Policy Briefings

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EVALUATION OF TWO ALTERNATIVE CARBON CAPTURE AND STORAGE TECHNOLOGIES

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Key Points

- ***Carbon dioxide capture and storage (CCS) is one of the technologies for fighting climate change in the future. The use of CO_2 for enhanced oil recovery (EOR) paired with storage in deep saline formations (DSF) could effectively help to support CCS demonstration projects, reduce costs and thus guarantee the future economic viability of power plants incorporating both EOR and CCS.***
- ***CCS without EOR is highly unprofitable at both current and expected carbon market prices.***
- ***The profitability of these technologies is highly influenced by the volatility of future electricity prices, oil prices and carbon allowance prices.***
- ***Investment in EOR and secondary DSF storage can only be profitable with a long-term equilibrium price for oil higher than $51/barrel. When the investment decision can be made at any time the trigger value for optimal investment is significantly higher at $89/barrel. However, an increase in the investment cost can substantially raise these trigger prices.***

Carbon dioxide capture and storage (CCS) is frequently seen as an effective means of stabilising the global climate and as a key technology in the future portfolio of carbon abatement technologies together with descarbonising electricity generation and improving energy efficiency. Accordingly, the IPCC suggests that if the CCS option is not intensively exploited the cost of a 50%-reduction in emissions by 2050 would be 71% or USD 1.28 trillion higher. However, CCS technologies still need to attain a higher degree of maturity before they can play a significant role in the portfolio of mitigation options, and it is broadly expected that CCS will not become commercially available in the power sector before 2020.

One CCS strategy that offers attractive features is the use of captured carbon in **CO_2 Enhanced Oil Recovery (CO_2-EOR)**, which is a method of extracting oil from wells in which traditional techniques are unable to recover any more. It allows for a significant rise in the total amount of oil extracted and therefore in the profitability of the wells involved. Thus, EOR can help to store carbon captured, inter alia, at coal-fired power plants, which is the kind of plant on which we are focusing in this analysis. In the context of high oil prices and decreasing oil extraction in mature basins, investment in CCS in combination with EOR might become a profitable strategy.

But the profitability of installations of this kind is affected by several factors, such as **the cost of CCS in combination with EOR**, which depends mostly on the amount of electricity needed to compress CO_2; **the carbon emission allowances saved** that can be sold if the company operates within an emission trading scheme; **the benefits from the use of CO_2** as an input in the EOR process to extract oil; **and the benefits derived from public support** such as subsidies, fiscal incentives, loans, and so on. Therefore, profitability depends on the risks and the uncertainties caused by changes and volatility in electricity, oil and carbon emission allowance prices.

There are several barriers to the implementation of CCS technology, including financial, political, technical and public acceptability barriers. As of mid-2012 there were eight CCS projects up and running, capturing 23.2 million tonnes per annum. Another seven projects were under construction with a total additional capacity of 12.0 Mtpa. None of the existing projects is connected to power generation plants, though 2 of those under construction are for power generation and EOR.

A key issue is that implementing CCS technologies leads to increases in capital cost and operating expenses and decreases energy efficiency at plants of this kind.

Analysis of commodity prices for managing risk

A **stochastic model** analysis of commodities brings to light the expected tendencies of electricity, oil, and carbon allowance prices in the futures markets (risk-neutral world).The data used are for all 713 days from 12/01/2009 to 08/31/2012, consisting of 32,250 observations of monthly UK Base Electricity Futures on the Intercontinental Exchange. The information also includes the cost of fuels and CO_2 allowances. The term structure of futures contracts for **electricity** shows seasonality together with a process of mean reversion.

In the case of **oil**, the prices on the futures markets show no seasonality, but they do show a mean-reverting behaviour. The long-run equilibrium price shows some volatility. Moreover, the term structure of future prices for oil incentivises early investment.

Finally, the price of **carbon allowances** shows no seasonality and no mean-reverting behaviour, but does show a stable slope with the initial price being a little volatile but becoming less so with each passing day. Carbon prices are relatively low and thus do not contribute significantly to generating incentives for investing in CCS.

The cost and profits of investment in CCS with EOR and DSF

For the purpose of the analysis a baseline scenario is defined with representative values based on the relevant literature. However, it should be noted that each specific project will have its own characteristics such as the distance between capture and storage or storage capacity available, so parameters would need to be changed accordingly.

Revenues and costs are considered in the following three stages: capture, transportation and storage. It is assumed that the construction of the CCS unit will take 4 years for the investment decision to the time when plant becomes operational. It is also assumed that once the investment project is approved (and implemented) the useful lifetime of the plant will be 20 years, and no additional decommissioning costs are considered for CO_2-EOR.

To obtain the cost and profits for projects of this kind, many factors need to be taken into account. On the one hand, the existence of the CCS unit entails a **loss of efficiency** which translates into a lower electricity output for the same amount of fuel. This in turn means less revenue from electricity production. The efficiency loss is estimated to be 10.34%, equivalent to 26.67% of the electricity that would be generated without CCS. Logically, there is a shortfall in electricity production which will be covered by other electricity generating units that could be either renewable or gas-fired power plants.

On the other hand, although the ratio involved is high CCS technologies cannot capture all the CO_2 emitted. Here it is assumed that **85% of emissions from a coal-fired power plant can be captured**. Considering a plant with a capacity of 1,000 MWe which is working 80% of the time, the yearly output without CCS is thus 7,008TWh. The numbers can be seen in Table 1.

Table 1. Coal-fired Power Plant and CCS Cost .

Without CSS			With CSS		
Capacity installed	1000	MWe	Capture efficiency	85	%
Capacity factor	80	%	Annual capture	5,231,935	tCO_2/year
Yearly operation	7,008	hours	Annual emission	923,283	tCO_2/year
Annual output	7,008,000	MWh/year	Plant efficiency	28.43	%
Plant efficiency	38.77	%	Electricy consumed	1,868,800	MWh/year
HR	8.3721	GJ/MWh	Capacity installed	733.33	MWe
Fuel Energy needs	65,065,726	GJ/year	CSS Overnight Cost	1,735	$/kW
Emission factor (100% efficiency)	94.6	$KgCO_2$/GJ	CSS Total Overnight Cost	1,272.333	M$
CO_2 emissions	0.878	tCO_2/MWh	Variable O&M Cost	4.80	$/MWh
Yearly emissions	6,155,218	tCO_2/year	Total Variable O&M Cost	24.668	M $/year
			Fixed O&M Cost	33.54	$/kW
			Total Fixed O&M Cost	24.596	M $/year
			Total Fixed&Variable O&M Cost	49.264	M $/year

From these calculations it can also be shown that 1,868,800 MWh of electricity generation will be lost per year at a cost that can be expected to increase. Moreover, 5,231,935 tCO_2/year will cease to be emitted at a value that can also be expected to grow year by year. This could be considered as a benefit if CO_2-EOR projects paired with storage in deep saline formations (DSF) were eligible to take part in CO_2 trading schemes. Furthermore, the cost of investing in CCS is $1,272.333 M and the fixed and variable operating and maintenance costs per annum amount to $49.264 M.

In relation to EOR storage, the CO2 needed varies from 0.25 to 0.40 tCO_2 per barrel of oil produced. It is then assumed that with CO_2-EOR a further 3 barrels of oil can be extracted per tonne of CO_2 injected while oil production is decreasing together with the need of CO_2. Thus, the total production in 20 years will be 138,969 M barrels, so for a $10.50/barrel EOR operation cost, the total EOR operation cost will be $1,459.175 M. Moreover the CO_2 injected will be 46.323 M tCO_2, but if retention efficiency is 60% as some studies argue, then 27.7956 M tCO_2 will be sequestered in the oil field. The remaining 58.3157 M tCO_2 will be injected in the

DSF. For a transportation and storage cost of \$3.075/tCO_2, the total DSF transportation and storage cost will be \$179.321 M for CO_2 -EOR paired with DSF. Table 2 compares the cost of the $C0_2$EOR + DSF technology and CO_2DSF technology alone. From these calculations it can also be shown that 1,868,800 MWh of electricity generation will be lost per year at a cost that can be expected to increase. Moreover, 5,231,935 tCO_2/year will cease to be emitted at a value that can also be expected to grow year by year. This could be considered as a benefit if CO_2-EOR projects paired with storage in deep saline formations (DSF) were eligible to take part in CO_2 trading schemes. Furthermore, the cost of investing in CCS is \$1,272.333 M and the fixed and variable operating and maintenance costs per annum amount to \$49.264 M.

Table 2. Summary of Profits and Costs.

	CO2-EOR + DSF (20 years)	CO2-DSF (20 years)	CO2-DSF (40 years)
Stochastic Profits			
Oil	138.969 M barrels	-	-
CO_2 EOR	27.7938 M tCO_2	-	-
CO_2 DSF	58.3157 M tCO_2	5,231,935 tCO_2/year	5,231,935 tCO_2/year
Stochastic Cost			
Electricity	1,868,800 MWh/year	1,868,800 MWh/year	1,868,800 MWh/year
Deterministic Cost	**\$4,237.312 M**	**\$2,579.377 M**	**\$2,901.141 M**
CSS Capture Cost	\$2,257.613 M	\$2,257.613 M	\$2,257.613 M
EOR Transportation Cost	\$341.203 M	-	-
EOR Operation cost	\$1,459.175 M	-	-
DSF Transportation & Storage costs	\$179.321 M	\$321.764 M	\$643.528 M

The present value of investment in CCS with EOR and DSF

The value of such an investment will depend on the stochastic prices of electricity, oil and carbon, the present value of deterministic investment and operation and maintenance costs, the loss of efficiency of the coal-fired power plant and the quantity of oil obtained per tonne of CO_2 injected. The riskless interest rate used is 1.49%, which corresponds to UK debt maturing at 10 years.

Table 3. Base Case Results

CO_2-EOR+CO_2-DSF (20 years)		
Net Present Value (NPV)	**+4,639.1**	**M \$**
Deterministic cost	-4,237.3	M \$
Electricity costs	-4,091.8	M \$
Oil profits	+11,432.0	M \$
Carbon profits EOR	+416.0	M \$
Carbon profits DSF	+1,120.2	M \$
NPV/tCO_2 captures	**44.33**	**M \$**
NPV/barrel	**33.38**	**M \$**

Table 3 shows the Net Present Value (NPV) and other values related to it. Thus, the NPV of CO_2-EOR with secondary DSF storage is positive at +4,639.1. These results are mainly due to the high prices of oil. It should be noted that the long-term equilibrium price (estimated from the futures market for oil) is \$94/barrel, and that 3 barrels can be extracted per tonne of CO_2. Therefore, a sensitivity analysis is also conducted, taking into account the uncertainty and variability of oil prices. The model gives NPV=0 when the price of oil is \$50.95/barrel. As Figure 1 shows, if the oil price is below this value it would not be profitable to invest in this technology. When there is a cost increase of \$2 M a minimum price of \$69.37 \$/barrel is necessary.

The option value of investment in CCS with EOR

When the decision whether to invest or not can be made at any time in a given time-frame (10 years for instance), the trigger price for an optimum investment is \$89/barrel, higher than the price in the base case. This result shows a significant influence of the impact of the carbon price growth rate - significantly higher than the risk-free interest rate - which means that higher oil prices are needed to make the investment at initial moment, when there is the possibility of postponing the investment.

The option value of investment in CCS without EOR

Finally, for the case of non-EOR, that is when carbon is merely stored in DSF and oil is not extracted, the decision whether to invest or not to invest depends largely on the carbon allowance price, which in turn depends on its volatility and its growth rate. Thus, to obtain an NPV of 0, the price would have to range from \$85.34 to \$203.40/tCO_2.

However if the expected rise in the price of carbon in a risk-neutral world is greater than the riskless interest rate, the rational decision is to postpone the investment. Thus, if governments are especially interested in developing this kind of technology, subsidies might be needed. If the subsidy is only available at the initial time then the value of waiting is the same as in the previous cases. The minimum subsidy in the initial moment is the exact difference between the continuation value and the net present value at that time.

Table 4 shows the amount of subsidy needed to develop this technology and not to wait, taking into account different carbon prices and their volatility, and assuming that the growth rate of carbon price in the future market is 0. As can be seen, when carbon prices increase the NPV also increases, but so does the value of waiting. Moreover, lower volatility has a very significant effect, reducing the continuation value and thus encouraging investment earlier.

Table 4. Subsidy (M$) without EOR and no growth in carbon prices in the future market

Carbon price	NPV	Volatility = 0.4535		Volatility = 0.30		Volatility = 0.20		Volatility = 0.10	
		Wait	Subsidy	Wait	Subsidy	Wait	Subsidy	Wait	Subsidy
40	-3,261	981	4,242	409	3,671	114	3,375	2	3,263
50	-2,409	1,435	3,844	711	3,119	275	2,684	17	2,426
60	-1,556	1,931	3,487	1,083	2,639	524	2,080	82	1,639
70	-704	2,470	3,173	1,517	2,221	861	1,564	251	955
80	149	3,034	2,885	2,004	1,855	1,281	1,132	574	425

Conclusion

The use of CO_2 for EOR paired with storage in DFS could effectively help to support CCS demonstration projects, reduce costs and thus guarantee the future economic viability of power plants incorporating both EOR and CCS technologies. We show that these investments in CCS with EOR face a cost increase in operation and maintenance and an efficiency loss and therefore are not highly profitable at current oil prices. Only investments with EOR and secondary DSF storage may be profitable (NPV>0) with a long-term equilibrium price for oil higher than $50.95/barrel. When the investment decision can be made at any time, the trigger value for optimal investment is significantly higher at $89.29/barrel. However, an increase in the investment cost can substantially raise these trigger prices.

Moreover, it is shown that current carbon prices and their trend and volatility do not significantly contribute to generating major incentives for CCS without EOR technologies. For them to be profitable, there must be an initial carbon price equivalent to a constant carbon price of $73.91/tCO2. Therefore, a rational decision would be to postpone the decision on investment without EOR. In this case, significantly higher prices for carbon are needed, and this opens up the possibility of designing effective subsidy schemes that support early investment decisions. However the subsidies are very high and run into billions of dollars.

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