Carbon Capture, Utilisation and Storage

SUBSEA ENGINEERING OPPORTUNITY
International Market Insights Report Series

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Scottish Enterprise

Contents

1. Summary

This report is part of a series of reports considering the opportunities for the Scottish oil and gas (O&G) subsea supply chain in other subsea and related markets. The report is a desk review considering the international activity of each of the sectors including where there is current activity and where there is the potential for activity based on published targets and available resource and opportunity. The report also considers the particular synergies of the given sector and the subsea oil and gas supply chain. These opportunities cover where there is a direct cross over and also where there are opportunities for collaboration to provide innovative solutions.

Carbon capture, utilisation and storage (CCUS) has a direct link with the O&G supply chain, using many of the same techniques and equipment. For subsea specifically this report will concentrate on the utilisation, transportation and storage of carbon dioxide (CO_2). Here many of the techniques are the same or similar, accounting for the needs of CO_2 compared to natural gas.

As many CO_2 storage locations globally are offshore, there is a physical disconnect between the capture and the storage of the gas. For a CCUS project to work efficiently there needs to be a continuous supply from where the CO_2 is captured to where it is utilised, e.g. EOR+, or stored.

The Scottish opportunity for CCUS is therefore most likely to be linked to where Scottish products, services and expertise that exist within the standard oil and gas arena can be exported to areas that are looking at offshore storage of CO_2 co-located or linked to the capture. These opportunities are rare at present, based on global activity (see section 3.3.2 below) but existing engagement should allow opportunistic activities.

Figure 1 below, shows important development milestones for global CCS projects in 2016. Although this figure does not show the detail, it further highlights that the majority of projects are onshore activity. There is a selection of offshore projects including Sleipner Vest in Norway, and the Petrobras Santos Basin project off the Brazilian coast, more details on these are described in the following sections.

Figure 1: Development milestones in global CCS projects. Source GCCSI 2016.

2. Sector overview

Carbon Capture, Use and Storage (CCUS) is the removal of Carbon Dioxide (CO_2) from emission streams or the environment, its transportation and then subsequent use and/or storage. The CO_2, from power generation, can be removed pre-combustion, post-combustion or through oxyfuel combustion, as well as capturing from other industrial processes and directly from the environment, before it is transported by pipe or by ship to its storage location in depleted O&G fields or deep saline aquifers.[1]

As a technology, CCUS is not just about power generation emissions but also about industrial applications. Global CO_2 emissions from fuel combustion in 2014 were 32,381 Mt of CO_2[2], from industrial emissions they were 9,000 Mt of CO_2 in 2013. Although industrial emissions are dwarfed by fuel combustion, they are anticipated to grow to by 50 percent by 2050 under a '*business as usual'* scenario according to the Global CCS Institute.[3]

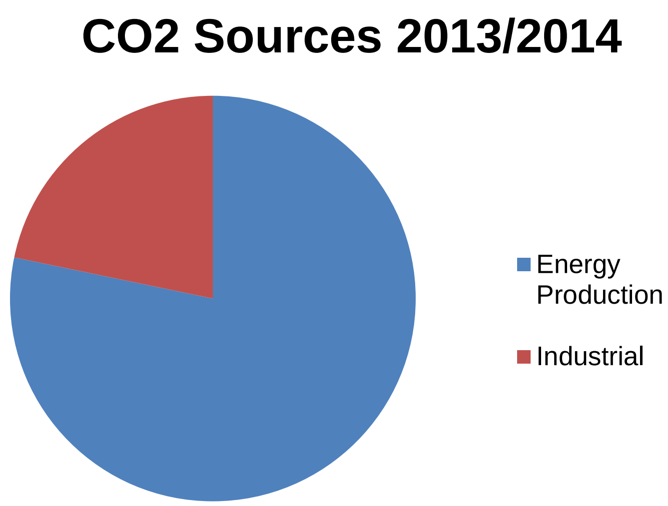

Figure 2: Chart showing the split in sources of CO_2. Source: IEA (Energy Production, 2014), GCCSI (Industrial Emissions, 2013)

As this paper is concerned with the subsea elements of the CCUS sector the focus will be on the *transportation, some uses* and *storage* aspects of CCUS rather than the capture of CO_2 as such. The utilisation aspect of CCUS is in relation to where the CO_2 is used for other processes rather than stored (although through the use it may also be stored). Examples of this include in the food and drink and chemicals industries, however, these are fairly low volume uses. With respect to subsea, a potential use of the carbon dioxide is for enhanced oil recovery (EOR), although the low oil price has impacted on the incentives for EOR there is still a strong driver for it.

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[1] Carbon Capture and Storage Association, What is CCS?, Accessed October 2017
[2] International Energy Association, Key World Energy Statistics, 2016
[3] GCCSI, The Global Status of CCS 2016, Volume 2 Projects, Policy and Markets, 2016

Enhanced Oil Recovery

CCUS can make use of existing oil and gas infrastructure in the transport and injection of CO_2 into depleted reservoirs. This process is well understood as it has been used as a means of enhancing oil recovery from existing reservoirs, although this is largely carried out onshore in the USA where supply and demand of CO_2 coexist. Such Enhanced Oil Recovery (EOR) has been done with the sole intention of maximising output from existing wells. There is now discussion of a more advanced EOR, so called EOR+, whereby there would be a dual purpose of extracting more hydrocarbons and storing CO_2 underground. In current EOR practices it is estimated that approximately 40% of the CO_2 injected could be permanently sequestered in the reservoir.[4]

EOR+ would require a shift from current EOR activities where minimal CO_2 is used in the process to a place where activities based on both hydrocarbon extraction and CO_2 storage are considered equally. To facilitate this change site for EOR+ would need, according to the IEA[5]:

- additional site characterisation and risk assessment to evaluate the storage capability of a site;
- additional monitoring of vented and fugitive emissions;
- additional subsurface monitoring; and
- changes to field abandonment practices.

EOR+ adds cost and risk to standard EOR practices and is not currently (2015) being done anywhere in the world. It is worth noting that, through analysis of a hypothetical oil field, EOR+ could be more profitable than standard EOR. The additional benefit is achieved where there is a benefit to storing CO_2, such as carbon pricing and supportive policy measures.

The IEA show that globally, EOR+ offers a significant proposition, with up to 375 Bbbl of additional oil produced from suitable fields and the storage of between 60 and 240 gigatonnes of CO_2. However, this is a long-term prospect.[5]

Climate Change Policy

In a climate change policy context, the storage of emitted CO_2 will be a tool in tackling climate change. The Conference of the Parties (COP21) in Paris 2015 (196 countries) agreed to limit global warming to below 2°C above pre-industrial levels, with additional commitment to “pursue efforts to limit” warming above 1.5°C.[6] The IEA scenario for keeping global warming below 2°C (2DS) includes the need for 4,000 Mtpa CO_2 storage capacity by 2040.

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[4] Journal of Petroleum Engineering, First CO2-Enhanced-Oil-Recovery Demonstration Project in Saudi Arabia, 2017

[5] International Energy Association, Storing CO2 through Enhanced Oil Recovery, Insights Series, 2015

[6] United Nations Climate Change, The Paris Agreement, Accessed October 2017.

3. Subsea engineering needs

For Carbon Capture, Use and Storage (CCUS) there is an almost prefect overlap between existing technology in the O&G market and what is needed to fulfil this opportunity. The projects also operate within the same space and so it is more of a sidestep than full diversification into an unknown sector. There will be many similarities with the subsea supply chain including types of project management and contracting, however, key players such as Operators will likely operate these projects from separate sections of the company to the O&G operations as well as differences in terms of commercial and business models. The crossover may be even greater in CCU projects were the captured CO_2 is being used in EOR or EOR+, as this is working on current O&G projects.

Although from a technology point of view the crossover in the necessary technologies is a win, the reality is that subsea CO_2 usage and storage will mostly happen in areas that already have an established O&G subsea supply chain, although there are exceptions such as Taiwan who have deep saline aquifers, but no O&G reserves. It may be that Scottish companies are already working in these regions, as a significant section of our business is based around international activity, so our goal here will be to maximise the Scottish content in the regions where we already have the connections. In the more distant future when CCS is more established it may be that opportunities open up in non-traditional O&G markets, such as those nations that have access to deep aquifers, but not necessarily O&G reserves. These opportunities are likely to be further away as less research into geological conditions and storage capacity will have been done in these areas without natural O&G resources.

From the Company Capability Assessment there were 10 Scottish companies identified that have activities focussed on subsea CCUS. There are 100s more companies that have capabilities to work in this sector these will be detailed in the activity breakdown below.

As discussed in section 2, this paper is focused on the transportation and utilisation/storage elements of the CCUS sector. The technology requirements of these will be looked at below and have been separated into the following sections:

- Site selection and project logistics
- Transportation
- Utilisation and Storage
- Operations, Maintenance and Monitoring

3.1. Site Selection & project logistics

The storage of CO_2 must be done in appropriate rock formations - in depleted O&G fields, unmineable coal seams or deep saline aquifers. **Depleted oil and gas fields**, normally found in sedimentary basins, are a good fit for CO_2 storage as they are known to be capped to prevent leaks of the stored gas. A potential risk is where the storage medium is fractured, from the O&G activity, this could then cause potential leaks. Storage in these formations already occurs to a small degree through the use of CO_2 in EOR, where some of the utilised gas remains in the reservoir.

Unmineable coal seams potentially provide storage where the CO_2 gas replaces methane gas molecules that are attached to the coal. There are questions over the environmental benefits of this as methane is a potent greenhouse gas so releasing this to use and burn potentially negates the benefit of storing the carbon. This method is still in research and has not been tested yet.

Deep saline aquifers, like O&G fields, can be onshore or offshore, they refer to any formation that bears a saline solution. As seen in Table 1 deep saline aquifers offer the greatest capacity for storage of CO_2 and are more geographically spread than O&G bearing formations.

In each of the storage solutions a good storage reservoir is one that has a highly porous and permeable rock structure (i.e. the pores are interconnected to allow the spread of the gas) such as sandstone and is covered with an impermeable cap rock that seals the reservoir and prevents leakages.

Similarly, to O&G exploration surveys can be used to identify areas of interest. Firstly, a seismic survey is conducted to understand where the potential storage locations may be. Then multibeam sonar can be used to understand the seabed conditions. Geotechnical surveys will be used to take core samples from the seabed to be able to make decisions about foundations, construction methods, etc. Many risks that are encountered in O&G drilling will be of a concern here too, such as hidden boulders, gas pockets and salt formations. More detailed seismic surveying can be used on an area of interest in order to find out as much detail as possible about the medium that will be drilled through. The Scottish supply chain has at least 57 companies who work in the service provision, manufacture or supply or survey equipment, geosciences surveys, data acquisition, data interpretation and reservoir modelling.

As well as survey, Scotland boasts strengths in project management from the oil and gas sector, this knowledge and experience of managing subsea projects will be hugely important for CCUS. Alongside PM is the important area of HSE. Risk identification, analysis and mitigation is a strength that has been built in the Scottish subsea sector through decades of experience and learning from past events. There are 122 Scottish companies that operate in the survey, PM, HR and HSE and training sectors.

3.2. Transportation

In Figure 3 below it can be seen how CO_2 changes phase depending on temperature and pressure. Beyond the critical point of high temperature (31.1 °C) and high pressure (74 bar) CO_2 enters a supercritical state. This phase means that although the CO_2 retains some of the properties of a gas (such as viscosity and therefore its ability to fill pores), it has the density of a liquid, therefore improving transport and storage efficiency. For example, CO_2 stored at 1000m depth will have a density of 1/300th of room temperature and pressure CO_2.[7] It is therefore desirable to transport and store CO_2 in a supercritical or dense phase, any transportation mediums therefore have to be design to operate in the required temperature and pressure ranges, i.e. above 31.1°C and greater than 74 bar pressure. Typical CO_2 pipeline conditions are 85-150 bar and 13 – 44°C.[8] Impurities in the CO_2

[7] Carbon Storage Taskforce, Department of Resources, Energy and Tourism, Canberra, National Carbon Mapping and Infrastructure Plan – Australia, 2009

[8] Leung, D.Y.C., Caramanna, G., Mercedes, M., Maroto-Valer, An overview of current status of carbon dioxide capture and storage technologies, *Renewable and Sustainable Energy Reviews*, **39** (2014) pp426-443

stream which will vary depending on the source of the CO_2 and the capture technique will have an impact on the critical point, likely pushing it to higher temperatures and pressures, as well as corrosion potential and issues with injection.

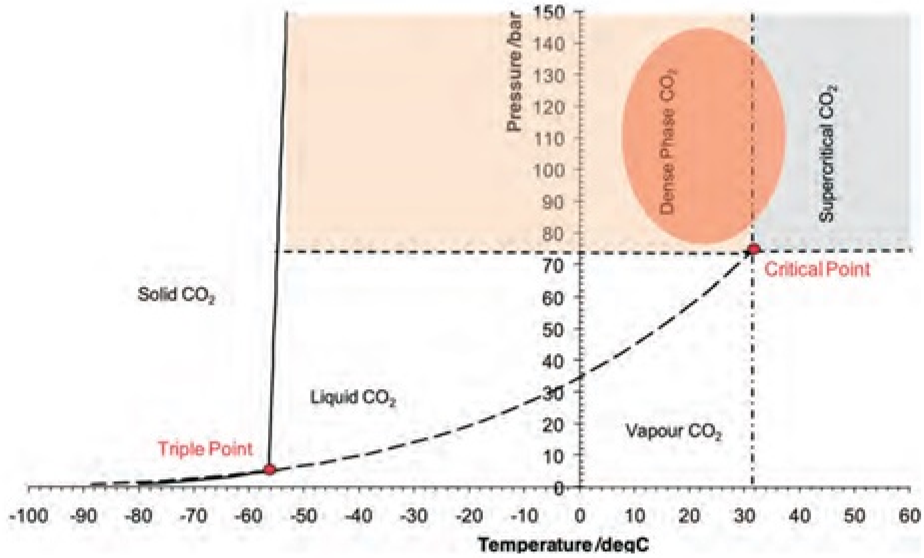

Figure 3: Phases of CO_2 depending on temperature and pressure. Source: Australian Carbon Mapping and Infrastructure Plan.

Carbon Dioxide can be transported by road or rail (for onshore applications); ship; pipeline; or used in-situ. Distance to site, volume of gas and type of source of CO_2 (how permanent is the source) will all have an impact on which transportation method is chosen for a project. Excluding **road** and **rail**, the report will focus on ship, pipelines and in-situ use.

Transport by **ship** will involve vessels, vessel logistics and interactions with the port and harbour services. Ship technology for the transportation of CO_2 will be closely linked to the technology developed for the LPG market. Cost of ship transport is estimated at US$20-30/tonne for volumes over 2 $MtCO_2$ per year and transportation distances similar to those anticipated in the North Sea.

In-situ use is where the CO_2 is stripped from the produced fluids, cleaned and dried, and then returned to the well to be used for extracting further hydrocarbons. The example of the Santos Basin project in Brazil has the CO_2 being stripped from the gas at the site on an FPSO and pumped back to the well for EOR. The FPSO is standard O&G technology, already having the capability to process the produced fluids on board, before reusing the gases.

Pipelines are cheaper and, depending on length, can carry a greater volume, but they need to be considered in the context of the length of life of the CO_2 source, e.g. a power station source needs to have a lifetime in excess of 23 years for the economic viability of the pipeline. A network where CO_2 is collected from a variety of sources and fed into a trunk pipe, could alleviate this risk. A network could also reduce pipeline costs by 25%, but all sources would need to be the same pressure, temp, water content, etc. before they are combined. Pipeline installation will be the same as for the oil and gas production sector, just using a different grade of pipe and valves. The machinery needed for e.g. trenching and boulder clearing is the same, as are the ships and techniques needed for pipe lay, such as stick lay and reel lay. CO_2 pipelines are most often made from carbon steel, made in 12 m insulated sections. The pipeline is laid with crack arresters every 350 m and block valves every 16 – 32 km.[8]

There is a potential that cost savings could be made by reusing existing pipelines, but the suitability would need to be verified. The extent of surveys, replacing valves and the reduced lifespan (as it has already done years of service) may not make this as an attractive economic option as it would first appear however. The main points to consider for re-using a pipeline for CO_2 transport is the material of the pipeline and the opportunity for re-compression.

It is likely that CO_2 pipelines design and specification will already be covered under national regulations for hydrocarbon pipelines to cover, safety considerations, design, etc. These may need to be developed or adapted to ensure they are appropriate for CO_2 but will be a strong starting point.

Scotland has at least 77 companies working in pipelines, flexibles, risers and flowlines.

The O&G sector use mono-ethylene glycol (MEG) to dry produced gas before it is compressed and exported to shore via pipeline. This is a process that could be adapted for the transportation of CO_2 to ensure that the water content of the CO_2 is low enough that corrosive carbonic acid doesn't form and cause damage to the pipeline.

3.3. Utilisation and Storage

As stated above the utilisation referred to in this report is specifically related to the use of captured CO_2 for EOR and EOR+. For EOR the same activity as currently takes place in oil and gas production will be utilised as these scenarios will already have the pipelines in place for using water and produced gas to enhance the oil field recovery. It may be that the pipelines/risers carrying the CO_2 gas may need to be of a higher grade than is currently used in the return of natural gas to the well, and therefore upgraded for CO_2 use.

For new storage applications there will be similarities with the development of an oil well in terms of technology for drilling: the drill rig; a subsea template, if being used; a blow out preventer (BoP); subsea manifolds; and control modules that link the CO_2 pipeline with the injection architecture or with risers coming from a ship.

Scottish companies with experience in drilling, manufacture, installation, etc. are all relevant here. In the Scottish supply chain there are around 282 companies that operate in this space, including specialities in manufacture and provision of templates and manifolds; drilling machinery; drilling fluids; downhole tools and instruments; wellhead equipment; well enhancement; and production enhancement.

In terms of storage, it is most efficient to store CO_2 in the supercritical phase as the increased density that is described in the previous section maximizes the storage volume. Storage reservoirs must therefore be at a suitable depth to maintain temperature and pressure. Although the reservoir conditions will have an impact on the phase as well, it is anticipated that reservoirs at a depth of

800 m or deeper will be suitable for maintaining the supercritical phase.[7]

3.4. O&M and Monitoring

There will be a requirement to ensure that any stored CO_2 stays within the formation it was injected into, there will therefore be a need to monitor the storage reservoirs to ensure there is no CO_2 leakage. It may be that new technology or techniques may need to be developed but they are likely to be closely related to current and existing IRM techniques/technology.

One example of monitoring for leaks is a project led by Edinburgh University and trialed in Canada. They have injected noble gas tracers along with the CO_2 which can then be used to monitor where the CO_2 plume disperses in the reservoir or aquifer.[9]

The effect of long term exposure to CO_2 is becoming more understood. Corrosion will occur more rapidly where water content is above 50ppm as then carbonic acid is formed which corrodes the carbon steel. CO_2 corrosion rates are >10mm/year.[8]

Pipelines will need to be monitored periodically to assess integrity. Subsea inspection, repair and maintenance (IRM) is a key strength of the Scottish subsea supply chain with approximately 223 companies operating in this area. This will involve the use of divers and remotely operated or autonomous vehicles, inspection technology, sensors and data acquisition and analysis, amongst others. Monitoring surveys are likely to include x-ray, acoustics and electro-magnetic techniques as well as inspection pigging for the transportation pipelines.

The Scottish Association of Marine Science (SAMS) has a CO_2 underwater test facility which was used to monitor the effects of a CO_2 release on the surrounding environment during a 2012 project. The infrastructure is still there and could be used again for testing of this nature.[10]

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[9] University of Edinburgh, News, Scientists apply fingerprint test for CO2 storage, 2017
[10] Taylor, P., et al, Impact and recovery of pH in marine sediments subject to a temporary carbon dioxide leak, *International Journal of Greenhouse Gas Control*, **38** (2015) pp93-101

4. Global CCUS Markets

Worldwide there are 38 large scale CCS projects which includes 15 operational projects (totalling 30 Mtpa) and a further six due to come online by the end of 2017, with a cumulative total of approximately 40 million tonnes of carbon dioxide captured per annum (Mtpa) (1 percent of what is needed for the IEAs 2DS scenario). These are located primarily in the US and Australia as well as the Middle East. These projects are a mixture of industrial and power generation applications, and are predominantly onshore.

There has been significant progress in the last decade for CCS, from less than ten operational projects in 2010, however, progress has slowed due to a contraction in funding streams worldwide. The Global CCS Institute (GCCSI) has predicted a further five large scale projects, which are currently in the 'define' stage, could be operational by 2022, that would add 4 Mtpa of storage to the global total.

In addition to the large scale, projects there are also hundreds of smaller scale pilot and demonstration projects that are planned and operating worldwide that continue to aid and improve our understanding of the technology.

GCCSI highlight activity in Australia, Brazil, Canada, China, France, Germany, Japan, the Netherlands, Norway, Saudi Arabia, South Korea, Spain, the United Arab Emirates, the United Kingdom and the United States showing a good breadth of interest across the globe, although stresses that this is not an exhaustive list.[11]

The IPCC estimates that there is between 1,678 and 10,000 GtCO_2 potential storage capacity globally. The breakdown on storage reservoirs is shown in Table 1 below.

Table 1: Estimate of Global CO¬¬2 storage capacity. Adapted from IPCC, 2005, Special Report on Carbon Dioxide Capture and Storage

Reservoir Type	Lower Estimate (GtCO_2)	Upper Estimate (GtCO_2)
Oil and Gas fields	675	900
Un-minable coal seams	3-15	200
Deep saline formations	1,000	Uncertain, but potentially 10,000

Based on the recommendations for IEAs 2DS scenario of an annual storage capacity of 4,000 Mtpa CO_2, even the IPCCs low estimate would provide in excess of 400 years of storage capacity.

4.1. The Americas

In 2016 the Petrobras operated Lula and Sapinhoá field developments, located offshore BRAZIL, reached 3 million tonnes of CO_2 injected into the producing reservoirs. The fields are located approximately 300 kilometres off the coast of Rio de Janeiro in ultra-deep waters as part of the

[11] GCCSI, 2016 Summary Report, 2016

Santos Basin pre-salt oil field. The system uses CO_2 separation and injection systems on board four floating production storage and offloading (FPSO) vessels. The CO_2 is separated on site as part of the natural gas processing and injected for EOR.[12]

The **USA** is generally supportive of CCUS, and has a lengthy track record of using CO_2 in EOR onshore. Supportive proposed new legislation would raise the value of storing CO_2 to US$30 and remove a national storage cap of 75 Mt. However, the US EPA's Clean Power Plan (CPP), which established emission guidelines for fossil-fuel fired power stations, is currently (as of 28 March 2017) under review as part of President Trump's Executive Order on Energy Independence. This is in addition to a judicial review taken by 27 states over the CPP.[13]

The **CANADIAN** Federal Government in 2015 adopted new CO_2 performance standards for coal-fired power stations. In addition to this a national 'floor price' for carbon was announced requiring all provinces and territories to have carbon pricing by 2018. The Provincial governments in Canada have been supportive of CCUS and policy enacted in Alberta and Saskatchewan has contributed to the development of recent large-scale projects. British Columbia and Nova Scotia are also proceeding with CCUS related legislation or policy[14]. Canada has experience in using CO_2 injection for EOR, but this has been entirely onshore. Canada is also home to the demonstration project – Boundary Dam, which can capture 1 Mtpa of CO_2, the carbon is captured post combustion from a coal-fired power station and is used for EOR.

MEXICO has seen a number of supportive policies including the inclusion of CCUS in the Energy Transition for Cleaner Fuels where it is fitted to energy generation and results in emissions no greater than 100kgCO_2/MWh and the publication of the *CCUS Technology Roadmap* in Mexico. The Roadmap identifies the following key stages:

- Incubation
- Public Policy
- Planning
- Pilot and demonstration scale projects, including a pilot project in the oil industry, a pilot project in the power generation sector, and a demonstration scale project
- Commercial scale project.[3]

Mexico is championing the development of research into CCUS through international collaboration, and are in the process of developing a multi-disciplinary research centre for CCUS in order to facilitate theses collaborations. They have also developed higher education courses to develop skills in the CCUS field.[15]

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[12] GCCSI, Projects Database, Petrobras Santos Basin Pre-Salt Oil Field CCS, 2017
[13] Federal Register, Review of the Clean Power Plan, 2017
[14] Natural Resources Canada, Carbon Capture & Storage, accessed October 2017
[15] Burton, E., Mateer, N., Mota, J. and Ascanio, G., CCUS Capacity Building and Technology Adoption in Mexico, Materials for Energy, Efficiency and Sustainability: TechConnect Briefs 2017, p285-288

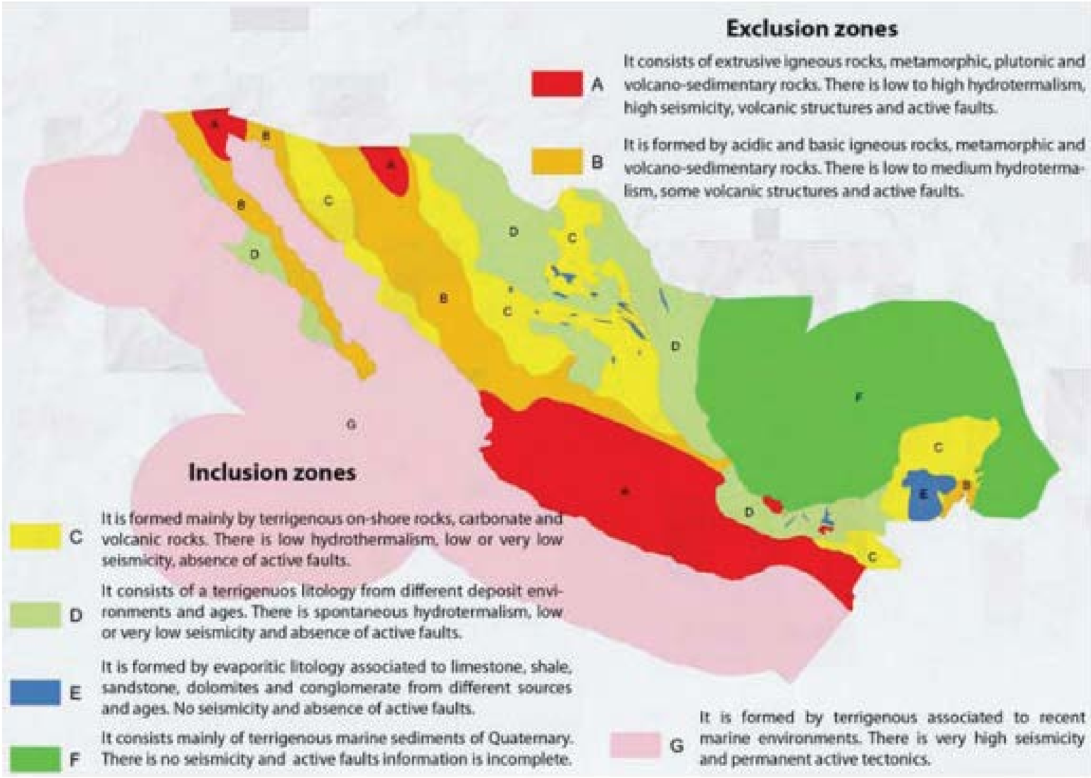

Figure 4: Map showing the storage assessment of Mexico's eleven geologic provinces. Source: CCUS Technology Roadmap in Mexico

4.2. Europe, Middle East and Africa

The only European CCS projects are in **NORWAY** where CO_2 separated from the natural gas produced from the Sleipner Vest (since 1996) and Gudrun (since 2014) fields is injected offshore into the Utsira formation. Almost 1 Mtpa of CO_2 can be stored annually. Constant monitoring, particularly using 4d seismic, has shown that the CO_2 stays in place in the formation.[16] A second project is in Snøhvit, where CO_2 from a LNG facility on the island of Melkøya, designed to capture 0.7 Mtpa, is piped to an offshore reservoir which has stored in excess of 4 $MtCO_2$ since 2008.[17]

The European Union is supportive of CCS as a means to meet climate change targets. Within Europe the greatest storage potential is found in the North Sea with the UK and Norway having the largest opportunities. In a policy context, the European Commission has built upon initiatives such as the EU Emission Trading Scheme (ETS) and Strategic Energy Technology (SET) Plan, but reform is required to make the EU ETS a more effective mechanism.

The Norwegians also operate a test centre at Mongstad which opened in 2012. Technologies that have tested in Mongstad include products from Aker, Alstom, Shell Cansolv, Carbon Clean Solutions

[16] Statoil, The Sleipner CCS experience, 2014
[17] Global CCS Institute, Projects database, Snøhvit CO_2 Storage, 2017

and ION Engineering.[18] A Norwegian strategy for CCS was published in October 2014 consisting of three pillars: research & demonstration; testing of technology and broad scale utilisation of CCS, alongside a commitment to establish at least one full-scale CCS demonstration facility by 2020.[3] The 2018 budget announcement in Norway has however, reduced the funding available to the full scale project demonstration to NOK20m (€2.14m) from the 2017 governmental financial input of NOK360m (€38.5m).[19]

In the UK, CCS received a significant blow when the Government withdrew its £1bn CCS Competition in 2015. However, the Clean Growth Strategy published in 2017 renews interest in the technology, stating a key policy related to the reduction of carbon emissions is to *Demonstrate international leadership in carbon capture usage and storage (CCUS), by collaborating with our global partners and investing up to £100 million in leading edge CCUS and industrial innovation to drive down costs*.[20]

Early stage projects in the UK include the Acorn project, which aims to demonstrate a lowest cost full-chain CCS project. The project utilizes legacy infrastructure from the sweetening plant at St Fergus, along with existing pipelines tot eh offshore storage field. CO_2 will be captured from industrial processes and capture partners are planned to increase over the lifetime of the project. The project is part funded by the European Commission and has support from the Scottish Government and offshore injection is due to start in 2021/22.[21]

The NETHERLANDS have had a long term interest in CCS, including the Rotterdam Capture and Storage Demonstration Project (ROAD) which planned to use the Q16-Maas field for initial storage, 2,800 m under the North Sea seabed, with an estimated storage capacity of 2-4 $GtCO_2$.[3] However, in mid-2017 the major partners Uniper and Engie pulled out from the project, thereby cancelling it.[22] The Dutch government however still see a future in CCS and in October 2017 published coalition plans relating to emission reductions. The plan states that CCS will deliver at least 20 million tonnes in CO_2 emission reduction each year by 2030. This statement is Europe's most ambitious CCS plan to date. The overall carbon reduction plan, including other low carbon technologies, has an annual budget of €4bn.[23]

The EU is supporting CCS development through the Accelerating CCS Technology (ACT) programme[24]. The programme is a Norwegian-led Horizon 2020 "ERA-Net" where member states provide funding which is topped up by a contribution from the EU. The first call has €28.8m funding from partner member states and a further €12.2m from the European Commission, totalling €41m for this first call. The first call for proposals was published in 2016 and received 38 applications, of which eight projects were offered funding. The eight projects include all elements of the CCUS system: legal and social

[18] House of Commons Energy and Climate Change Committee, Future of carbon capture and storage in the UK, 2016
[19] Bellona Europa, Norway jeopardizes CO2 capture and storage while the Netherlands embraces it, 2017
[20] Department for Business, Energy and Industrial Strategy, Clean Growth Strategy: executive summary, 2017
[21] Pale Blu Dot, The Acorn Project website, accessed February 2018.
[22] Port of Rotterdam, ROAD project to be cancelled, CCS to continue, 2017
[23] Bellona Europa, New Dutch government puts CO2 capture and storage at forefront in climate plan, 2017
[24] ACT - Accelerating CCS Technologies, Project website, Accessed November 2017

sciences as well as studies covering entire port areas and at the smaller scale 3D printed solid adsorbents of CO_2[25]. One of these projects is the UK's Acorn project, which kicked off its feasibility study in September 2017.[26] A second call is due to be published in June 2018, details of which will be available early in 2018.

In the **MIDDLE EAST**, large-scale projects, including the Emirates Steel Industries CCS project, are in operation and significant research and development activities are underway. This is onshore activity however.

SOUTH AFRICA has a pilot project, the Pilot CO_2 Storage Project (PCSP), which is looking to inject, store and monitor between 10-50 Mt of CO_2 in a deep saline aquifer in the onshore Zululand Basin. Feasibility studies began in 2009 and in 2016 they worked to characterise a prospective storage site with seismic analysis and further explorative drilling.[3]

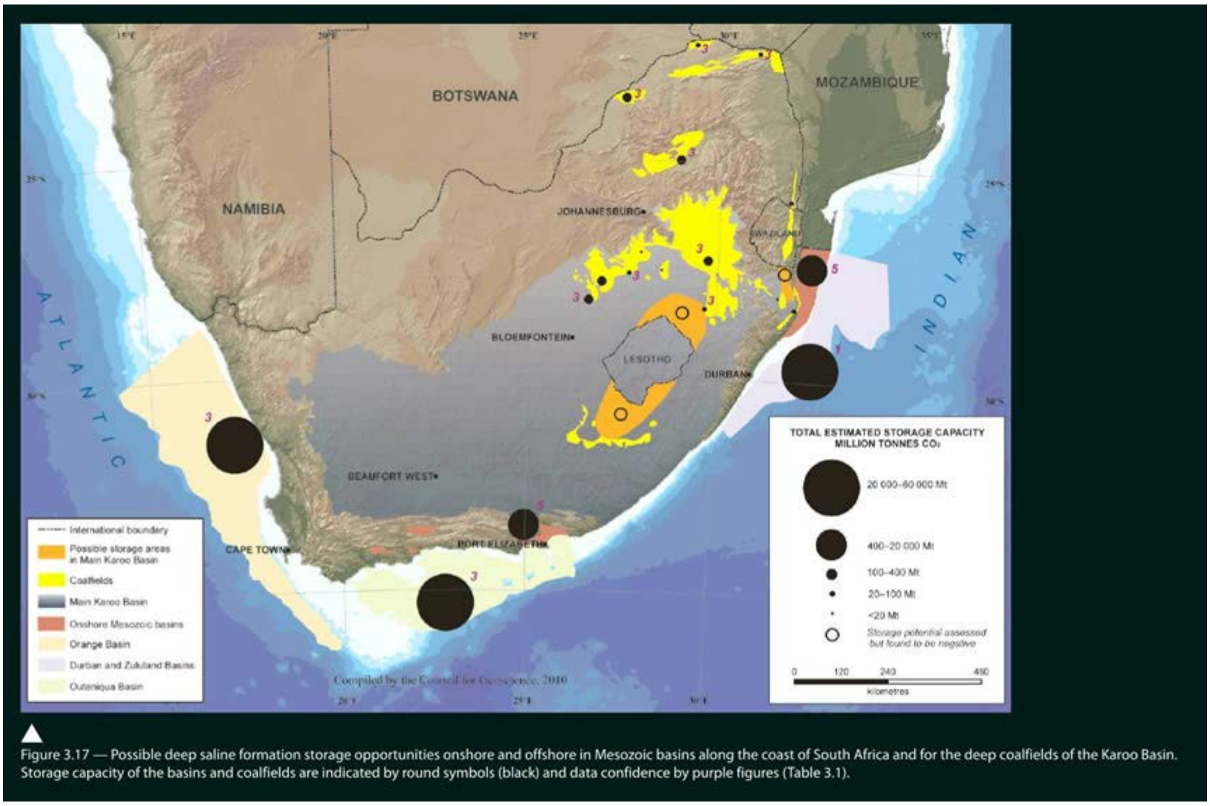

Figure 3.17 — Possible deep saline formation storage opportunities onshore and offshore in Mesozoic basins along the coast of South Africa and for the deep coalfields of the Karoo Basin. Storage capacity of the basins and coalfields are indicated by round symbols (black) and data confidence by purple figures (Table 3.1).

Figure 5: Possible deep saline formations suitable for storage on and off the South African coastline. The black dots represent the estimated storage capacity. Source: SACCCS Atlas

In 2010 the South African Council for Geosciences published an Atlas outlining the opportunity for CO_2 storage. The Atlas estimated a total storage capacity of 150 $GtCO_2$ found mainly in the Outeniqua (48 $GtCO_2$), Orange (56 $GtCO_2$) and Durban/Zululand (42 $GtCO_2$) Basins, showing that 98% of the storage capacity is offshore in deep saline aquifers. These estimated capacities however do not take into consideration the technical aspects such as depth and distance from CO_2 source.[27]

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[25] Accelerating CCS Technologies, Eight transnational projects funded with € 38 million to accelerate CCS technologies in Europe, 2017
[26] Acorn, ACT ERA-Net, Scottish CCS project gets under way, 2017
[27] Atlas on the Geological Storage of Carbon Dioxide in South Africa, Council for Geosciences, 2010

4.3. Asia Pacific

The Federal and State governments in **AUSTRALIA** are supportive of CCUS projects through funding and development of necessary legislation. However, a change in Federal legislation removing the carbon pricing and prospects of an emissions trading scheme in 2014 have had an impact on the sector.[28] The Australian governments have provided funding for four multi-user infrastructure projects. From these projects of particular interest is the CarbonNet project which looks at offshore storage of CO2 collected from various sources within the Latrobe Valley, then transported by a shared pipeline to an offshore storage site in Gippsland. The project is aiming to be able to store 5 Gtpa of CO_2. The project has completed a feasibility study and is currently in the process of securing approvals for a marine seismic survey to be completed in 2018 and for drilling an appraisal well for retrieving rock samples in 2018-19 to investigate the properties of the rock that will form the 'rock cap'. [29]

Australia has a huge potential for CO_2 storage and the particularly relevant basins are highlighted in Figure 6 below. A 2009 report on National Carbon Mapping estimated that there was 16.5 $GtCO_2$ storage available in O&G reservoirs, of which 15.6 $GtCO_2$ is located offshore, and a further 33 – 226 $GtCO_2$ available in aquifers. The range of estimate comes from the presumed efficiency of storage of the CO_2 within the aquifer, ranging from 0.5% for the lower estimate to 4% for the higher estimate. These figures are given with 90% confidence.[30]

In 2016, the Australian Government announced funding of around AUD$23.7 million (£13.6mn) for projects and organisations involved in CCUS research and development. The seven 50 per cent funded projects include:

- Carbon Transport and Storage Company/Glencore – CCS Demonstration Project in the Surat Basin of Queensland
- Shell Australia – subsurface assessment of the Petrel Sub-Basin in the Northern Territory
- Peter Cook Centre/University of Melbourne – subsurface multi-physics simulation software
- CSIRO – injection and measuring activities in the Lesueur Formation in Western Australia, and extension of IHI's post combustion capture pilot plant at AGL's Loy Yang power station
- Energy Pipelines CRC – testing of CO_2 pipeline safety and efficiency
- University of Queensland – geotechnical and techno-economic study of deep aquifer dynamics.[31]

[28] Department of Industry, Innovation and Science, CCS Western Australian South West Hub Project Review Report, 2015
[29] Victoria State Government, Earth Resources, The CarbonNet Project, Accessed October 2017
[30] National Carbon Mapping and Infrastructure Plan – Australia, Carbon Storage Taskforce, 2009
[31] GCCSI, Australian Government funds seven projects under its CCS Research Development and Demonstration Fund, 2016

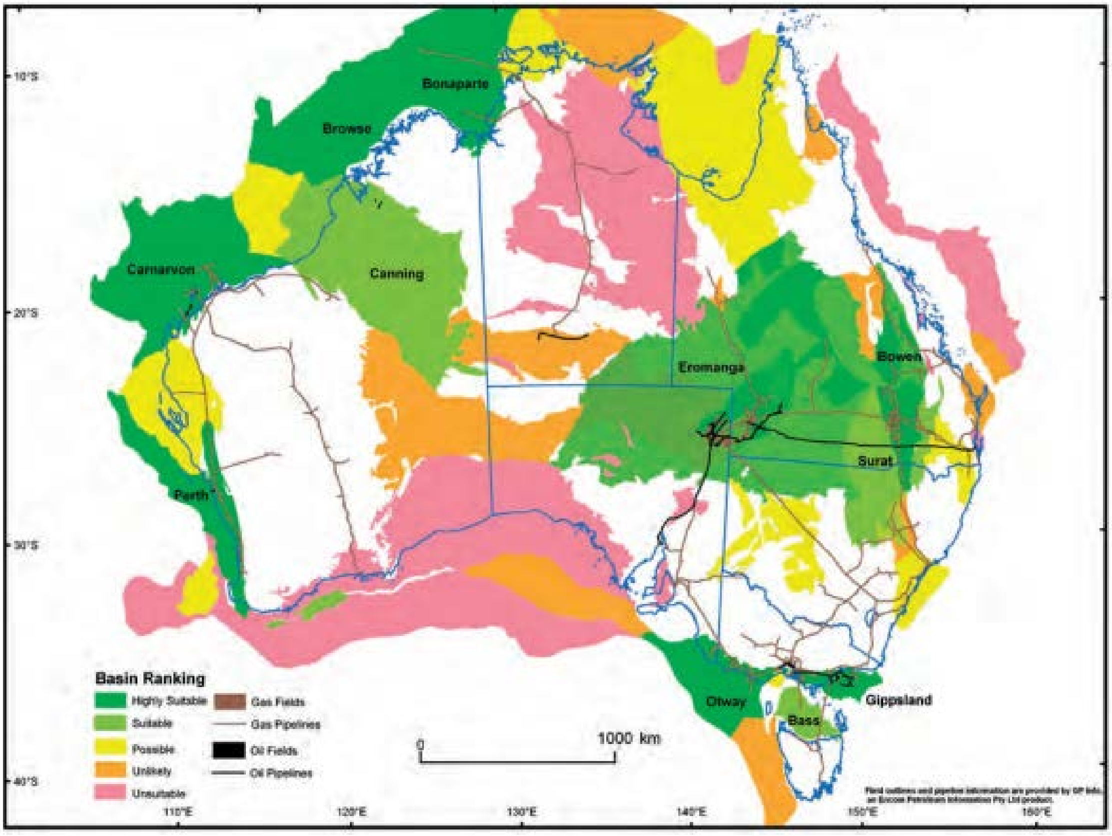

Figure 6: Australia's basins ranked for suitability for CO2 storage potential. Source: Carbon Storage Taskforce

The Australian government has also announced that CCS projects will be eligible to bid into Clean Energy Finance Corporation (CEFC) financing.[32]

In **JAPAN** the Government, through the Ministry of Economy, Trade and Industry (METI) and the Ministry of the Environment (MOE) and in partnership with leading industrial companies, have a strategic approach to CCS. Figure 7 below shows the structure of the Japan CCS Co. Ltd. and the strategic approach of the Government. The program includes investigating potential storage sites; the economic feasibility and the necessary legislative; and policy structures required for long term storage of CO_2.

The Japan CCS Company is undertaking a project called the 'Investigation of Potential Sites for CO_2 storage' in the financial year 2017. The project is acquiring geophysical data and analysing geological structures. The project furthers work carried out in 2013 by METI and MOE which suggested candidate survey sites for CO_2 storage including the use of Shuttle Ships for the transportation phase. The aim is to select prospective sites for CO_2 storage by 2020.

An additional project is the 'Tomokomai CCS Demonstration Project' which has been contracted and injection started in April 2016 into the nearshore storage sites through a directionally (horizontally)-

[32] APPEA, Gas industry welcomes carbon capture and storage support, 2017

drilled well from shore. The project plans to store at least 100 Mtpa of CO_2 and will provide additional information on the development of CCS and the application of CCS to industrial processes such as Hydrogen production.[3,33]

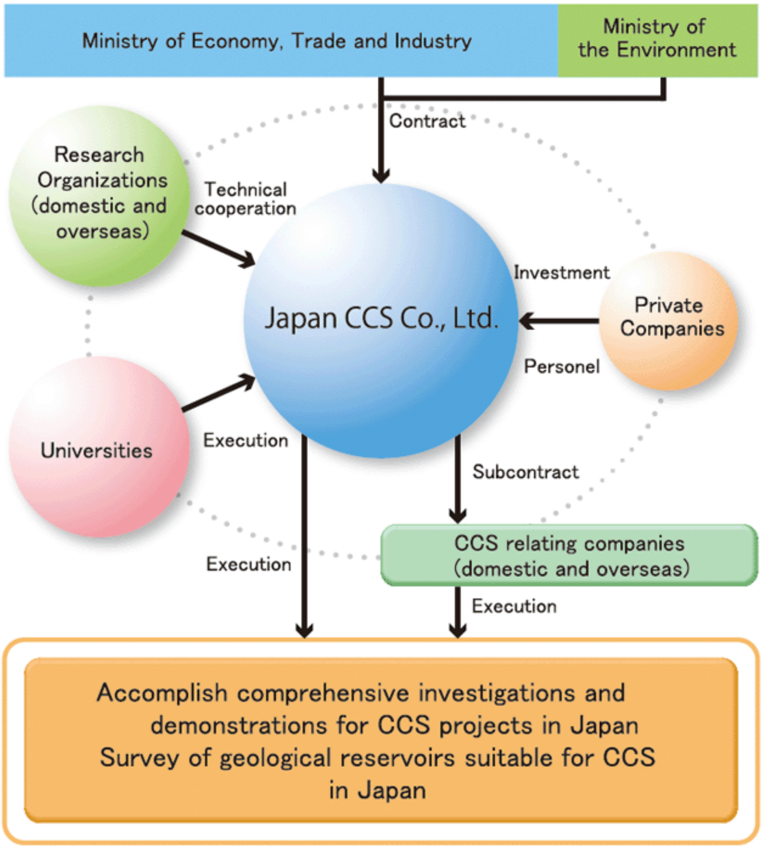

Figure 7: Structure of CCS activity in Japan. Source Japan CCS Co.

CHINA has a track record in CCUS, including 9 pilot projects developed since 2005. The Asian Development Bank published a roadmap for CCS in China in 2015 which recommends a staged approach for development. Initial activities should be targeted at low cost carbon capture from coal and chemical plants which, with parallel intensive R&D could also help bring down costs, this method, proposed until 2025, would hope to see cost competitive CCS by 2030. [34]

In April 2016, the National Development and Reform Commission (NDRC) and the National Energy Administration (NEA) published a high-level document, 'The Energy Technology Revolution Innovation Action Plan (2016-2030)', that identifies 15 innovation missions including nuclear energy, high-efficiency coal utilisation, solar, wind and *CCUS*. An accompanying document, the 'Energy Technology Revolution Key Innovation Action Roadmap' presents specific innovation goals and operational measures for the innovation missions. The innovation targets include:

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[33] Japanese CCS Co. Ltd, Investigation of Potential CO_2 Storage Sites, 2017
[34] Asian Development Bank, Roadmap for Carbon Capture and Storage Demonstration and Deployment in the People's Republic of China, 2015

- By 2020, construction of demonstration projects in a range of relevant applications, such as oil, chemicals, power, mineral and bioengineering, as well as a large-scale full chain demonstration project.
- By 2030, construction of demonstration projects based on IGCC, industrial CCUS hubs and commercial CCUS for coal-fired power generators.
- By 2050, mature commercial development of CCUS across industrial and power applications, including mitigation cost reductions of at least 60 per cent compared to 2015.[3]

The focus of the Chinese activity seems to be largely on the carbon capture aspect of CCUS, although EOR, both for recovery of oil and water, is high on the agenda as well. However, as their activities are currently focused onshore and related to capture this report will not go into any more detail on China.

There is also significant activity on CCS in **TAIWAN**, where the government has continued to fund R&D projects in this area. The Taiwanese are particularly interested in the calcium looping capture technique and have the largest pilot plant of this kind run by the Industrial Technology Research Institute and the Taiwan Cement Corporation. Taiwan Power Corporation is seeking to test CO2 injection and monitoring technologies.[3] Current research estimates a CO_2 storage capacity of 113.5 $GtCO_2$ offshore (with a further 2.8 $GtCO_2$ onshore) [35]

As Taiwan does not have their own oil and gas reserves the possibility of using depleted O&G reservoirs is not available. They do have deep saline aquifers and although these saline aquifers exist on and offshore, the offshore sites have less potential barriers, such as public opinion, and so are therefore the preferred option for CO_2 storage.[36]

Figure 8: Figure showing the distribution of sedimentary basins at the mid-Taiwan strait. Source: Taiwan Power Company

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[35] ZEROCO2.NO, Taiwan accessed November 2017

[36] Chiao, C-H., Chen, J-L., Lan, C-R., Chen, S. and Hsu, H-W., Development of Carbon Dioxide Capture and Storage Technology - Taiwan Power Company Perspective, Sustain. Environ. Res., **21**(1), 2011, pp1-8

Appendix: List of Acronyms

2DS	The IEA Scenario for keeping global warming below 2°C
ACT	Accelerating Carbon Capture and Storage Technology (EU Programme)
Bbbl	Billion barrels
BoP	Blowout preventer
CCS	Carbon Capture and Storage
CCUS	Carbon Capture, Utilisation and Storage
CO_2	Carbon Dioxide
COP21	The 21st Conference of the Parties
CPP	Clean Power Plan (USA)
EOR	Enhanced Oil Recovery
EOR+	Enhanced Oil Recovery Plus (EOR plus additional storage of CO_2)
ERA-Net	European Research Area Network
EU ETS	European Union Emissions Trading Scheme
FPSO	Floating production, storage and offloading
GCCSI	Global Carbon Capture and Storage Institute
$GtCO_2$	Gigatonne of carbon dioxide (equivalent to 1000 Megatonnes)
IEA	International Energy Agency
IGCC	Integrated gasification and combined cycle (a type of power plant)
IPCC	International Panel on Climate Change
$kgCO_2/MWh$	kilograms of carbon dioxide per megawatt hour of electricity generated
METI	Ministry of Economy Trade and Industry (Japan)
MEG	Mono-ethylene glycol
MOE	Ministry of the Environment (Japan)
Mtpa	Million tonnes per annum (measure of storage capacity)
NDRC	National Development and Reform Commission (China)
NEA	National Energy Administration (China)
O&G	Oil and gas
PCSP	Pilot CO_2 Storage Project (South Africa)
R&D	Research and Development
ROAD	Rotterdam Capture and Storage Demonstration Project
SAMS	Scottish Association of Marine Science
SET-Plan	Strategic Energy Technology Plan (EU)