacity will attract additional industrial development because it will offer the lowest risk transport and storage solution for future CCS.

Over the longer term, common oversized infrastructure could assist the roll-out of full scale CCS by lowering the cost of transport and reducing the number of pipelines required; this would also have knock-on positive impacts such as reducing the amount of disruption to communities along transport routes, less environmental impact and a more streamlined consenting process. Oversizing of transport infrastructure in Scotland during the early stages of CCS roll-out would also be an enabler for future import opportunities of CO₂ from other parts of the UK and EU. The opportunity exists for the St Fergus gas terminal to act as a gathering and compression hub for captured CO₂ to condition the gas for despatching offshore via existing gas pipelines to depleted gas fields and saline aquifers.

With approximately 6,000km of operational pipelines in the North Sea servicing 62 hydrocarbon fields and more than 1,200km of pipeline in planning or under consideration, the opportunities for clusters to be developed on the back of existing and planned infrastructure, particularly around the Forth estuary and in the the North East of Scotland, are significant.
Shipping
Gas carriers are separated into three main categories by the type of gas carried: Liquid Petroleum Gas carriers (LPG); Ethylene carriers carrying ethylene and LPG; and Liquefied Natural Gas Carriers (LNG). The design and operation of CO₂ carriers will be very similar to that of Semi-Refrigerated LPG carriers.

Ship transportation of CO₂ has been taking place for nearly 20 years, although only in small parcels for industrial and alimentary purposes. The existing fleet of four vessels currently dedicated to transporting CO₂ are around 1,000 m³ each. For the larger volumes required for CCS purposes it is likely that the CO₂ will be carried at 7-9 bara and down to around –55°C. This is practically the same cargo condition as that of the significant fleet of semi-refrigerated LPG carriers currently in operation. Six such LPG/ethylene carriers of 8-10,000 m³ in the ownership of IM Skaugen of Norway are already approved for the carriage of CO₂. It is anticipated that CO₂ carriers for CCS purposes are likely to range from 10,000 m³ to ~40,000 m³, most typically in the 20-30,000 m³ range.

The fleet of semi-refrigerated carriers presently engaged in the transportation of hydrocarbon gases number more than 300, with a service record totalling more than 5,000 ship years. While CO₂ carriers will be designed to load and discharge in normal ports, they may also be equipped for discharging offshore.

The requirements for shipping of captured CO₂ as part of a CCS operation have yet to be fully determined although it is anticipated that a model similar to that employed in the shipping of LNG would be suitable e.g. storage occurs quayside and suitable shipment vessels are loaded/unloaded in batches. In order to deliver the facilities required to allow ship transfer of CO₂, significant infrastructure at ports would have to be constructed; a recent study on Teesside indicated upwards of 90,000 tonnes of quayside storage capacity would be required to enable the shipment of 10 million tonnes of CO₂ per year. Industry experts currently envisage that infrastructure requirements for CO₂ shipping would extend to two ship berth, gasification and compression pumping facilities, storage tanks and associated support facilities. Peterhead port already has a tanker jetty which could provide this type of facility although further investment and expansion would probably be required to accommodate future CO₂ shipments; port owners have expressed interest in examining opportunities for Peterhead to develop appropriate infrastructure.

It has been demonstrated that the cost per tonne of CO₂ transported by ship drops by volume transported therefore additional volumes are beneficial and create further incentive for import of captured CO₂ from the wider EU. The use of shipping to transport CO₂ could enable the development of CCS in areas without access to pipelines or storage locations e.g. Southwest England and South Wales. In order for Scotland to capitalise on the opportunity associated with import of captured CO₂ by ship, it is essential that the transport infrastructure within Scotland is developed ahead of the opportunity which is anticipated to be over the longer term. Whilst the option of offshore injection directly from CO₂ carriers is likely in the future, it is envisaged that initial projects could involve shipment via Peterhead to an onshore hub at St Fergus for further transport into a network of offshore pipelines to storage sites.
Storage
A large amount of work has been done on evaluating storage potential within the hydrocarbon fields and saline aquifers of the northern North Sea with the consistent conclusion that the storage capacity offered by these geological formations is likely to exceed the requirements of Scotland’s carbon emissions and could potentially provide a long term safe storage solution for captured CO2 from across the EU. The Europipe Study in 2010 suggested that under certain scenarios Scotland could potentially provide 50% of all the offshore storage space available across the 27 member states of the European Union.

During the demonstration phase of CCS development, it is likely that depleted hydrocarbon fields will be the predominant type of storage facility to be utilised due to the fact that large amounts of seismic data are already available for these formations, generated during the hydrocarbon exploration and extraction operations, thereby reducing the costs and risks associated with their development. This is illustrated by the selection of Goldeneye gas field for storing captured CO2 from the Longannet and Peterhead demonstration projects and the proposed use of the Hamilton Field in the East Irish Sea for the Ayrshire Power Hunterston project.

Other proposed CCS demonstration projects in the UK are considering the use of captured CO2 in EOR operations e.g. the Don Valley Power project being developed by 2CO20. Whilst technically challenging, the inclusion of EOR in the development of CCS projects has the potential to improve the economic viability of deployment; one recent academic study estimated that up to 3 billion barrels of additional oil could be realised from North Sea fields through EOR. However, it is recognised that commercial EOR investments offshore may only proceed to a significant extent once the maturity of capture technologies have been de-risked and demonstrated at scale.

Beyond demonstration projects, the storage capacity required for full capture plants and major industrial emitters will be multiplied many times. Studies to date have indicated that the capacity of a number of saline aquifers in the northern North Sea could provide sufficient storage capacity for emissions from Scotland and the wider EU for more than 100 years21.

Future Generation Scenarios
With ambitious targets for the growth in renewable energy generation, particularly from on and offshore wind over the period to 2030, coupled with the closure of existing nuclear stations, it is likely that Scotland will require the construction of additional ‘fill-in’ generation capacity to compensate for the intermittency associated with wind power. This is likely to take the form of fossil plants with full carbon capture which can provide the load flexibility necessary to balance the generation to grid.

In order for such plants to be constructed in Scotland, it will be necessary to demonstrate the availability of infrastructure capable of transporting and storing the CO2 emissions captured. The reinforcements to the electricity grid currently being planned to deal with the increased flow of renewable power from Scotland could also support the creation of new CCS plants.

The development of a substantial CO2 transport and storage network could act as an attraction to power intensive industrial activities to locate in Scotland thereby contributing to economic growth whilst supporting the government’s ambition of a low carbon economy over the next few decades. Such development would increase the quantity of CO2 captured and stored in Scotland further demonstrating the capacity to provide a CO2 transport and storage solution for carbon emissions from further afield.

20. www.2coenergy.com/don_valley_power_project.html
**Investment**

The creation of a sustainable long term CO₂ transport network capable of servicing a growing CCS sector and providing the flexibility required to accept industrial emissions will require significant capital expenditure. The table below illustrates indicative costs associated with the development of such a network to enable the maximum benefit to Scotland from the development of CCS.

The total installed cost of a pipeline is made up of a number of cost categories including Materials, Labour, Right-of-Way (ROW) costs and other miscellaneous expenses. The illustration of costs associated with these development scenarios ranges from total capital spend on pipeline infrastructure under the 2020 scenario of up to £323M, increasing to cumulative spend of £2.8BN by 2040. Development of shipping routes could require capital investment ranging from £947M under the 2030 scenario (includes Forth and Teesside clusters) up to cumulative spend of £1.7BN by 2040.

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<td></td>
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<td>Indicative OPEX²³ (£M/yr)</td>
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**Notes:**

22 Costs extrapolated from ZEP publication The Costs of CO₂ Transport (www.zeroemissionsplatform.eu/downloads/813.html)

23 Annual operational cost of pipelines is assumed to be equivalent to 1% of capital cost

24 Assumed refurbishment cost of £400,000 per km

25 Assumed refurbishment cost of £500,000 per km

26 Assumed capital cost of £35,000/km/inch diameter

27 Assumed capital cost of £50,000/km/inch diameter

28 Includes costs for alternative West-East route for Hunterston demonstration

**Carbon Capture and Storage CO₂ Transport Options for Scotland**

Detailed construction cost data for actual CO₂ pipelines are sparse and largely confidential; as a result it is not possible to develop an accurate cost model without a detailed specification of the actual pipeline planned and the proposed route.
CCS systems will not produce constant flows of CO₂ as the volume of emissions will be synchronous with the operational loads of the relevant power stations. It is envisaged therefore that a network of storage hubs will need to be developed over the longer term in order to reduce costs and risks to CCS operations; capital costs for these facilities is not included in the above figures. Opportunities for line pack in CCS pipelines are thought to be limited and any intermediate storage requirements are likely to be addressed through the use of depleted hydrocarbon reservoirs which would act more as a buffer to absorb intermittent peaks in flow.

The case for investment in such a pipeline network would have to take account of multiple factors such as the cost of capture, price of carbon, additional oil production (in the case of EOR), the price of oil, public acceptance and environmental impact. It is intended that the next phase of this study will examine these issues in greater detail with input from industry and academia.
Issues and Barriers

Introduction
In order for Scotland to capitalise on the huge opportunity presented by the prospect of CCS being developed as envisaged in this study by 2030, a number of issues will need to be addressed. These include investment in infrastructure, certainty over storage asset suitability and availability, technology development and public awareness and acceptance. Failure to address these issues creates a risk that investment in the necessary CCS infrastructure will not proceed quickly enough to enable large scale roll out of CCS in the period between 2020 and 2030.

There are numerous factors which will influence CCS deployment, including:

- Weak economic or regulatory incentives for power or industrial emitting sources to justify the higher capital and operating costs associated with CCS operation.
- An unstable regulatory environment and the technological development risks that accompany any technology in its demonstration phase cause uncertainty with respect to recovery of the initial investment and making a return on that investment in the medium term.
- The costs and risks involved still present a major problem. The initial investment costs needed for CCS are prohibitively expensive in the context of financial returns which are at present too uncertain to attract private sector investors.
- The current carbon price does not provide a sufficient incentive for CCS. This is due to an economic gap between the price of CO₂ emission allowances on the carbon market and the marginal cost of abating an equivalent amount of CO₂ by means of CCS. Operators thus currently lack the incentive to invest in CCS.
- The eventual capacities, locations and timings for CCS deployment are highly uncertain. This makes planning for CCS difficult for both governments and industry.
- There has been limited operational experience in large scale CO₂ injection – consequently there are no well calibrated or fully accepted criteria for CO₂ storage capacity and suitability determination.
- The technical and economic viability of CCS at large scale remains to be demonstrated.

Current predictions suggest that the carbon price on its own will not create the incentive necessary for private capital to finance demonstration projects and launch a commercially viable CCS industry. Additional mechanisms will therefore be necessary, in the form of public funding or government incentives. The proposed Electricity Market Reform (2011) includes the option of a Contract for Difference Feed in Tariff, index-linked to fuel price, which could help support long term investment in CCS. Exact details of how the proposed mechanisms within EMR will impact on the development and deployment of CCS remain uncertain and industry scrutiny and recommendations to government will be required ahead of implementation to ensure appropriate incentive are in place. The Thermal Generation and CCS Industry Advisory Group have set up a task group to conduct a coordinated examination of the implications of the EMR for the power sector in Scotland.

The installation and deployment of CCS infrastructure is, by and large, expected to be driven by regulatory intervention and support. The UK Government is playing a lead role across EU Member States in making CCS a commercial reality through support both in terms of policy development and funding.
Compared to other substances that are routinely transported by pipeline, the issues associated with CO₂ are complex. Even small changes in pressure and temperature can lead to rapid and substantial changes in the CO₂ physical properties. Whilst this can be managed to make transportation as efficient as possible, it also presents technical challenges as it will often be undesirable to have multi-phase flows through a single system.

Pipeline design is a complex issue and a CO₂ pipeline system must be able to accommodate the full range of conditions including fast ramp-up rates and shut-downs of power stations and the closure of geological storage sites. It must accommodate varying flows, surges and variations in composition of the CO₂ fluid itself. Key issues unique to CCS are:

- Chemical and physical properties of the CO₂ including any impurities within the CO₂ stream
- Consideration of pressures, to maintain the CO₂ in the required phase throughout the network without exceeding safe levels at other points
- Legislation specific to CO₂ including UK Health and Safety requirements and international codes of practice.
- Water and CO₂ together can form carbonic acid which is detrimental to pipelines causing corrosion on the internal surfaces
- Hydrates could be formed at low temperatures which could cause blockages in equipment, valves and scaling of the pipeline.

The quality of carbon dioxide (CO₂) entering any system may have a significant impact on the storage and transportation aspects of the CCS network. Any capture process is likely to result in the capture of other contaminants which may have negative impact on CCS schemes in several ways:

- Health and safety implications
- Capture energy usage and power station efficiency
- Transportation implications, property changes and costs.

Therefore the quality of the CO₂ stream needs to be defined. For proposed networks this definition becomes the entry specification to the network to which emitters must comply in order to enter the system.

Industry views many of these challenges as surmountable with the management of them being part of the basis of design of any system and work is being carried out at the TUV SUD NEL facilities in East Kilbride to examine many of the technical issues associated with CO₂ specifications and metering.
Regulatory

Full chain CCS projects are some of the largest infrastructure projects ever considered in Scotland with some of the greatest amounts of public funding necessary. These are complex projects involving multiple interest groups and a range of overlapping regulatory regimes.

The regulatory framework for CCS is emerging well in the UK, with regulators taking a positive, enabling approach to CCS projects, whilst protecting the environment and human health. However, aspects of CCS regulation are still emerging, particularly offshore, where there is greatest uncertainty for developers, and it is likely that regulators and developers will ‘learn by doing’.

Co-operation and joint working across Government departments and regulators will be essential to ensuring effective management of CCS regulation within the demanding timescales required by the UK and EU CCS competitions.

There is general support amongst developers, regulators, NGOs and government for managing project applications collectively through a project monitoring board that can consider the collective time management of all of the permits to ensure the regulatory regime aligns to the developer timelines. It is evident that early discussions with stakeholders are key to streamlining the regulatory process in all parts of the CCS chain. A good example of regulatory cooperation and learning is the CCS Regulatory Toolkit developed by the Scottish Government which maps out the range of environmental, technical, safety and legal regulations which will require compliance during the delivery of a CCS project. This work was supported and endorsed by the Global CCS Institute and is now being used by other countries as best practice and tailored for implementation in their regulation of CCS projects e.g. Romania. The Scottish Government has also created a CCS Project Monitoring Board to assist the development and planning process for individual CCS applications.

One of the main issues is the continuing uncertainty about the legal framework for CCS - a crucial element in financial calculations and the main cause of investors’ reluctance to commit themselves to CCS. This is particularly relevant in areas such as the liability regime for long term storage of CO₂. The environmental integrity of long-term storage has to be proven and a political, regulatory and legal framework needs to be developed.

In terms of cross border CCS deployment, there is limited legal and regulatory clarity for CO₂ storage development, creating challenging business models for storage.

There are long lead times for delivery of international legal agreements and major infrastructure. International agreements often take several years to broker, and it can take more than ten years from early design to the eventual operation of a large pipeline that crosses international borders. Therefore in order to achieve a ‘Very High’ scenario for CCS deployment across the EU in 2030, a number of legal and regulatory issues will need to be resolved before 2020.
Commercial

Insufficient financial or regulatory incentives for CO₂ capture remain the biggest barriers to widespread CCS deployment in Europe. The locations and amount of demand in 2030 are highly sensitive to policy and market influences. The price of carbon needs to rise significantly to make CCS a viable business proposition. There will be a need to have transport of CO₂ regulated like natural gas. EOR agreements for injection of CO₂ into wells for increased production from marginal fields could make the economics of CCS more attractive. An increase in pipeline capacity and associated infrastructure which would accompany the use of captured CO₂ in Enhanced Oil Recovery could provide benefits to the long term CCS market – essentially using oil revenues to build out the infrastructure. However in some recent examples from the USA, the seller of the CO₂ has been responsible for building connecting pipelines to existing trunklines and it remains unclear which party will be responsible for the building of larger trunklines and hubs required for a CO₂ network.

CCS project revenues are critically dependent on prices for avoided CO₂, and additional incentives prior to commercial roll out. The Electricity Market Reform (EMR) currently being proposed by the UK Government includes the setting of a carbon price floor with a target of £30/Tonne by 2020. The tax would be levied from 2013 to ensure the combined carbon price that starts at £16/tonne would steadily rise by £2 every year. The recent DECC consultation on EMR set out a scenario to £70/tonne by 2030.

Other key proposals within the EMR include Feed-in Tariffs which would result in a top up payment to low carbon power generators, a Capacity Mechanism which would provide for additional payments through a Contract for Difference arrangement to encourage the construction of reserve plants and an Emissions Performance Standard which would discourage the construction of inefficient unabated fossil fuel plants. Successful business models will need to take into account the inter-dependent nature of CCS chain. In general the downstream components (transport and storage) will be dependent on the upstream components for revenue, while upstream components depend on the availability of the downstream components (to avoid CO₂ penalties). This implies that there must be clearly identified value, responsibilities and allocation of risk between the main project partners in the CCS chain.

Different business models will lead to different market risks for participants in the CCS chain (capture, transport, storage):

- Fully integrated project – where all the partners invest in a single entity, or joint venture, to own and run the project and receive the same return on their investment
- Take-or-Pay (fixed price) contract – where the contracts specify a fixed payment to each partner
- Market (variable price) contract – where the contracts specify a price per unit of CO₂
- 50:50 contract – where 50% of revenue is fixed and 50% variable.
Different contract structures highlight the risks borne by the partners in the CCS chain. For example, under the fully integrated contract, the transport and storage operators accept the market risk associated with the generation of electricity as well as the financial risk associated with capturing and storing CO₂. The question then becomes: are the parties willing to accept this risk?

There are many types of risk associated with the CCS chain, including operational (e.g. storage site operational difficulties), market (e.g. lower market spreads), technology, regulatory and financial risks – and the structure of the business model will dictate the impact each of these has on partners in the CCS chain.

Some of the key questions that require answers:

- Development of business model for the CCS Chain
  - Who will be the players in the transportation and storage components?
  - Will transport and storage be regulated to encourage clustering/collaboration or will it be left to the market and point to point solutions?
  - Interactions across the chain require to be developed and proven?
  - Interaction between two essential industries with differing business models
    - Power industry – low risk, low return
    - Oil / gas industry – high risk, high return

- New transport industry required to connect the capture and storage sectors
- New storage industry required to deliver the storage service that increased deployment of CCS will require
- How do public sector and industry partners stimulate development of new CO₂ capture, transport and storage developers/operators in Scotland?
- Sources of private and public funding e.g. power generators, offshore operators, investment banks, national governments, EU?

Government consider that where private sector organisations are willing to invest in additional pipeline capacity over and above the oversizing that is related to retrofit, then they should also be able to do so at marginal cost and that this could considerably add to the potential attractiveness of such an investment. However, the current position regarding incentives for oversizing investment makes this difficult in the short-term.

Other Issues

Public acceptance of CCS is likely to be an important factor in its development as a safe and effective means of reducing CO₂ emissions. A number of surveys suggest that current public perception of CCS is uncertain and unfavourable when compared with other technologies that could help in reducing emissions.

Given the potentially crucial role for CCS in a low carbon future, it is important to consider how best information can be communicated which will better inform the public and other key stakeholders about CCS by providing unbiased factual and concise information on the role of CCS in reducing emissions. The recent study on progressing Scotland’s CO₂ storage opportunities examined options for stakeholder engagement at various levels from individual projects to international cooperation.
Governments will have an important role in helping to facilitate and encourage engagement and discussion between all the various stakeholders who are likely to be involved in the development of CCS. For example, information and discussions can be held with local communities where projects may be developed.

One area where this has raised particular concern is the construction of pipelines to convey CO₂ both on and offshore, the extent to which these should be sized to take larger quantities of CO₂ than the initial capture plant warrants, and the extent to which any oversizing should be publicly funded.
Summary

Scotland has the potential to be at the forefront of CCS infrastructure development and with the right commercial, economic and regulatory conditions could capitalise on this opportunity by creating one of the world’s first CCS cluster networks and developing Scottish supply chain capabilities and expertise which can be exported to other nations developing CCS in years ahead. For example, China currently has 687GW of installed coal capacity which is forecast to increase to 933GW by 2015.

Realising the opportunity will require a phased approach in the demonstration and deployment of CCS projects and associated infrastructure; it is essential that government support and incentives are available in the early phase of development to the creation of networks which can accommodate future growth in the sector, allowing multiple emitters to share the infrastructure, thereby reducing the cost and risk to projects and increasing the chances of securing the necessary development funding.

With significant storage capacity already identified across a range of offshore locations, Scotland offers one of the lowest risk options for CO2 storage in the world. The detailed information available for declining hydrocarbon fields and a number of large saline aquifers means that Scotland can provide CCS projects with multiple options further reducing the project risks associated with the transport of CO2 to a single storage site.

Whilst it is impossible to accurately predict the cost of pipelines and related infrastructure without detailed knowledge of project parameters and specified routes, an indicative range of costs can be established using industry guidelines for generic pipeline costs. These indicate that the level of capital investment in transport infrastructure required to facilitate the development of a Scottish CCS cluster and the creation of a network of CO2 storage assets in the North Sea is likely to be in the region of £4.5bn by 2040.

A number of barriers to the development of CCS have been identified and these will need to be overcome to attract the investment required.

• Large infrastructure funds generally require low risk projects to invest capital - the CCS sector in Scotland will have to present a credible low risk proposition to private sector funders to attract necessary finance. The presence of a large amount of existing infrastructure should make this achievable in the early phase of CCS demonstration; however it will be necessary to illustrate that Scotland is a comparatively low risk location to attract investment in a wider CO2 infrastructure network.

• Strong policy signals from Government – Scottish Government has demonstrated its support for CCS through their publication of the CCS Roadmap in 2010, support for the Scottish Centre for Carbon Storage, engaging with the European Commission and partner countries in supporting policy development through the Scottish European Green Energy Centre, setting up of the CCS Project Monitoring Board and identifying a need for new flexible baseload generating capacity in Scotland’s National Planning Framework 2.
• **Availability of suitably proven geological storage sites** - studies already completed in Scotland mean that the availability of information on storage sites is amongst the best anywhere and this can provide reassurances to project developers and financiers thereby reducing cost and risk profiles for CCS projects utilising the storage capacity in the North Sea.

• **Technical design of transport infrastructure** - transportation of anthropogenic CO₂ captured from power generation stations has yet to be demonstrated on a commercial scale. However, experience of developing transport networks for natural CO₂ for EOR in the USA presents a useful starting point. Scotland has the potential to utilise that experience through the presence of a number of American oil majors in the North Sea to actively pursue opportunities to develop and demonstrate technologies for the use of captured CO₂ in EOR operations alongside the proving of geological storage facilities.

• **Public acceptance of CO₂ storage** - with a number of EU states already signalling a policy position against the storage of CO₂ in onshore aquifers, Scotland has an opportunity to demonstrate that the North Sea storage assets have the capacity to accept captured CO₂ from CCS projects across the EU in a safe, cost effective manner which minimises any environmental impact.

The development of the CCS industry is an economic growth opportunity that can bring many benefits to Scotland. To maximise this opportunity there will be a need to invest in the associated transportation and storage infrastructure required to lower the risk profile for deployment of CCS in Scotland and establish a competitive position for Scotland in this global market.

With plans for three large scale CCS demonstration projects in Scotland there exists a window of opportunity for the coordinated early development of a CO₂ transport network which is sufficient in scale and flexibility to cater for a much larger volume of emissions in the future and provide early confidence for investors that Scotland is capable of delivering world leading CO₂ transport and storage solutions.

Of 13 projects remaining in the New Entrants Reserve competition (NER300) for match funding by the European Union from the sale of 300 million ETS credits, 7 projects are from the UK and of those 3 are located in Scotland. This illustrates the scale of the ambition for CCS in Scotland.

On the regulatory front, Scotland has demonstrated global leadership with the development of the CCS Regulation Toolkit which has been endorsed by the Global CCS Institute and the approach is now being adopted and adapted by other countries around the world as a model of best practice.

It is clear that early investment in oversized infrastructure for CO₂ transport will encourage the development of a CCS cluster in Scotland making the collection and transportation of captured CO₂ cheaper in the long term for power stations and industrial emitters located here. Building of appropriate infrastructure will also support the development of Enhanced Oil Recovery in the North Sea and enable the creation of a CO₂ storage industry capitalising on Scotland’s wealth of experience in the offshore oil & gas sector. Failure to invest in the necessary infrastructure could delay the wider deployment of CCS by the creation of pipeline capacity bottlenecks as well as increasing the final cost of implementation.
Scottish Enterprise will work with partners in government, academia and industry to promote the development of CCS infrastructure in Scotland, making the case for investment in order to realise the benefits associated with the longer term opportunity which CCS presents. This will require further development of infrastructure options including detailed assessment of costs; technical evaluation of proposed networks; identification of funding sources; identification for incentives for oversizing; identification of project barriers and evaluation of the business models which can facilitate delivery.
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