

Carbon capturing the imagination

Coal power gen is the key carbon problem and solution

Many nations are targeting an 80% reduction in carbon emissions by 2050. Carbon reduction can be met through (1) energy efficiency, (2) a higher proportion of renewable energy capacity and (3) cleaner thermal generation. We think cleaner coal is integral to addressing climate change as coal provides c.40% of global electricity and is the biggest single source of carbon emissions. Coal is not going away as the world still has 120 years of coal reserves and China is adding a new coal plant every two weeks to meet rising electricity demand.

Carbon goals can't be met with more wind and solar

There are inherent problems with the unpredictability of renewables and until storage technology is advanced, it appears to us that coal will continue to play an important role in the generation mix. Many operators claim supplying more than 20% of electricity through renewables risks excessive stress on the grid, leading to blackouts or higher reserve margins which will push up electricity prices.

Carbon capture (CCS) increasingly on the political agenda

Carbon capture technology is currently expensive and unproven. We notice a heightened interest in the technology with many governments providing subsidies for R&D and large scale demonstration projects. However, a commercial solution is unlikely to be available until 2015 at the earliest. There are a wide range of estimated costs for the technology but the consensus among participants in the industry seems to be that CCS will only be viable with a long term carbon price of between €30-40/ton or a new entrant based power price of around €75/MWh.

Pushes capex and power prices up for utilities

Carbon is currently trading at around €15/ton in the European Union and is free in the US. Expensive CCS technology is likely to push carbon prices higher or else the carbon reduction targets have little chance of being met in our opinion. For traditional utilities this means we can expect higher capex for retrofitting the installed coal base and higher power prices to compensate for this investment. We would highlight the cleaner utilities such as Verbund, Fortum, Iberdrola and the wind operators as the main beneficiaries of this trend.

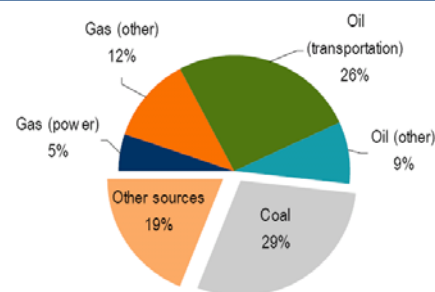
Drives upgrade cycle for equipment providers

Given the early stage of CCS there are no real pure play listed technology companies. We would highlight the traditional manufacturers such as Alstom, Aker and Siemens as the main beneficiaries of investment in CCS. The respective manufacturers are developing different technologies (pre/post production) and it is difficult to say at this stage who will emerge as the leader but Alstom seems to be making the most headway with its involvement in the pilot projects.

Bank of America Merrill Lynch

Matthew Yates >> Research Analyst MLPF&S (UK) matthew.yates@baml.com	+44 20 7996 4537
Eric Lopez >> Research Analyst MLPF&S (UK) eric.j.lopez@baml.com	+44 20 7996 4143
Mark Troman >> Research Analyst MLPF&S (UK) mark.troman@baml.com	+44 20 7996 4194
Angello Chan >> Research Analyst Merrill Lynch (Hong Kong) angello.chan@baml.com	+85 2 2161 7187
Steven Milunovich, CFA Research Analyst MLPF&S steven.milunovich@baml.com	+1 646 855 1272

Chart 1: Coal based generation accounts for almost 30% of US greenhouse gas emissions



Source: EIA (2007)

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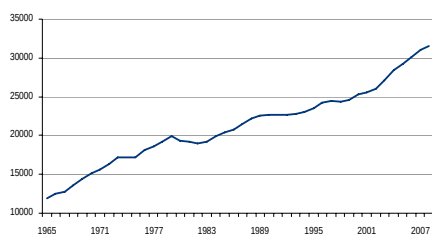
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Carbon capture is a critical contributor to a low carbon world

We believe that CO₂ capture and sequestration (CCS) is the critical enabling technology that would dramatically reduce global CO₂ emissions while enabling the world to meet its growing energy needs and prevent an excessive rise in electricity costs. Much of investor/corporate attention at present is focused on the renewable energy technologies of wind and solar. In this report we attempt to demonstrate that CCS can actually surpass renewables in its contribution to reducing global carbon emissions.

Chart 2: Global CO₂ emissions (mn tonnes)
have tripled over the last 40 years



Source: BP

The holy grail of carbon reduction

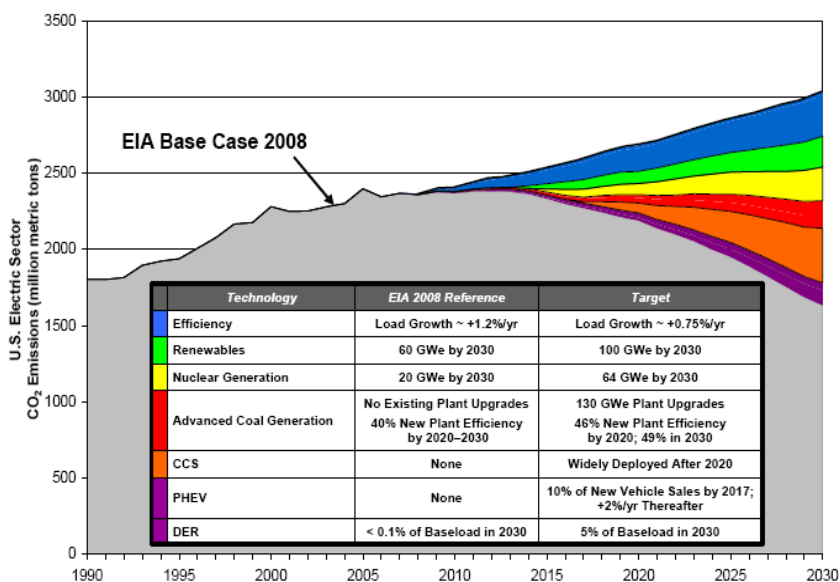
Coal power plants are the biggest contributor to carbon emissions; about 30% of US emissions according to the EIA (see Chart 1) and 40% globally according to the World Energy Forum. Coal power plants are therefore the greatest opportunity to reduce emissions in our view. The potential of CCS is on a par with the electric car in terms of the holy grail of reducing carbon emissions but doesn't seem to get an equivalent amount of press attention.

An average size coal power plant produces about 3mn tonnes of carbon emissions each year and CCS could reduce CO₂ emissions by approximately 80-90% compared to a plant without CCS. Even the WWF recognise that coal power plants are likely to persist and so are supportive of CCS.

CCS is twice as important as renewables for carbon reduction

Chart 3 suggests that under a business as usual scenario in the US, carbon emissions in 2030 would be 30% higher than today. The EIA (Energy Information Administration) believe that CCS can reduce carbon emissions by 400mn metric tons (about 17% of current emission levels) and is the largest single contributor towards reducing emissions. Chart 3 suggests CCS can reduce carbon emissions by twice the amount of renewables.

Chart 3: Path to lowering US electricity related CO₂ emissions by 30% by 2030

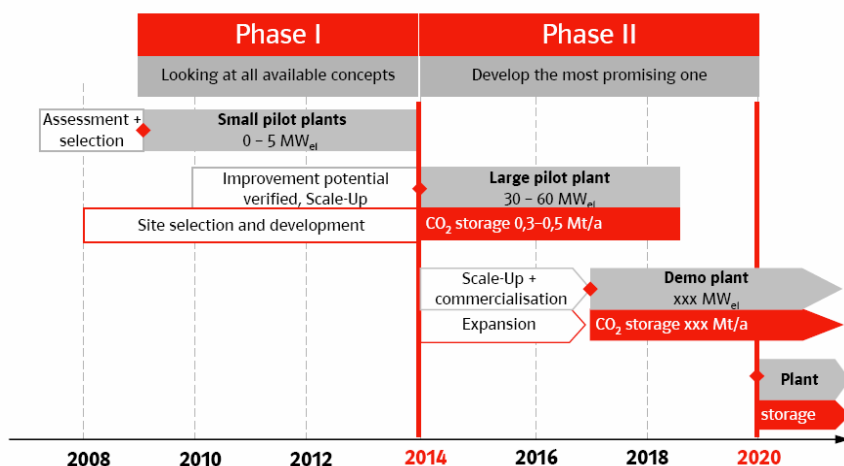


Source: EIA

Not a 2010 story, maybe a 2015 story but definitely a 2020-30 story

CCS is the concept of capturing carbon emissions from sources such as power plants and storing them beneath the surface. The technology is relatively expensive and unproven today. However, we think the proliferation of pilot projects over the next few years will help to develop, refine and ultimately reduce the cost of CCS so that it can be commercially deployed after 2020.

Chart 4: Timeline to commercialisation



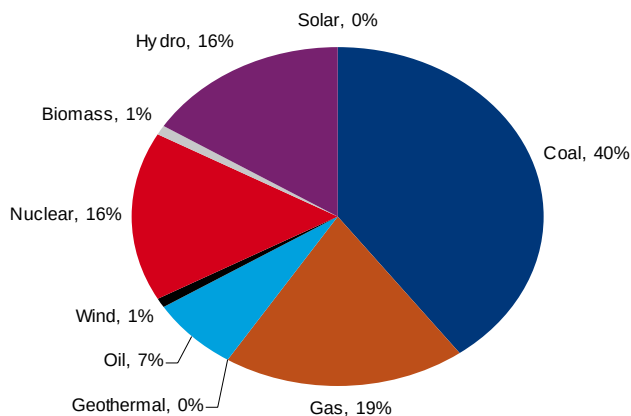
Source: E.ON

Coal's crucial role in the energy mix

Despite the rapid growth of wind and solar installations over recent years, the technologies still only account for around 2% of the global electricity mix. If we were to assume that annual wind and solar installations grew by a 20% CAGR between 2009-20 then they would still only account for around 10% of electricity generation. There are certain drawbacks with renewables and benefits of coal such that we would expect coal to remain an important part of the energy mix:

- Wind and solar are fairly predictable over an extended time frame but load factors can be volatile over a shorter period. To counter this volatility, utilities may have to build greater reserve margins which in turn are likely to lead to higher electricity prices. Various governments are targeting 20-30% of electricity to come from renewables in 2020 but what provides the other 70-80%?
- Some utilities have argued that more than 20% renewables penetration would jeopardise the reliability of energy supply. Whilst 20% is still far from the current rate, the point is that renewables cannot be the sole answer to reducing carbon emissions by the quantities governments are targeting.
- Coal is 'cheap' and abundant. The world's coal reserves are not expected to run out for another 120 years. In addition, China and India view coal as a relatively cheap way of meeting rising electricity demand. Coal is also available from less politically unstable countries than gas and oil.

Chart 5: 2008 Global electricity generation (TWh)

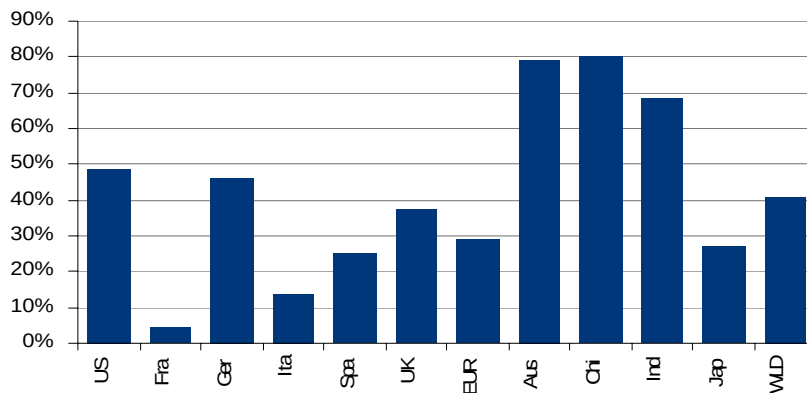


Source: EIA, BAS-ML calculations

Coal is still in vogue in developing nations

Coal accounts for 65% of global generation capacity and about 40% of global electricity production when adjusted for load factors (see Chart 4). Coal generation ranges from 49% in the US, 29% in Europe and 80% in China.

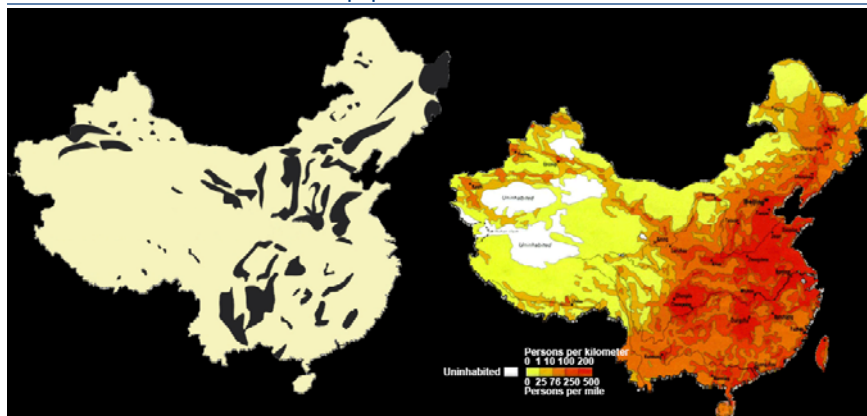
Chart 6: % of electricity production from coal



Source: EIA

Very little coal capacity has been added in the US and Europe over the last 5 years as utilities get increasingly concerned about long term carbon prices. About 80% of the new generation capacity added in the US and Europe since 2000 has been a combination of gas and wind. However, the story is very different in emerging markets such as China where there has been a very strong growth in demand for electricity and the country has an abundance of (cheap) coal reserves from which to satisfy this appetite. Based on China's next 5 year plan we calculate that a new coal plant will be built every other week. Over the course of a year this new coal capacity in China is equivalent to the UK's entire generation capacity. China's coal reserves are also located near to population demand which is not the case for gas and solar which are more concentrated in the west.

Chart 7: China coal reserves versus population



Source: Entergy

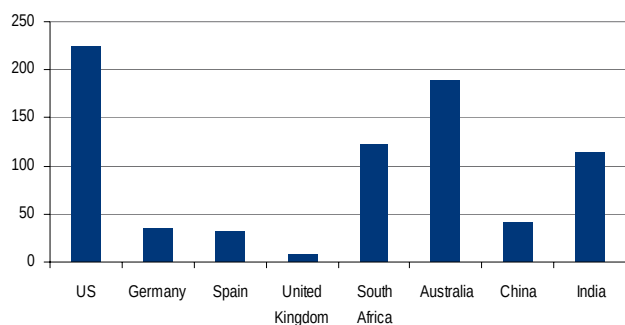
Coal becoming more, not less important to the world

The growth of China, India and other emerging markets means that coal will become a higher, not lower part of the global energy mix in the near term, despite the recent growth of renewables such as wind and solar. The nuclear renaissance will play a role in cleaner energy (even in China where there are very ambitious nuclear plans) but lead time on a nuclear plant is around a decade so projects approved now are unlikely to start production much before 2020. In addition, there is political resistance to nuclear life extensions in Germany and Spain which makes the case for continued coal generation, albeit hopefully cleaner.

Ample coal reserves wont be depleted anytime soon

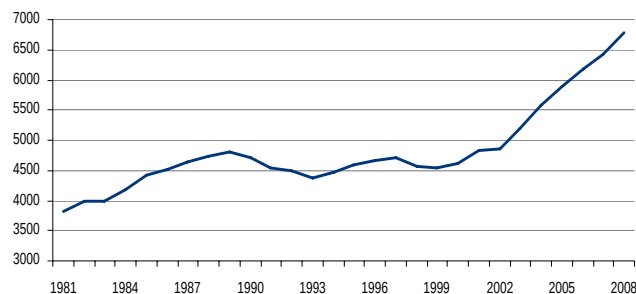
According to data from BP, it is estimated that the world has around 120 years worth of coal reserves based on current consumption rates. The reserves range from over 200 years in the US, to 50 years on average in the EU and 40 years in China. Individual country reserves are less relevant given the ability to import and export coal. The point we wish to stress is that a 'peak coal' scenario which forces utilities to focus on other generation sources is unlikely in the next couple of decades and therefore new coal plants are likely to be constructed. According to the BP data, emerging markets count for around 65% of global coal demand.

Chart 8: Coal reserves to production ratio



Source: BP

Chart 9: Annual global coal production (tonnes)



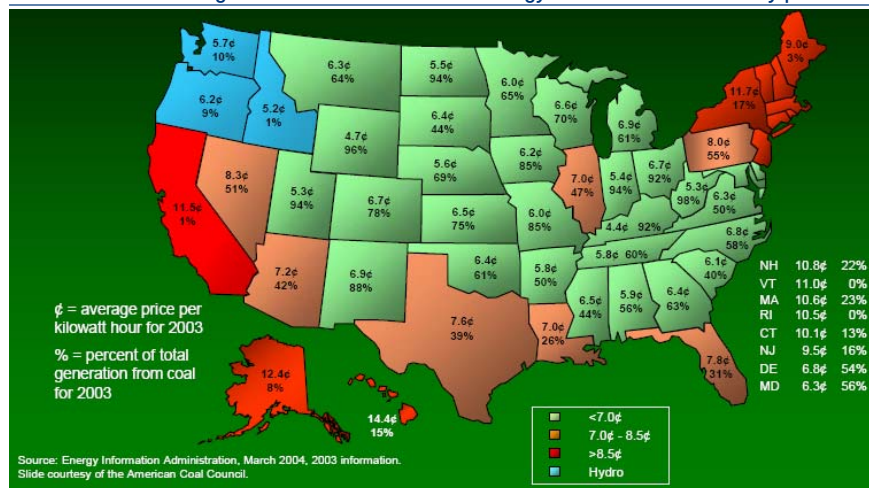
Source: BP

The coal lobby is still strong in the US

Obama has faced opposition from within his own Democratic party to his energy policies encapsulated by the Waxman-Markey Bill. Senators in opposition seem to be focused in the more 'coal heavy' states as these areas would be hit hardest by proposals to introduce a mandatory renewable portfolio standard and a carbon cap and trade system.

Trying to pass legislation that will result in higher electricity costs for businesses and consumers during a recession, when unemployment is close to 10%, is going to be very tough. The goals of the Waxman-Markey bill are likely to be watered down substantially before they pass a reluctant senate in our view. The Bill did contain a couple of specific references to CCS, namely that the EPA (environmental protection agency) will develop a national strategy for CCS and there will be tougher performance standards for any coal plants built after 2015.

Chart 10: There is a high correlation between % of energy from coal and electricity price



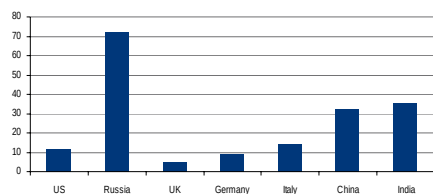
Source: EIA

Gas reserves are lower than coal

According to data from BP, the world has around 60 years of proven gas reserves based on current consumption rates. This is only half the ratio of coal reserves. Looking on an individual country basis shows that the US has only 12 years of gas reserves and will therefore become increasingly dependant on imported LNG (liquefied natural gas). Likewise, Germany only has 9 years of gas reserves remaining and will become increasingly dependant on pipelines originating from Russia.

Chart 4 showed that coal accounts for around 40% of global electricity generation. Whilst gas is a 'cleaner' fuel and has increased its contribution to the energy mix over the last decade, we do not think gas could ever fully substitute for coal. Firstly, gas reserves are lower than coal, especially in the US. Secondly, dependence on imported gas carries political risks as we have witnessed over the last couple of years when Russian pipelines have been shut off during disputes. We believe therefore that coal will remain an integral part of the world's energy mix and CCS is critical to meeting carbon reduction targets.

Chart 11: Gas reserve/production ratio



Source: BP

Subsidies vital to bridge the initial cost gap

CCS is not competitive today with carbon prices at only €15/ton. With little visibility into where carbon prices might be in ten years time, it is difficult to justify the R&D for CCS in the interim. A lot of investment is needed to refine the technology and costs will come down through economies of scale as the technology is more widely deployed. CCS therefore needs government support in order to assist its path down the cost curve. This is a common process for renewables as wind and solar have received (or been promised) tens of billions of euros in subsidies in the last few years.

If the ball started rolling on CCS demonstration projects today, it would be 2015 before they are online and then 2020 before the next batch of commercialised solutions was rolled out. If politicians are serious therefore about meeting 2020 targets for reducing carbon emissions then CCS momentum needs to pick up relatively soon. Fortunately, in the last 12 months there seems to have been a notable increase in political support across the world for CCS. The head of E.ON's UK business, Paul Golby, stated "if they fund it, we will fit it".

Political momentum accelerating

The EU intends to have 12 CCS trials up and running by 2020 and in October announced it had awarded six projects €180mn each to fund demonstration projects, with the same sum coming from national governments. The winners were Vattenfall (Germany), Powerfuel (UK), Endesa (Spain), Enel (Italy), a project in Poland and a consortium in Holland.

The UK government has been a vocal supporter of CCS and has intentions of fully subsidising one large project and three smaller projects with the successful bidders set to be announced in early 2011. The UK intends to fund two projects using post combustion and two plants using the pre combustion method. The three competing parties for full funding are E.ON, SSE and Scottish Power (Iberdrola). The fall in energy demand has prompted some utilities such as Centrica, RWE and another E.ON project to postpone investments in retrofitting coal capacity. The subsidies would be paid for by a surcharge on electricity bills, estimated at 2-3% by the climate change minister Ed Miliband.

The US stimulus package passed earlier this year included about \$3.4bn of research grants which covers areas such as CCS storage demonstration projects and research into geologic sequestration. Elsewhere in the world, Canada has promised CAD\$2bn for 3-5 projects of which CAD\$343mn, or 45% of the cost, was recently pledged to a project by TransAlta. Australia is putting up AUD500mn for research and trials and in China several pilots are now getting underway.

€20bn of subsidies needed but that's half what Spain committed to solar

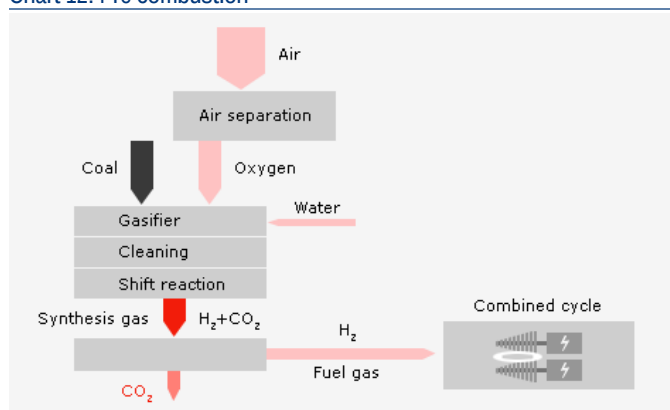
As an indication of the subsidies needed, RWE has guided that the capex cost for a 450MW project it is evaluating is €2.2bn (€1.6bn for power station, €0.4 for pipeline, €0.2 for storage). Assuming a handful of projects are necessary in Europe and a similar number in the US to evaluate different capture technologies and storage techniques implies that over €20bn of public funds is necessary. To put this into context, based on the amount of installations at the end of 2009 (c.3.7GW) Spain has committed to spending €40bn on solar subsidies over the next 20 years plus many more billions for the 18GW of wind capacity it has installed promising a premium to market electricity prices.

Here comes the science

An in-depth MIT study concluded that it's far from clear what the best technology for CCS is. Large scale demonstration projects are needed to get a better assessment of the costs and practicalities of different techniques. There are three different technologies for capturing carbon that differ in whether carbon is removed before or after a fuel is burned. In all cases, the aim is to produce a concentrated CO₂ stream that can be transported (in the form of a liquid) to a sequestration site.

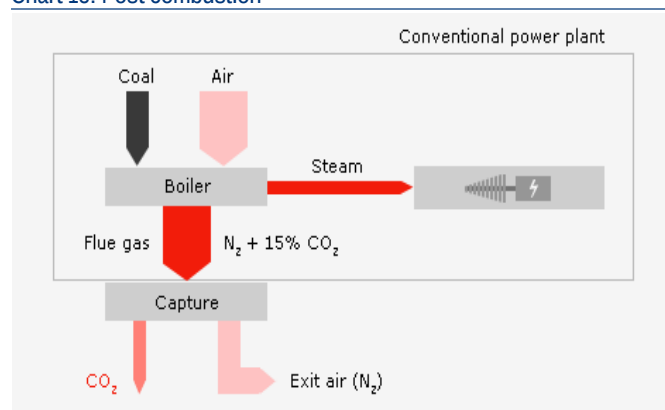
1. Pre combustion – removes the CO₂ before combustion and produces hydrogen as a by product
2. Post combustion – separates CO₂ from the other flue gases once a fuel is burned by using chemicals called amines
3. Oxyfuel – burns fuel in oxygen rather than air which creates a higher concentration of CO₂ in the flue gas, making it easier to separate the CO₂

Chart 12: Pre combustion



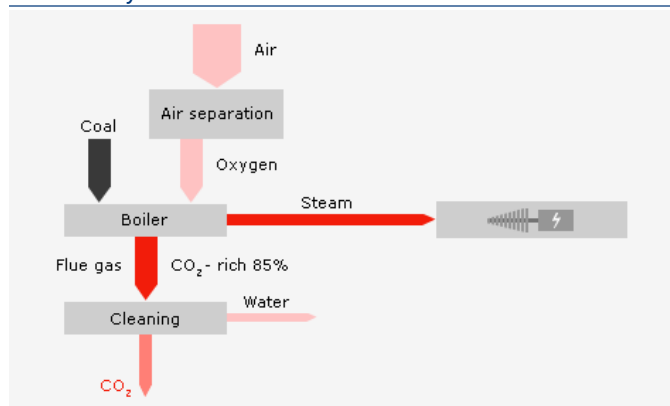
Source: E.ON

Chart 13: Post combustion



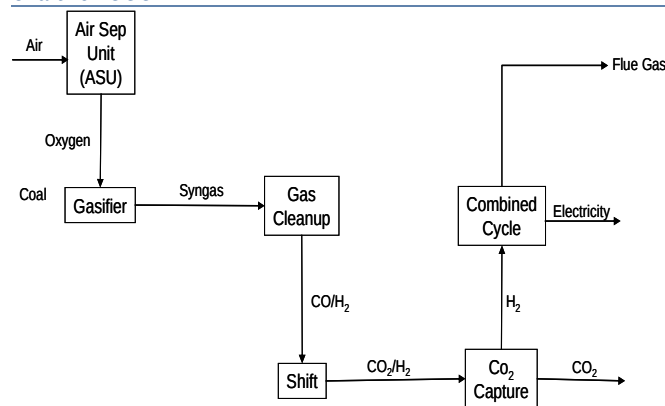
Source: E.ON

Chart 14: Oxyfuel



Source: E.ON

Chart 15: IGGG

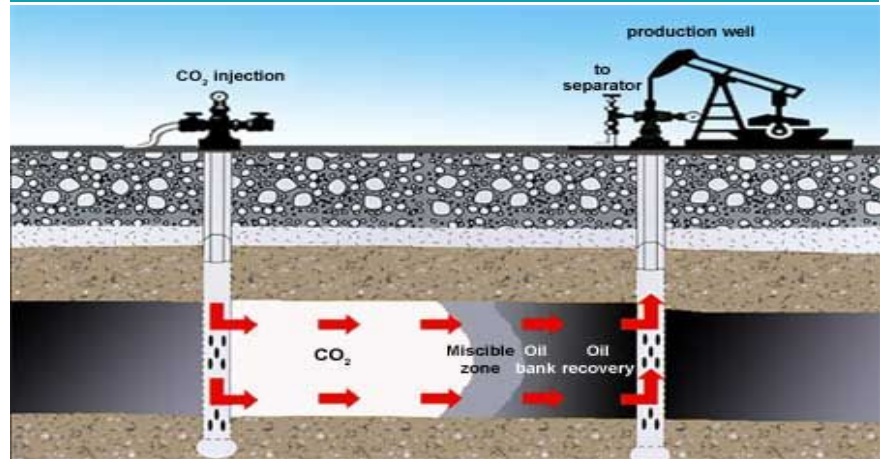


Source: MIT

CCS is already used in some applications

CCS is used today for enhanced oil recovery such as the In Salah field in Algeria. CO₂ is injected into a gas reservoir in order to increase the pressure and force more oil to the surface. In addition, CO₂ is routinely captured during natural gas treatment and in the production of hydrogen, ammonia and ethanol. In most cases the CO₂ is simply vented to the atmosphere. CO₂ is also captured from the flue gas stream at some power plants burning coal or gas and then sold as a commodity to nearby food processing plants for use in soft drinks.

Chart 16: CCS – already proven in small scale for enhanced oil recovery



Source: University of Edinburgh

Pre-Combustion is potentially the best but can't be retrofitted

Siemens and GE appear to be focusing on pre-combustion carbon capture, a more complicated technology. This technology is applied to newly built plants rather than retrofitting existing plants. A power plant that uses this technology can be referred to as IGCC (Integrated Gasification Combined Cycle).

Precombustion (see Chart 12) capture involves removing all or part of the carbon content of a fuel before burning it. In IGCC the coal is not burnt as in conventional steam generation, but first converted into a combustible raw gas (syngas) in a gasifier at high temperatures. This gas, consisting of carbon monoxide and hydrogen, is then scrubbed and the CO converted into CO₂ and H₂.

The next step is for the carbon to be captured and safely stored. The remaining hydrogen is combusted in the gas turbine which drives a generator to produce electricity. The hot waste gases that emerge are mainly nitrogen and pure water vapour; these are used to generate steam. The steam drives a turbine and a second generator to produce power. Because the electricity is generated in a particularly effective combination of gas and steam turbine, this power-plant principle is referred to as a "combined-cycle power station."

An advantage of the Pre-combustion system is that the CO₂ is present in much higher concentrations in the syngas than in post combustion flue gas. In theory, CO₂ capture should be less expensive for pre than post and a higher percentage of CO₂ is captured (90-95%). Whilst pre-combustion reduces the efficiency of the plant, the loss is only slightly less than using the post-combustion method. Among all the power-plant options with carbon capture, the IGCC technology is the only solution on a commercial scale today.

The main disadvantage with pre capture is that capital costs are higher and it is a technically more complex process. For example, there are high levels of NO_x emissions which requires expensive scrubbers. Also the engineering challenges appear greater throughout the IGCC system as it requires more sophisticated technology in the gasification process and ideally within gas turbines themselves.

Post Combustion could be the most widely deployed

The basic method behind the post combustion process is that the CO₂ is isolated from the other flue gases (i.e. post combustion gases) via ammonia which reacts with the CO₂.

For a more detailed description of the process (illustrated in Chart 13) the starting point is combustion where fuel (coal or gas) is burned with air in a boiler to produce steam; the steam drives a turbine to generate electricity. This is followed by the cleaning of the flue gas of impurities such as nitrogen and sulphur. The CO₂ is separated at this stage by a 'scrubbing' process which involves liquid chemical solvents, usually a basic amine to react with the acidic CO₂, which bind with the CO₂ and remove it from the clean flue gas leaving just water vapour and nitrogen to be released into the atmosphere. The captured CO₂ is then transported to a location where it can be stored.

The big advantage of post combustion technology is that it can be retrofitted to the large installed base of existing coal and gas power plants. This is particularly important given the recent boom in coal plant construction in India and China and the new plants that are likely to be built between now and when CCS technology is commercially deployable.

The main disadvantage is that the process of separating CO₂ using a chemical solvent requires a lot of additional energy (roughly twice as much as pre combustion) and therefore cost. Lower plant efficiency (is roughly 30% less than a normal coal plant) means more fuel is needed and consequently more water is needed for cooling.

Some studies referred to by Alstom, who are pioneering this technology, suggest that CO₂ capture via amine scrubbing and compression could raise the cost of electricity from a new coal plant power plant by over 60 percent, although no definitive analysis seems to exist for a full scale capture plant yet. Dow Chemical and BASF are working with the capital goods companies to develop a breed of ammonia that is more efficient and lower cost.

Oxyfuel - not yet out of the lab and into the fire

Another way to capture CO₂ is to use a process called Oxyfuel combustion, which burns fossil fuel in nearly pure oxygen rather than in air (as used in the pre/post-combustion process) resulting in a more complete combustion.

To give a more detailed overview of the process (see Chart 14), nitrogen is removed from the air to create pure oxygen and so the combustion process produces a nitrogen free flue gas with a high concentration of CO₂ and water vapour. The next step is to clean the flue gas of impurities such as sulphur dioxide. The flue gas (water+CO₂) is then cooled to condense the water vapour in the exhaust stream leaving just the separated CO₂.

The primary advantage of this method is that it captures close to 100% of the CO₂ compared to only around 85-95% for pre or post combustion. The oxyfuel process has been designed in a way that it could be retrofitted to existing coal plants as well as newly built plants which means it could be more broadly deployed than either pre or post combustion.

The disadvantage of oxyfuel is that the technology is still at an early development stage which creates a high degree of uncertainty about the cost, although the high concentration of CO₂ should make it cheaper to extract. The main technical problem with this method is that separating oxygen from the air requires a lot of energy and reduces efficiency by 20-30%, about the same as pre or post combustion.

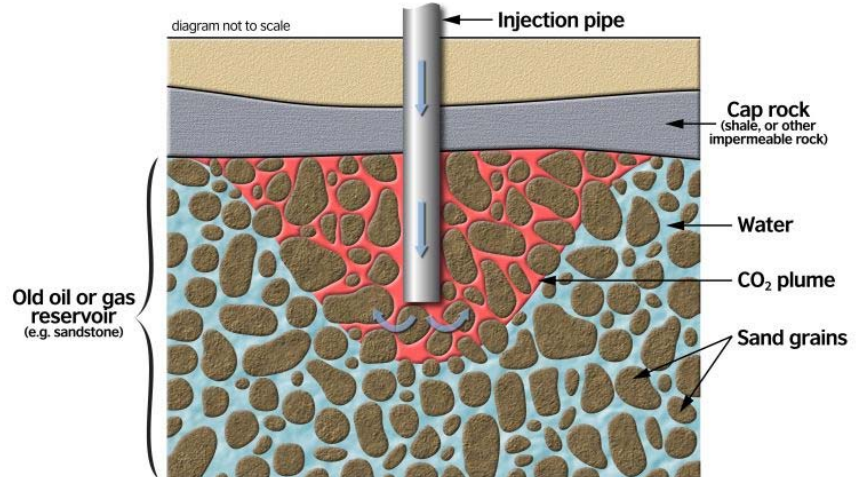
How to store and transport carbon

Full CCS deployment not only requires the development of a technology process for capturing carbon, but also an entire network of large-scale transportation and storage sites. Geological storage aims to store carbon thousands of feet below the earth's surface by trapping the liquefied carbon inbetween rocks.

The three main types of geological storage are oil and gas reservoirs, deep saline formations (potentially under the ocean) and unminable coal beds. Storage sites must generally start at a depth of 800m or lower, where prevailing pressures and temperatures usually keep CO₂ in a liquid state.

CO₂ is more buoyant than water meaning that when injected into a reservoir it will rise up through the pore spaces in the reservoir rock until it reaches the impermeable cap rock. The cap rock must have such low permeability that it prevents any further migration (rising of the carbon) toward the earth's surface. The gas fields in Germany, for example, have proved their tightness across millions of years by their very existence today.

Chart 17: Carbon storage below the surface

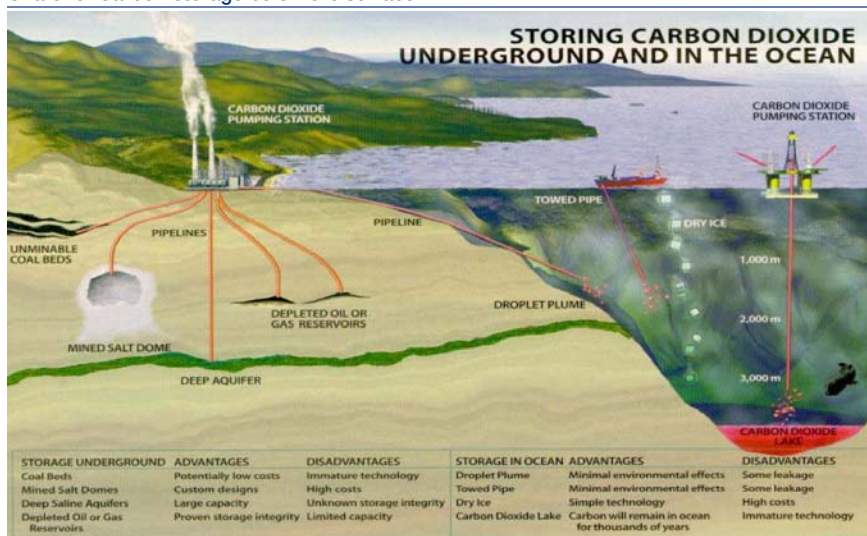


Source: University of Edinburgh

Estimates of the total storage space available vary widely, but they generally indicate that space exists for hundreds of years of CO₂ emissions at current levels. Carbon captured from coal would occupy five times as much space underground as the coal itself as each carbon atom is joined by two oxygen atoms (hence CO₂).

Storing carbon in the ocean is possible given the contrasting densities, however this method is unlikely to be permanent and would increase the acidity of the water, having a negative effect on sea life. The UK is evaluating the old gas reservoirs in the North Sea for storing CO₂.

Chart 18: Carbon storage below the surface

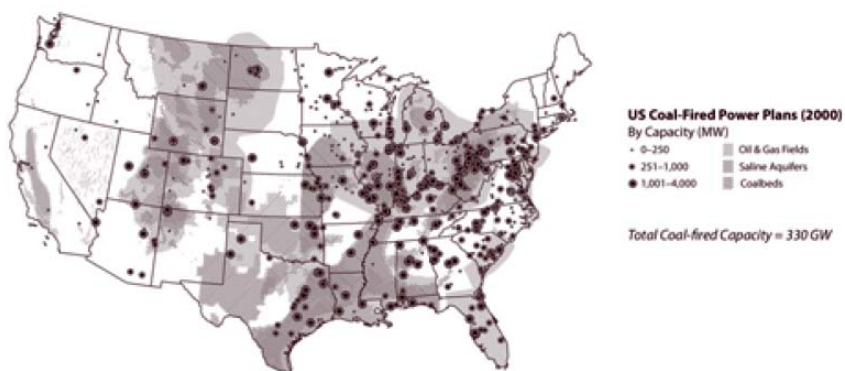


Source: EIA

Transportation a time and cost challenge not technological

Concentrated streams of CO₂ can be moved safely at high pressure through pipelines. Transportation is already demonstrated in the US where there are over 4,500km of pipeline, primarily in Texas, for transporting around 40mn tons of carbon which is used in enhanced oil recovery. Whilst it will take time and a lot of capital to expand the network of pipeline, the constraint here is not a technological one. The cost for building a pipeline will depend on distance and terrain as costs are higher when the pipeline is offshore or routed across heavily congested areas, mountains or rivers.

Chart 19: Location of coal plants relative to potential storage sites



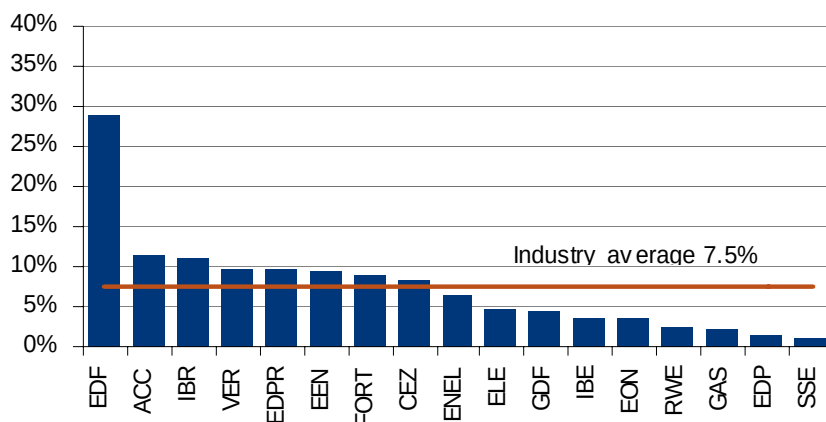
Source: MIT

CO₂ can also be transported as a liquid in tanker ships, similar to the way in which liquefied natural gas (LNG) is often transported. Iberdrola's subsidiary Scottish Power are evaluating the cost and practicalities of transporting carbon from a power plant in Scotland to a storage site in the North Sea via ships rather than pipeline; particularly during a small scale trial where it is harder to justify the pipeline investment.

CCS cost and Utility implications

We think CCS is a material long term earnings driver for utilities as CCS strongly influences the carbon and therefore power price. For the so called 'dirty' utilities, the cost of CCS will determine the capex cost of meeting carbon reduction targets whilst for the 'cleaner' utilities, a high carbon price could mean wider spreads and higher profitability.

Chart 20: Net income impact of €5/ton higher carbon price



Source: Banc of America Securities - Merrill Lynch estimates

Chart 18 above shows the degree to which individual utilities would benefit from a higher carbon price. EDF is in theory the biggest winner given its mostly nuclear asset base although the upside is far less than implied in the chart given the French power price is more regulated. Verbund, Fortum and CEZ are all relatively clean with large amounts of nuclear and hydro capacity (see Table 1). The wind operators are also major beneficiaries; whilst most markets have a fixed tariff, the capacity in Spain gets a market power price plus set €30/MWh premium and the earnings impact is magnified by the high leverage of these companies. However, there is a cap of €91/MWh in Spain so the wind operators would only benefit to an extent.

Table 1: 2013 estimated production (GWh) ranked by coal production

	Nuclear	Hydro	Lignite	Wind	Coal	Gas	Others	Total
E.on	83	14	5	11	104	50	5	271
ENEL	44	71	0	5	86	67	22	296
RWE	45	4	71	10	74	40	2	246
EDF	502	41	1	Subsidiary	43	29	0	619
GDF	48	43	0	7	36	125	0	258
Drax	0	0	0	0	21	0	4	25
Iberdrola	25	15	0	Subsidiary	19	65	0	124
Fortum	30	23	0	0	12	0	0	65
Gas Natural	4	10	0	4	8	67	0	94
SSE	0	3	0	2	8	15	0	28
EDP	1	10	0	Subsidiary	6	12	1	31
Cez	26	0	32	0	0	0	0	59
Verbund	0	28	0	0	0	4	0	32
Iberdrola Renovables	0	1	0	37	0	0	0	38
EDP Renovaveis	0	0	0	22	0	0	0	22
Acciona	0	2	0	13	0	0	0	15
EDF Energy Nouvelles	0	0	0	7	0	0	1	8

Source: Banc of America Securities - Merrill Lynch estimates

Carbon prices need to be €30-40/ton to stimulate CCS deployment

Although the technical processes involved in CCS have been demonstrated in other industrial applications, no commercial power plant scale projects are currently in operation and therefore the costs remain highly uncertain. As well as the absolute carbon price, visibility into how the carbon price will evolve is also crucial to encouraging investment in CCS. The carbon price can be seen as a carrot (incentive) or stick (penalty) depending on your outlook but ultimately it must be set at a level where utilities switch capacity to cleaner forms (wind/solar) or where technologies such as CCS can earn the required rate of return to justify the investment.

Table 2: Cost of carbon avoided using CCS

Institution	€/ton
EPRI	36-53
McKinsey	31-48
IEA	36-68
Australia National Labs	41-53
MIT	49-60
NTEL	50-72
ICF	26-31
European tech platform	18-30
Harvard	21-35
Average	34-50

Source: Various

The estimates of industry experts (see Table 2) conclude that CCS will ultimately require a carbon price of around €40/ton (versus €15/ton today) to justify the investment. As we said earlier, given coal power plants are the major source of CO₂ emissions, they are the best way of reducing CO₂ and an appropriate carbon price will have to be set as a sufficient incentive to get CCS built. Our current valuations for utility companies are only based on €23/ton from 2013.

We think the cost estimates of more than €50/ton could be on the high side as the cost reductions from innovation and manufacturing scale are under-estimated judging by some of the more recent forecasts such as the report by Harvard which suggested a mid point of €28/ton was needed.

Dr Nicolas Vortmeyer, chief executive of Siemens energy fossil power generation, stated in a FT article in July that a carbon price of at least €30/ton was needed to make CCS economical in the long run. The current cost of deploying CCS is much higher as prototype systems are patched together with components largely designed for other applications such as enhanced oil recovery. We have spoken to several utilities involved in small scale trials who all endorsed the view that €30/ton carbon is likely to prove a minimum requirement.

Table 3: New build cost (€/MWh) for conventional coal plant

Capital cost vs					
CO ₂ price	10	20	30	40	50
1400	53	60	68	75	83
1700	57	65	72	80	87
2000	62	69	77	84	92
2300	66	74	81	89	96
2600	71	79	86	94	101

Source: Banc of America Securities - Merrill Lynch estimates

Cost comparison breakdown gets to a €45/ton carbon conclusion

In Table 4 below we layout the generation cost of a CCS equipped coal plant compared to a conventional coal plant. The total cost difference, once transportation and storage are considered, is almost €20/MWh. This assumes the current carbon price of €15/ton. In order to raise the conventional generation cost to the equivalent level of CCS, we calculate a carbon price of close to €45/ton is needed. This is roughly consistent with the third party estimates we showed in Table 2. We would assume that as the technology is refined the thermal efficiency of CCS is improved and the capital cost is lowered which would reduce the carbon price needed.

Table 4: New build cost (€/MWh) for CCS plant

Capital cost vs					
CO ₂ price	10	20	30	40	50
1400	67	68	69	70	71
1700	72	73	74	75	76
2000	76	77	79	80	81
2300	81	82	83	84	85
2600	86	87	88	89	90

Source: Banc of America Securities - Merrill Lynch estimates

Note - both examples assume a 10% WACC

The vast majority of incremental costs for CCS are for the capture part (c.75%) rather than the transportation and storage (25% combined). The transportation cost could be much lower once a national network has been established, but the initial cost would be higher. The costs for injecting the CO₂ into geologic formations will vary on the formation type and its properties. Costs increase as reservoir depth increases and a range of injection costs has been given as wide as \$1-8/tCO₂. We have not assumed any provision for future storage seepage as is common with nuclear plants.

The build cost of a CCS plant is higher because it is a more complicated process with more steps involved. The current build cost of CCS is higher than we have assumed in Table 3 but we are trying to get an idea about the long run cost once the technology has been better developed.

The thermal efficiency is lower because a lot of energy is consumed in the capturing process (this varies between pre or post capture processes). The variable costs are higher because the lower efficiency means more coal is needed to generate a given amount of electricity which in turn means more water is needed for cooling. There is also the variable cost of the amines used in the scrubbing process for the post production method. We have assumed CCS cuts carbon emissions by 85% which we think is a conservative assumption compared to some studies which suggest CCS would reduce emissions by 90-95%.

Table 5: Cost difference between conventional coal generation and carbon capture (once commercialised)

Conventional coal assumptions		CCS assumptions	
Spot Coal price (\$/t)	80.0	Spot Coal price (\$/t)	80.0
Exchange rate (€/£)	1.45	Exchange rate (€/£)	1.45
Coal price (€/t)	55.2	Coal price (€/t)	55.2
Coal price (€/MWh)	7.3	Coal price (€/MWh)	7.3
Thermal efficiency	45%	Thermal efficiency	28%
CO2 emissions (kg/MWh)	750	CO2 emissions (kg/MWh)	113
O&M variable cost (€/MWh)	3.2	O&M variable cost (€/MWh)	10.0
O&M fixed costs (€/kW)	30,000	O&M fixed costs (€/kW)	30,000
Plant life (yrs)	45	Plant life (yrs)	45
Load factor (%)	75%	Load factor (%)	75%
Spot Carbon price (€/ton)	15.0	Spot Carbon price (€/ton)	15.0
Coal cash costs (€/MWh)		Coal cash costs (€/MWh)	
Fuel cost	16.2	Fuel cost	26.1
Carbon cost	11.3	Carbon cost	1.7
O&M variable cost	3.2	O&M variable cost	10.0
Total marginal cost	30.7	Total marginal cost	37.8
O&M fixed costs	4.6	O&M fixed costs	4.6
Total cash costs	35.2	Total cash costs	42.3
Coal capital cost		Coal capital cost	
Build cost (€ per kW)	1,600	Build cost (€ per kW)	2,000
Plant life (yrs)	45	Plant life (yrs)	45
Cost of capital (%)	10.0%	Cost of capital (%)	10.0%
Load factor (%)	75%	Load factor (%)	75%
Total capital cost (€/MWh)	24.7	Total capital cost (€/MWh)	30.9
Coal cost (€/MWh)	59.9	Coal cost (€/MWh)	73.2
		Transport	2.25
		Storage	2.25
		Total (€/MWh)	77.7

Source: Banc of America Securities - Merrill Lynch estimates

Pre combustion seems to have a cost advantage over post

The cost for the different CCS technologies (pre/post combustion) varies at the capture stage rather than the transportation and storage which are similar. As well as the physical capex cost to add extra processes for flue gas cleaning etc, CCS significantly reduces a plants efficiency because of the extra energy required to run the capture equipment, recover CO2 from the amine solution and compress the CO2 to a supercritical fluid.

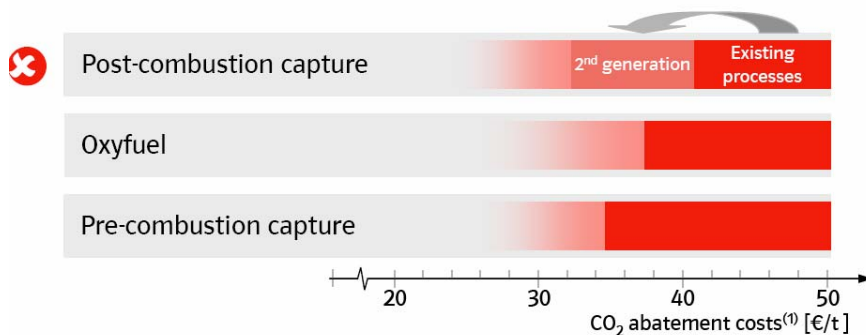
The efficiency loss does vary by the process used as the efficiency for a pre combustion CCS plant is 34% while the efficiency of a post combustion plant is understood to be around 23%. Post combustion has the lower efficiency because of the energy used by the chemical solvent in the scrubbing process. We assumed the efficiency of a conventional coal plant is 45% which is based on the latest turbines from Mitsubishi. However, the installed base of coal plants is likely to have a much lower level of thermal efficiency as they will be largely using older versions of turbines.

In Table 3 we took the mid point of the efficiency range for CCS but if we were to compare pre and post we would get a cost of €73 and €83/MWh respectively. However, this assumed the capital cost of the two systems is similar which is debatable. Given post combustion is designed as a retrofitted system it may be deployed on a larger scale (ie equip more plants) which may bring down the cost. However, as things stand it appears that a pre combustion system is cheaper as this can be specifically designed for new power plants rather than having to adapt the solution to fit existing plants.

Post combustion costs may surpass pre combustion

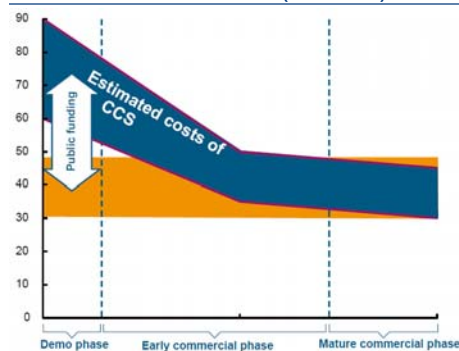
An E.ON presentation from 2008 stated that the carbon abatement cost of using post combustion was €40-50/ton, oxyfuel was €38-50/ton and pre combustion was €34-50/ton. However, the company believes that the second generation of post combustion equipment will bring the cost down to €32/ton which would make it the lowest cost solution.

Chart 21: E.ON's cost comparison of the different processes



Source: E.ON

Chart 22: Economics of CCS (€/ton CO₂)



Source: McKinsey study

Cost evolution linked to innovation and scale

According to the European technology platform for zero emission fossil fuel power plants, the present cost of CCS was estimated to be €50-100 per tonne of CO₂. This cost is expected to come down once the technology is refined and manufactured in scale (see Chart 20). However, there is considerable disagreement and uncertainty about where the costs will ultimately come down to as illustrated in the forecast range of €18-72/ton in Table 2.

In the meantime, it is clear that public funding will be needed to bridge the gap between the initial demonstration cost and when the technology is fully commercialised. Carbon today trades at around €15/ton in the European Union (and zero in the US) which is insufficient to stimulate investment based on all the cost analysis we and third party researchers have done. Either the carbon price would have to be progressively raised over the next decade (possible but politically difficult) or direct subsidies will have to be given to set up pilot CCS projects. Fortunately, political support has accelerated recently and a number of projects are underway (see Table 6). A lot of the trials appear to focus on the post combustion method because it would be quicker to deploy on a trial stage than a newly built coal plant using pre combustion.

27 November 2009

Table 6: Selected pilot CCS projects

Location	Companies	Technology/Description	Output (MW)	Start date
Abu Dhabi	BP-Rio Tinto	NGCC + EOR + Storage in saline aquifer	420	2013
China	Huaneng , GreenGen	IGCC + shift + precombustion	100	2015
UK	E.ON, Mitsubishi	IGCC + shift + precombustion (may be capture ready)	450	Postponed
UK	SSE, Doosan Babcock	PC (supercritical retrofit) + post-combustion capture	500	2011
UK	SSE, Doosan Babcock, Siemens	Oxyfuel	1000	2011
US	FutureGen	IGCC + shift + precombustion	275	2012-2017
Scotland	BP / SSE DF1, Peterhead	autothermal reformer + pre combustion, storage in oilfield - EOR	350	2010
US	BP DF2, Carson,	IGCC + post-combustion amine, potential storage in the oilfield - EOR	500	2011
Norway	Karsto,	NGCC + post-combustion amine, potential storage in the oilfield - EOR	430	2009
Netherlands	Nuon	IGCC with option to capture	1200	2012
UK	Powerfuel, Hatfield Colliery,	IGCC + shift + precombustion	900	2010
UK	RWE	Post-combustion		2016
Australia	Stanwell	IGCC + shift + precombustion, storage in saline reservoir	100	2012
Holland	E.ON, GDF Suez	Pulverized Coal. Will store CO2 in north sea.	1100	
Poland	PGE, Alstom	Advanced Amines	150	
Canada	TransAlta, Alstom	Chilled Ammonia	200	
Norway	StatoilHydro	Advanced Amines, stored in a deep saline acquifer in the North Sea		2007
Germany	VattenFall, Alstom	Oxy Comb. May be extended to 300MW.	30	2008
Germany	RWE, BASF, Linde	Pre combustion. Store in saline aquifers 550km away, transport the gas in a pipeline.	450	2014
Virginina	RWE, Alstom, ADP	Ammonia based technology		
illinois	Edison	Post-combustion	1536	2012
North Dakota	Great River Energy	Post-combustion	1110	2012
Canada	Nova Scotia Power	Post-combustion	320	2012
Utah	Intermountain Power Agency	Post-combustion	950	2012
Oregon, Ohio	First Energy	Post-combustion	176	2012
West Virginia	American Electric Power, Alstom	Ammonia based technology. CO2 stored 2km underground.	20	2009
Finland	Fortum	Post combustion	565	2015
UK	Iberdrola, Aker	Post combustion with storage in North Sea	300	2014
UK	Centrica / Progressive Energy	IGCC + shift + pre-combustion	800	Postponed
Indiana	Duke Energy	IGCC + shift + precombustion	630	2012
North Dakota	Basin Electric Power Cooperative	Ammonia based technology	120	2012
Oklahoma	American Electric Power	Ammonia based technology	200	2012
Texas	NRG	Ammonia based technology	125	2012
Canada	TransAlta	Ammonia based technology		2012
UK	RWE	CCS Technology	1000	2016
China	Peabody Energy & partners	CCS Technology	650	2018
North Dakota	AMP-Ohio	Ammonia based technology	1000	
California	BP-Rio	IGCC	500	2014
Australia	BP-Rio	IGCC	500	2014
Canada	EPCOR	IGCC	500	2015
China	Huaneng,	IGCC	400	2015
Norway	Karsto,	NGCC	384	2012
Norway	Mongstad,	Post-combustion	280	2014
UK	Powerfuel,	IGCC	900	2010
Netherlands	RWE	Post-combustion	160	
Canada	SaskPower,	Post-combustion	300	2011
Canada	SaskPower,	Post-combustion	100	2015
UK	SSE	Post-combustion	800	2014
Germany	Siemens,	IGCC	1,000	2011
Australia	Stanwell,	IGCC + shift + pre-combustion, storage in saline reservoir	100	2012
Netherlands	Nuon	storage in saline reservoir	1,300	2010
Netherlands	Electrabel	Pulverized Coal	800	
Italy	ENEL, Eni	Post-combustion	660	2012
Italy	ENEL, IFP public research body	Post-combustion	250	2015
Poland	PGE Elektrownia	amine based scrubbing technology	858	2015
Germany	E.ON	Post combustion technology developed by MHI	30	2010
New Jersey	SCS	IGCC with storage 70 miles offshore	650	
Texas	Tenaska, Fluor	Working on design before deciding to go ahead	600	
Alabama	Southern Company, Mitsubishi	Post-combustion	2525	2011

Source: Companies, Banc of America Securities - Merrill Lynch estimates

What the big, coal exposed European Utilities are doing

There are a number of CCS projects already established for enhanced oil recovery such as in Algeria and the North Sea. The first pilot-scale CCS power plant began operation in Schwarze Pumpe, Germany in September 2008. However, whilst carbon has been captured, because of pending legislation it has yet to be pumped into the ground for storage. Vattenfall has developed a 30MW pilot plant which could be extended to 400MW, although the capital cost is believed to be around €1bn.

RWE are one of the biggest coal producers in Europe and are investing in developing demonstration projects in Germany, UK, US and the Netherlands. The company believes multiple projects are needed to evaluate the multiple technologies on offer. RWE is working with a variety of capital goods companies and chemical companies such as BASF and Linde to develop amines. In RWE's opinion, the post combustion technique is slightly more developed at this stage.

Iberdrola's Scottish Power subsidiary has two major coal plants in the UK. The company is planning a 300MW trial at its Longannet site in Scotland which is the third largest power station in Europe. Once the carbon is captured it will be stored in the North Sea and the company is working with Aker and Shell to understand pipeline transport and storing carbon in depleted gas fields. The company is hoping to win one of the UK grants and would expect to have the project up and running by 2014.

Enel, who is the second biggest coal power generator in Europe, signed a cooperation accord in October 2008 with Eni to develop CCS. The company is working on a pilot plant in Brindisi, Italy which should be completed by the end of 2009 and a commercial size project at its Port Tolle plant in Italy which will be commissioned in 2015. Enel announced in Sept 09 that it would conduct a feasibility study for CCS at a coal plant in China on behalf of the Chinese government.

E.ON is working with Siemens on a post combustion trial project in Germany which is scheduled to start in late 2009. E.ON has postponed a 300MW project in Kingsnorth, UK due to the fall in power demand. The company is continuing with trials in the US and Holland. E.ON is focusing its efforts on post production because of the retrofit potential, but acknowledges the winning technology is unknown today.

CEZ has a considerable amount of lignite coal capacity. Whilst the company is looking into CCS, it has not a key part of its 2020 strategy as the company believes CCS will only be commercially deployable after this period. However, the company is committed to supporting one trial project and has identified two sites which it is currently evaluating.

Not everybody is fully onboard with CCS

In stark contrast to the support for CCS listed above, Drax, the sixth biggest coal power generator in Europe, has shown limited interest in CCS. In an interview the CEO gave to the Guardian newspaper in May, a view was expressed that CCS may not prove to be the answer to reducing carbon emissions and would be expensive. In the meantime the company is investing in more near term solutions such as co-firing which involves burning biomass alongside coal. The company has commented that more visibility and a clearer framework is needed to justify investment in CCS and would most likely be a follower rather than a leader.

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