Carbon Capture, Use and Storage

In brief

Carbon Capture and Storage (CCS) technologies aim to capture as much as 85% of CO₂ emissions from power plants and heavy industry before transporting it by pipeline or ship and storing it at least 700 metres below the earth’s surface. Each step has several technology options, with different levels of performance and maturity, which can be combined in various ways depending on each specific case. The technology can be applied to energy production wherever CO₂ is produced in large quantities. This includes power generation, but can also be used in some industrial processes such as iron and steel or cement manufacturing. A holistic approach should be used to ensure that CO₂ emissions are avoided when capture is used – in other words, the whole supply chain should be taken into account.

Carbon capture and utilization (CCU) could go a significant step further by using the CO₂ in industrial processes, rather than simply storing it. The CO₂ has potential uses in the manufacture of synthetic diesel, biofuels, solvents and polymers and other biological and chemical processes. Given the likelihood that we will continue to rely on fossil fuels for some significant time to come, carbon capture, utilization and storage (CCUS) has the greatest potential to combat climate change. The technologies are still relatively expensive, but may well be able to address almost half of the world’s current CO₂ emissions, by preventing the gas emitted by large stationary sources from entering the atmosphere.

The technology

Carbon capture, utilization and storage (CCUS) is generally understood as consisting of three major steps: capture and com-
pression of the CO₂ at the emissions site; transport of the CO₂ to a storage location; storage, whereby CO₂ is permanently stored in geological formations, deep underground, or use, where CO₂ is utilised as a source of carbon in the synthesis of chemicals and fuels, as a basis for biological processes, in inorganic processes like mineralisation and as a working fluid. Each step has several technology options, with different levels of performance and maturity, which can be combined in various ways depending on each specific case.

The capture configuration can be as post-combustion, in which CO₂ is removed from exhaust gasses through absorption by selective solvents, as well as pre-combustion, whereby fuel is pre-treated and converted into a mix of CO₂ and hydrogen. The CO₂ is then separated and the hydrogen is used as fuel. A third option is oxy-fuel combustion, which burns the fuel with oxygen instead of air, producing a flue stream of CO₂ (which can be easily removed) and water vapour without nitrogen.

Large-scale CO₂ transportation is mainly by pipeline, with some shipping and road transport. CO₂ capture can be used with fossil-fuel power plants using pulverised coal, natural gas turbine combined cycle or Integrated Gasification Combined Cycle (IGCC). The first generation of commercialised plants is expected to have efficiencies of 33%, 48% and 35%, respectively.

The first CCS plants are likely to be coal-fired, because of their higher emissions and their extensive deployment. Technological developments should reduce the efficiency gap between plants with and without carbon capture by 2030.

Ongoing research

In 2005, a coalition of stakeholders that includes European utilities, petroleum companies, equipment suppliers, scientists, academicians and environmental NGOs set up the European Technology Platform for Zero Emission Fossil Fuel Power Plants (ZEP). The platform produced a roadmap for the development, demonstration and commercialisation of CCS. This has since been largely superseded by the European Industrial Initiative (EII) on the CCS Implementation Plan for 2013-15.¹

Under the original implementation plan, the European Council decided to support the deployment of 10 to 12 large-scale CCS demonstration plants in Europe by 2015.

The European Commission (EC) awarded EUR 300 million to the U.K. White Rose CCS project, which is part of a new coal-fired power plant, from which captured CO₂ will be piped for storage under the North Sea.

The industry

Globally, there are an estimated 38 active and completed pilot and pre-commercial implementation projects, aimed at demon-


**Fact file**

**Fossil fuel power plants**

- By 2020, advanced pulverised coal plants should have efficiencies up to 50%, and natural gas combined cycle plants up to 63%. Other technologies, such as integrated gasification in combined cycle (IGCC) and circulating fluidised bed combustion (CFBC) could be commercialised during the same period, with efficiencies reaching 45-50%.

- For the retrofitting of both existing pulverised coal (PC) plants and new PC combustion plants, oxy-fuel combustion could minimise the cost of CO₂ capture, as the flue gas may contain up to 90% of CO₂.

**Zero emission fossil fuel power plants**

- Zero emission power plants make the assumption that they will capture at least 85% of the CO₂ formed during the power generation process. The CO₂ that will be captured will be either transported to suitable underground locations where it will be stored permanently and safely, or transported to be further used in industrial processes as a raw material or working fluid (so-called carbon capture and utilisation – CCU).

- Zero emission plant technology is ready for the demonstration phase and could be commercialised as of 2020, with first-of-a-kind plants coming into operation by 2015. The first generation of commercialised pulverised coal, combined cycle gas turbine and integrated gasification in combined cycle plants with CO₂ capture are expected to have efficiencies of 33%, 48% and 35% respectively in 2025 (EC Energy Directorate).

- According to the EC Energy Roadmap 2050, 18% of electricity will be generated by power plants with CCS by 2050, i.e. in the current policy initiatives scenario. In some scenarios, the share could be higher, 19-24%, or even 32% if nuclear energy is constrained.
strating various combinations of CCS technologies (as of July 2013).

Two main industrial sectors are involved in developing CCS technology: electricity utilities and oil and gas companies, along with the corresponding fuel, equipment and service suppliers. This suggests a potential division within the CCS value chain, whereby the utilities could operate capture steps, and oil and gas companies could be involved in transport and storage. Iron, steel, cement and aluminium manufacturers, along with the fertiliser sector (accounting for about 19% of total world greenhouse gas emission), are also interested in using CCS.

Advanced fossil fuel plants with carbon capture would compete with conventional power plants for a share in power generation capacity if they become commercially viable within a carbon-pricing framework such as the EU Emission Trading Scheme.

According to the EU Energy Roadmap 2050, CCS from the power sector will contribute 19–32% of GHG emissions reductions by 2050. The installed capacity will have to grow from 3 GW in 2020 to 3–8 GW in 2030, 22–129 GW in 2040 and 50–250 GW in 2050, depending on the energy system scenario. This would require about 20000 km of pipeline infrastructure, according to ZEP. The 2013 IEA CCS Technology Roadmap points out that the capture of CO2 has to be successfully demonstrated in at least 30 projects from power and industry sectors by 2020.

In scenarios that assume renewables will play a greater role, fossil-fired power plants with carbon capture technology, which are inherently flexible, could be used to balance changing demand and provide back-up.

Renewable technologies should not be ignored when considering the impact of carbon capture plants: CCS may allow for negative emissions of CO2, if adequately combined with biomass sources (bio-CCS).

The increase in exploitation of shale gas, particularly in the USA, has led to a surplus of coal on the market. Imports of (relatively cheap) coal into Europe increased by 187% from 2005 to 2011. A possible effect of this would be to divert investors’ and utilities away from relatively expensive low-carbon technologies, including CCUS, especially while the carbon price remains low.

Barriers

Financial, social, infrastructure, environmental and regulatory issues could all present barriers to CCS demonstration and deployment.

There is a lack of political commitment to CCS by some Member States, exacerbated by problems with permitting procedures. Meanwhile, there is often no financial compensation for the additional capital and operational costs associated with CCS. European Trading Scheme quotas, as they exist, do not encourage efforts to reduce carbon emissions.

The first generation of CCS coal plants is expected to cost 60 to 100% more than comparable conventional plants. The cost of a natural gas plant with post-combus-

Illustrative deployment costs for CCS projects in Euros (2012)

<table>
<thead>
<tr>
<th>Nominal capacity (MW)</th>
<th>Overnight capital cost (EUR2012/kW)</th>
<th>Fixed operating and maintenance costs (EUR2012/kW-year)</th>
<th>Variable operating and maintenance costs (EUR2012/MWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulverised coal (PC)-CCS (advanced, single unit)</td>
<td>650</td>
<td>4 051</td>
<td>62.4</td>
</tr>
<tr>
<td>IGCC-CCS (single unit)</td>
<td>520</td>
<td>5 114</td>
<td>56.44</td>
</tr>
<tr>
<td>Natural gas combined cycle (NGCC)-CCS (advanced CC)</td>
<td>340</td>
<td>1 624</td>
<td>24.64</td>
</tr>
</tbody>
</table>

Source: EIA, 2013

For coal and natural gas power plants, the main contribution to capital expenditure comes from the capture step (75–78% contribution to the total CapEx), followed by transport (5–10%) and storage (15–18%).

Anticipated greenhouse gas savings

- In the EU, fossil fuel combustion accounts for 87.4% of CO2 equivalent emissions, most (34.5%) from power plants, followed by transport (22.7%) and manufacturing and construction industries (22.7%). The major contribution (24.7%) comes from coal, followed very closely by natural gas, (23.6%).
- Globally, all currently operational CCS projects have stored up to 59 Mt CO2. According to the EU Energy Roadmap 2050, CCS from the power sector will contribute 19-32% of reductions in GHG emissions by 2050.

2 http://www.erec.org/fileadmin/erec_docs/Documents/ERECS_Factsheet_on_Affects_of_Shale_Gas_on_RES.pdf

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Carbon Capture, Use and Storage

The capture, transport and storage of CO₂ itself implies extra energy consumption, which needs to be factored into costs and abatement calculations. There is a trade-off, then, between GHG emissions reductions through CCUS and reduced efficiency.

In order to move forward, it is essential to develop expertise through international collaborations and public-private partnerships.

Another key social and political challenge is gaining public confidence in many Member States. Several projects that envisaged CO₂ storage have been cancelled because of public opposition. These have been mitigated by information campaigns, or moving storage offshore, for example.

The CO₂ infrastructure still needs to be developed to ensure storage and risk management for possible CCS investors. There is also a need for suitable sites to be assessed.

The EU ‘CCS Directive’ adopted in April 2009 set out a legal framework for geological storage of CO₂. This directive has now been implemented by most Member States.

Needs

A prerequisite for the large-scale deployment of CCS is the demonstration of the technical and economic feasibility of existing technologies in a fully integrated chain. There is a need for more experience of CO₂ transport in order to enhance safety and thus gain greater public acceptance. Biomass as feedstock can potentially result in carbon neutral, even carbon negative plants.

For CCS to become commercially viable, financial incentives for demonstration activities will be vital. In the longer term, a stable carbon pricing mechanism is needed to enable global commercial CCS deployment.

Also, more efficient and cost competitive CCS technologies have to be developed through ongoing research. Priority topics include the improvement of power plant efficiency, the development of new materials (for advanced ultra-supercritical boilers and steam and gas turbines) and the development of innovative and more cost-effective capture processes. Further progress in the development of catalysts is also an essential stepping-stone towards the development of economically viable technologies for CCU.

The greatest concern in long-term geological storage is safety and security. The environmental impact and safety of CO₂ storage requires better understanding. Monitoring and modelling techniques, for checking CO₂ migration, diffusion, fluid-rock interactions, and cap rock integrity need to be developed for verifying storage security.

The financing and regulation of the infrastructure for CO₂ transport and storage will also need to be addressed.

Public perception will have a significant role to play in CCS deployment. Public awareness and knowledge of CCS is currently low and is a priority area to be dealt with by all actors involved.

Installed capacity

Fossil fuel power plants are still the backbone of the European electricity generation system, providing 52% of electricity demand in 2012, although this was down from 55% in 2010. Coal remains the main fuel (24.7%), followed very closely by natural gas (23.6%). (EC, 2012)

Energy forecasts show that this picture will remain in the medium to long term, with fossil fuels still generating 40-50% of electricity in 2030. The share of advanced coal and natural gas technologies among these future fossil fuel power plants will depend on the fuel prices and the carbon market, which, at under EUR 5/tonne of CO₂ equivalent, is currently too low to attract the required levels of investment without considerable public support. The impact of shale gas on the scenarios is still uncertain.

CCS capture plants will compete with conventional power plants as soon as they are commercialised, but the level of penetration will depend on the timing of commercialisation and deployment, the regulatory framework, the environmental constraints and the extent of the CO₂ transport network.

There are at least five on-going large-scale CCS projects in the EU. A ‘CO₂ hub’ in Rotterdam (Netherlands) aims to reduce the city’s emissions by 50% by 2025 with multiple storage sites. The ROAD project, also in Rotterdam, captures CO₂ (1 Mt/year) from a coal power plant and stores it in an offshore site. The North Sea storage project (Norway) is monitoring storage of CO₂, while the first phase of the Hypogen project in UK, Germany and Norway, aims to construct and operate a commercial-scale power plant with hydrogen production and CO₂ management (400 MW of electricity and 3 Mt/year of CCS). The Zero Emission Tolle Project (ZEPT) in Italy involves retrofitting a 660 MW power plant using the post-combustion approach to capture and store 1Mt/year of CO₂.

For further information:

SETIS Chapter on Carbon Dioxide Capture & Storage

The European Technology Platform for Zero Emission Fossil Fuel Power Plants (ZEP)
http://www.zeroemissionsplatform.eu/

The Carbon Dioxide Capture & Storage (CCS) European Industrial Initiative (EII)