PARTIAL CAPTURE OF CO_2

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1. Introduction

The need to substantially reduce emissions of CO_2 to the atmosphere to reduce the risk of harmful climate change is now widely accepted. One of the technologies which could help to reduce emissions is CO_2 capture and storage (CCS). A high percentage (e.g. ≥85%) capture of CO_2 at power stations and other large industrial plants will be essential in the long term to achieve the challenging targets for overall emission reduction, which may for example need to be around 80% by 2050 for developed countries. Some countries are likely to insist on high percentage capture in the near term to put them on track to achieving their long term goals but in some other countries a lower percentage emissions reduction may be considered to be acceptable and a useful contribution in the near-term. An example of this is the requirement in California for coal fired power plants supplying the state to have CO_2 emissions no greater than those of natural gas fired plants. Partial capture of CO_2 would be a way to satisfy such requirements. In some cases a requirement for partial capture may also help to facilitate CCS technology demonstration.

This report is a brief review of the technology and costs of partial capture of CO_2. The report does not attempt to prescribe policies for mandating CO_2 capture and whether partial capture should be part of a policy for reduction of greenhouse gas emissions. IEA GHG provides technical information which can be used by policy makers but it does not intend to be policy prescriptive.

2. Techniques for partial capture of CO_2

Most power stations include multiple power generation units. Partial capture of CO_2 could be achieved at a multiple unit power station by either:

1. Capturing a relatively low fraction of CO_2 in each power generation unit.
2. Capturing a high (e.g. ≥85%) fraction of CO_2 in one or more power generation units and not capturing CO_2 at the other units.

The latter technique has the advantage that if, or more likely when, tighter emissions regulations are introduced capture could be added to the unabated generation units and no changes would have to be made to the units that already have capture. For the first technique changes would have to be made to all generating units when higher percentage capture is required and this may involve making more modifications and longer overall plant shutdown.

An alternative to imposing CO_2 emission limits at each power station would be to regulate CO_2 emissions on a state, national or company-wide basis. This would enable the same overall reduction in emissions to be achieved by having some power stations with high percentage capture and some power stations with no capture. This would avoid the extra cost of having to install CO_2 pipelines to every site and would mean that the expertise for CO_2 capture could be concentrated at a smaller number of sites. There may also be savings in CO_2 storage costs, because capture could be installed only at power stations which are closest to good, low cost storage reservoirs. Conversely, partial capture may be attractive if the storage reservoirs that are close to a power station have insufficient capacity to store all of the CO_2 that will be produced by the power station over its remaining life.

Partial capture has been proposed for power plants that co-utilise fossil fuels and biomass. If the biomass is assumed to have zero emissions it would be possible to achieve low or even zero net emissions by capturing a quantity of CO_2 that corresponds to the quantity of CO_2 originating from the fossil fuel. From a regulatory perspective it may be preferred to have low net emissions from all power plants. However, from a practical perspective it may be possible to achieve the same overall CO_2 emission reduction at lower costs by capturing all of the CO_2 at some plants, resulting in negative net emissions at those plants, while capturing no CO_2 at other plants, as described earlier.

3. Capture technologies

3.1 Oxy-combustion

Oxy-combustion at power plants is inherently an ‘all or nothing’ capture technology and partial capture within an individual power generation unit is not feasible. Partial capture at a multi-unit power station site could be achieved by having some oxy-combustion power generation units and some conventional air fired units without capture.

3.2 Post combustion capture

Work has recently been published which indicates that reducing the percentage capture in post combustion solvent scrubbing processes would result in an increase in the cost per tonne of CO_2 avoided [1]. Costs per tonne of CO_2 avoided are shown to be almost constant between about 95% and 80% capture, to increase gradually by about 15% as the percentage capture is reduced from 80% to 50% and to increase more rapidly, by almost a further 50%, as capture is reduced from 50% to 25%.

Post combustion capture at large power generation units will probably require multiple capture modules, for example because of limitations on the size of shop fabricated equipment which can be transported to the site. In this case the optimum technique for partial capture would probably be to feed part of the flue gas to a capture unit which captures more than 80% of the CO_2 and by-pass the rest of the flue gas around the capture unit. The cost of partial capture, in terms of $/tonne of CO_2 avoided, would be similar to the cost for high percentage capture plant, but there would be lower economies of scale in CO_2 compression and transportation.

There is a possibility that novel capture processes could be developed which have a lower percentage capture than solvent scrubbing but lower costs per tonne of CO_2 captured. As discussed above, high percentage capture will be required in the long term so it appears unlikely that processes which can only capture a low percentage of the CO_2 will be developed as they would have only a short market lifespan. Even if such processes existed, utilities are unlikely to want to install them in power plants with long lives if they would be difficult or impossible to up-grade to meet future tighter emission requirements. There may be a niche application in power plants with short remaining lives, although installing low percentage capture units at such plants could face opposition from the public and regulators who may view it as perpetuating ‘old dirty’ power plants instead of building new low emission plants.

Some power plants have to vary their power outputs to match the daily and seasonal variations in power demand. For such plants it could be advantageous to size the capture unit to process only part of the flue gas, to operate the capture unit at continuous full load and vary the flowrate of the by-pass stream. Depending on the extent to which the power output has to be varied it may be possible to operate the capture unit at full load despite the variation in the power plant load. In some circumstances, particularly in integrated power grids, the same advantage could be achieved by having separate capture and non-capture power plants, operating the capture plants at full load and varying the outputs of the non-capture plants. IEA GHG is planning to undertake work on CCS power plant operating flexibility and analysis of this mode of operation could be assessed as part of this work.

Another partial capture option would be to build a post combustion capture plant capable of capturing a high percentage of the CO_2 and reduce the extent of capture at times of high power prices to maximise power output and revenue. However, this has been shown to be not economically attractive except during extreme circumstances [2].

3.3 Pre combustion capture

In IGCC with pre combustion capture the fuel gas from a gasifier is passed through a catalytic shift converter where CO is reacted with steam to produce H_2 and CO_2. The shifted gas is then passed to an acid gas removal plant where most of the CO_2 is separated. The resulting fuel gas which contains mainly H_2 along with the CO which was not reacted in the shift convertor and the residual CO_2 is burned in a gas turbine. Multiple stages of shift reactor with inter-cooling are needed to achieve high degrees of conversion of CO to CO_2 and high percentage capture of CO_2. Partial capture enables the steam consumption of the shift converter and the number of reactor stages to be reduced. The extent of capture in the acid gas removal plant can also be reduced, with resulting cost savings. Some types of gasifier, particularly those that feed the coal as a water slurry, produce a fuel gas with already contains a significant fraction of CO_2. A low percentage capture can be achieved by capturing only this CO_2, without having a shift converter.

Work on partial capture of CO_2 in IGCC has been reported by IGCC process developers and engineering contractors [3,4,5]. In reference 3, which is based on the GE Energy gasifier, the cost per tonne of CO_2 emissions avoided is about 5% lower for 50% capture than for 90% capture. The 50% capture case includes a single stage shift reactor and the 90% case includes a two stage shift. The cost per tonne of CO_2 avoided for a plant without a shift converter capturing 17% of the CO_2 is about 60% higher than for a plant with 90% capture. Reference 4 does not quote costs per tonne of CO_2 but the incremental capital cost for capture ($/kW) and the increase in plant heat rate are both about twice as high for 80% capture as for 50% capture and about three times as high for 90% capture. This indicates a much greater advantage for partial capture than reference 3. The data in this reference is for E-Gas gasifier plants. 50% capture is based on a single stage shift reactor and 90% capture is based on a three stage shift. Reference 5 shows that capturing 16% of the CO_2, i.e. the CO_2 present in the fuel gas before shift conversion, results in a cost per tonne of CO_2 avoided that is more than twice as high as for 85% capture. The conclusion that capturing CO_2 without shift conversion is relatively expensive is consistent with reference 3.

The costs of emissions avoidance in these references are calculated relative to a base case IGCC plant without capture. However this can give a misleading impression of the merits of partial capture in IGCC. At present IGCC without capture is generally considered to be more expensive than pulverised coal power generation without capture but the extra cost of capture in IGCC is lower than in pulverised coal power plants. The real overall cost of capture in IGCC therefore consists of the extra cost of building an IGCC compared to a pulverised coal plant plus the extra cost of including capture in IGCC. This is illustrated by Figure 1, which uses cost data for plants with and without 90% capture from a US DOE/NETL report [6].

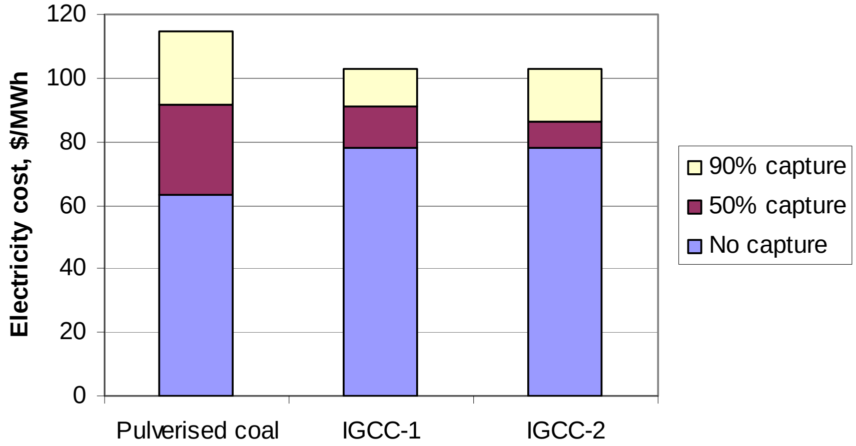

Figure 1 Costs of electricity with 90%, 50% and no CO_2 capture

Taking the lowest cost IGCC option from that report, it can be seen that the cost of power without CO_2 capture is higher for an IGCC plant than for a supercritical pulverised coal plant but the cost with 90% capture is lower for IGCC. IEA GHG has estimated the costs for 50% capture shown in Figure 1 to illustrate the merits of partial capture. For post combustion capture it has been assumed that the cost of capture increases in direct proportion to the percentage capture, which would be approximately the case for multi-train plants. Two IGCC cases are included: the IGCC-1 case is based on the relative costs of capturing 50% and 90% CO_2 in reference 3 and the IGCC-2 case is based on the relative costs in reference 4. It can be seen that for 90% capture, IGCC is substantially cheaper than PC but at 50% capture the costs for PC and the IGCC-1 case are the same and the IGCC-2 case is slightly cheaper. However this does not mean that IGCC is necessarily the least cost option for 50% capture. If a utility wished to achieve 50% overall capture of CO_2 across a portfolio of plants the lowest cost option would be to have a combination of IGCC plants with high percentage capture and pulverised coal plants with no capture. The resulting overall cost of abatement would be over 20% lower than for IGCC plants with partial capture based on the IGCC-1 costs for partial capture and 4% lower based on the IGCC-2 costs.

A utility may choose to build IGCCs with partial capture because the cost of upgrading them to high percentage capture at a later date would be lower than the cost of adding capture to a pulverised coal plant. Building partial capture IGCCs rather than a combination of high capture IGCCs and no-capture PC plants would be a type of capture ready pre-investment. IEA GHG's report on Capture Ready Plants [7] shows that major capture ready pre-investments are unlikely to be worthwhile unless capture is installed soon after the plant is built, mainly because of the effects of economic discounting and the risks of technological obsolescence and uncertainty regarding future regulatory regimes and carbon prices. The same conclusion would apply to up-grading a partial capture plant to high percentage capture, i.e. the pre-investment would only be worthwhile if the up-grading took place soon after the plant was built.

Partial capture of CO_2 can have some practical advantages in IGCC, particularly for the gas turbines [8]. In a plant with high percentage capture the concentration of hydrogen in the fuel gas feed to the gas turbine will be high and the volumetric heating value (Wobbe index) of the fuel gas will be substantially higher than for an IGCC without capture. This would require gas turbine modifications, although this could be overcome by nitrogen dilution. The Wobbe index of the fuel gas in a plant with partial capture would be similar to that of a plant without capture. Gas turbine manufacturers would currently have greater confidence providing turbines for plants with partial capture rather than high percentage capture.

4. Demonstration plants

Partial capture's main role may be in CCS demonstration plants. There is currently a large requirement to build new fossil fuel power plants to replace plants that are reaching the end of their useful lives and to satisfy increasing power demands. There is also a need to build plants to demonstrate CCS technology but the requirement for new power plant capacity greatly exceeds the requirement for CCS demonstration plant capacity. Requiring all new fossil fuel power plants to include full CCS from day one would be an expensive and high risk method of introducing CCS but requiring new plants to include a CCS demonstration module to capture part of the plant's CO_2 emissions, as has recently been specified in the UK, could be a way forward. The intention is that the plants would be upgraded to full CCS when the technology is technically and economically proven. For post combustion capture there would normally be a module to capture a high percentage of the CO_2 from a fraction of the plant's flue gas. Similarly for oxy-combustion, an oxy-combustion power plant unit would be built on a power plant site where the other units were air-fired. A different approach may be used for pre-combustion capture, where partial capture may be applied to the whole plant, for example to limit the hydrogen concentration in the fuel gas feed to the gas turbine, as described above. However, the resulting reduction in risk should be balanced against the possibility of delays in demonstration of high percentage capture.

5. Conclusions

Partial capture of CO_2 is not feasible in oxy-combustion power generation units but partial capture can be achieved at multi-units power plants by having some units with high percentage capture and some units without capture.

In a plant with post combustion capture the optimum method of achieving partial capture would be to by-pass some of the flue gas around the capture unit. The resulting cost per tonne of CO_2 avoided is expected to be similar to or slightly higher than for high percentage capture.

Partial capture can be achieved in IGCC by reducing the extent of shift conversion. The resulting cost per tonne of CO_2 avoided for partial capture (around 50%) is expected to be about the same or lower than for high percentage capture.

Based on current expectations of the relative costs of IGCC and pulverised coal plants, the lowest cost method of achieving partial capture would be to have a portfolio of IGCCs with high percentage capture and pulverised coal plants without capture.

Partial capture could be appropriate for power plants with CCS demonstration units.

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