carbon capture journal

May / June 2010 Issue 15

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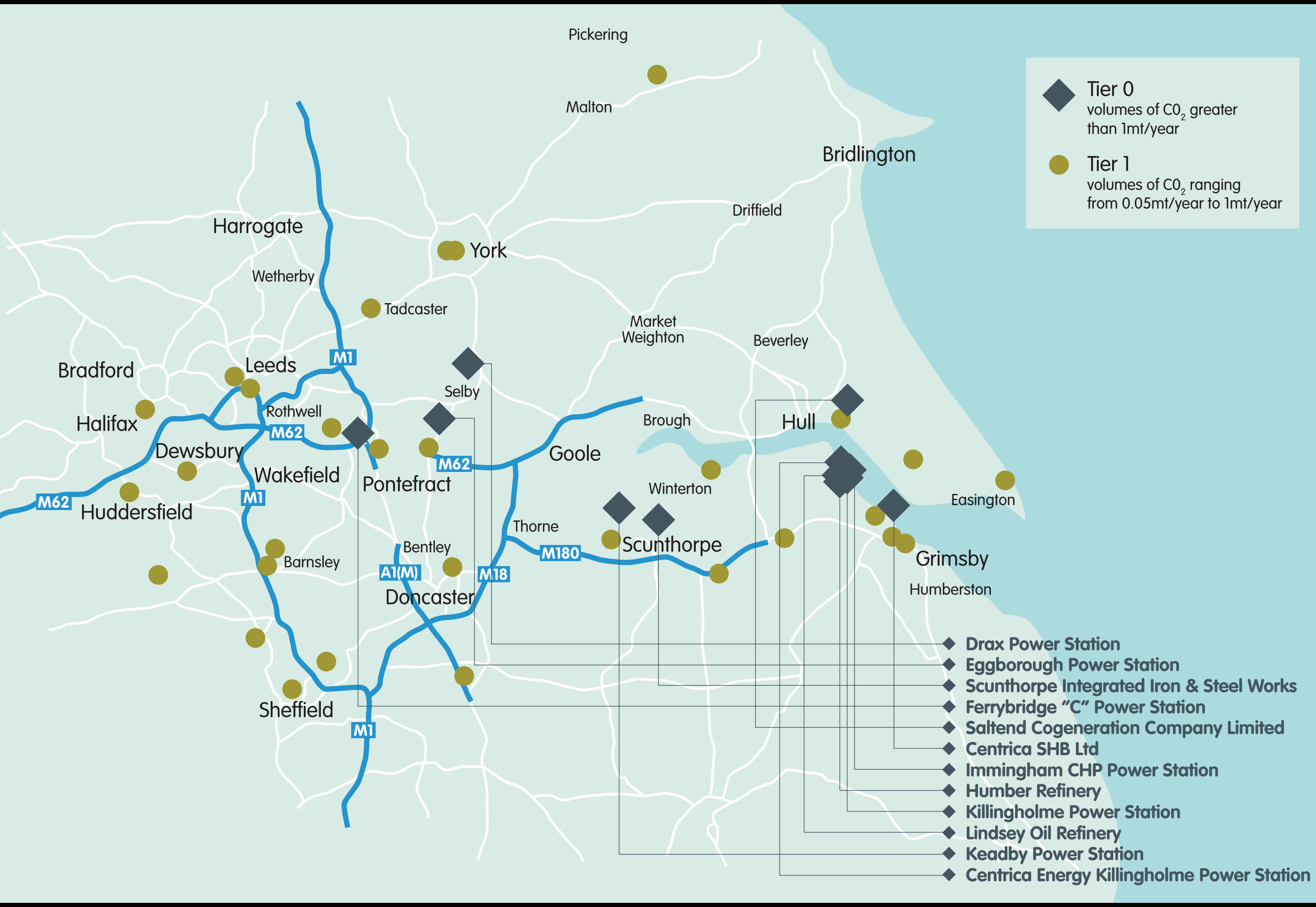
CCS legal column



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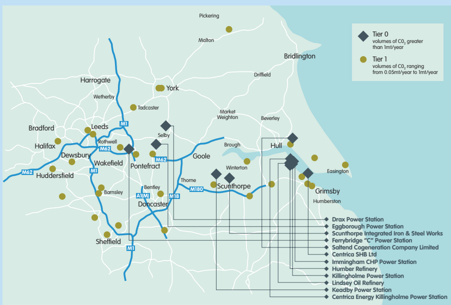
Front cover:
A proposed CCS network in Yorkshire and Humber could dramatically reduce costs for CO2 transport and storage in the region compared to stand alone projects (map courtesy of CO2Sense Yorkshire)



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Pöyry - implications of increased renewable power generation

This article is the second in a series that considers features of the future power markets in which CCS will be competing with a view to understanding the potential implications for the here and now. This article focuses on how the increase in intermittent renewable generation could reshape the wholesale power markets before considering the implications for CCS.

By Steve Esau, Pöyry Energy Consultants

Globally there are moves afoot to significantly increase the level of renewable generation. For example the European Union has committed itself to sourcing 20% of its energy from renewable sources by 2020, while the US and China currently have the highest and second highest level of installed wind generation respectively. As wind generation becomes a significant source of electricity, its intermittent nature means that there will be times when it meets most of the demand, times when it meets very little, and everything in between.

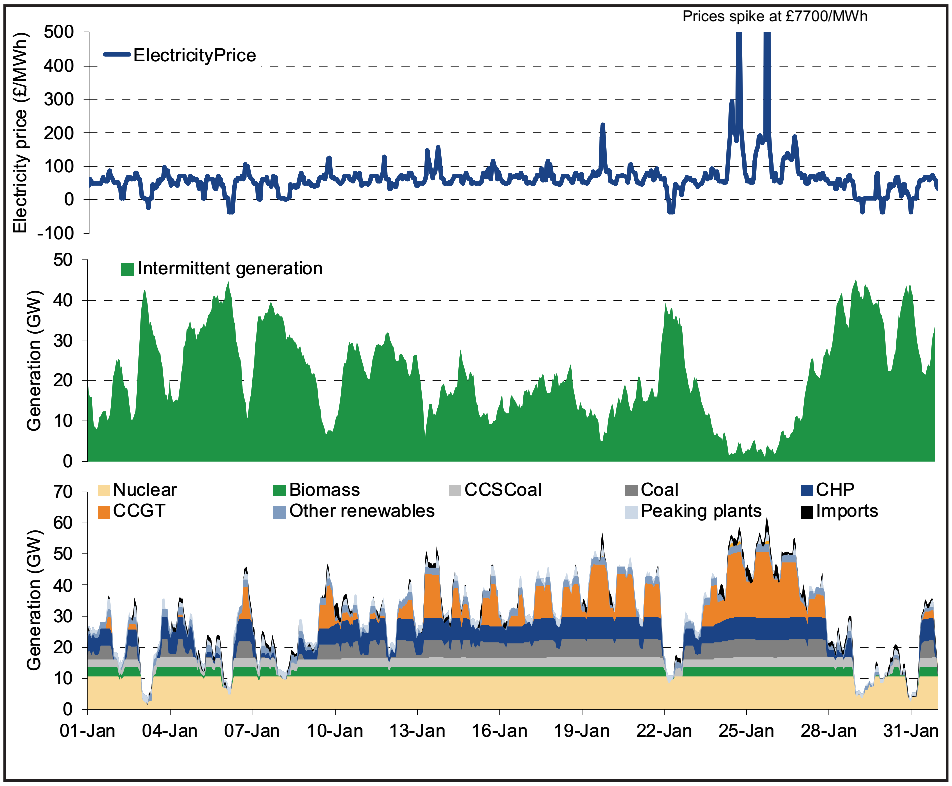
The uncertainty of the level of demand wind will meet more than a few hours ahead poses a significant challenge to the rest of the power system to ensure that it is able to respond to satisfy demand in a cost effective manner with negligible carbon emission. In 2009 we undertook an analysis of the impact of intermittency on the Great Britain (GB) and Irish electricity markets[1], and this article summarises the key findings of this study before considering the implications for CCS.

Key points from the Intermittency Study

In a world with a significant level of intermittent generation, both the level and timing of the demand that conventional generation[2] will need to meet will become increasingly uncertain, raising issues about the level and volatility of prices and the operational profiles of thermal plants. This will make it more challenging to develop business cases for investment in conventional generation.

Our study examined the impact of the wind/weather profiles from 2000 to 2007 on a plausible renewable-focused generation mix between 2010 and 2030. The following figure illustrates the outcome when we simulated the wind/weather profile from 2000 in January 2030, by which time we assume that the GB market has 43GW of installed wind generation capacity.

1 www.ilexenergy.com/?t=7_9Archive2009#PublicInt ermittency
2 The term conventional generation refers to dispatchable thermal generation, whether using carbon capture or not, and nuclear



UK market 2030: January power generation simulation

The top diagram shows the projected hourly prices through January, the middle diagram the level of intermittent generation in each hour and the bottom diagram the generation required to meet 'residual' demand from conventional sources.

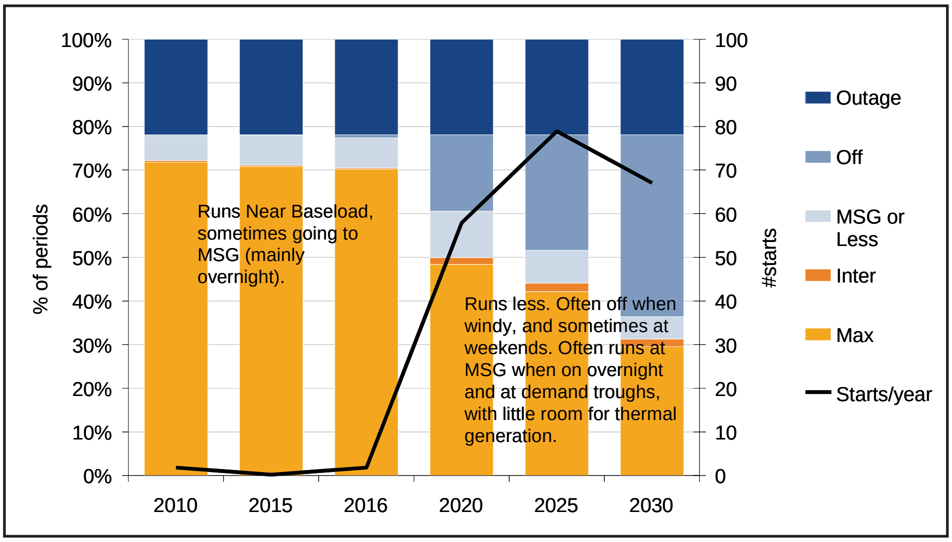
January 2000 in GB and Ireland was initially mild for a winter month, but toward the latter part of the month very calm and cold conditions prevailed before a large depression moved in bringing with it strong south westerly winds. The variation in simulated generation in the last 10 days of January creates price spikes when low intermittent generation coincides with high demand. It also leads to large swings in conventional generation required to match demand. Whilst the large swing in generation patterns shown in this month is striking it is by no means unique – indeed such swings will become an increasingly common feature of generation markets with high levels of intermittent generation.

Further, not only the level but the hour in which peak demand net of wind takes place can be expected to change from one day to the next. This changing nature of the demand (net of wind) profile raises significant issues for scheduling generation and trading power more than a few days ahead. Consequently, we consider that in an intermittent world, average prices and load factors will be less meaningful.

Implications for CCS

These findings have profound implications for conventional generation operating profile and revenue capture. Our analysis indicates that the load factor for thermal generation will fall while the number of starts will increase, as indicated in the figure (right).

This change in operational profile is significant for CCS plants, as their high capital costs suggest that they require a high



The changing operational profile for thermal generation

load factor to recover these costs. Further, there are technical challenges with ramping up and down a power plant that is integrated with a chemical processing unit and connected to CO2 transport network and storage facilities. While steps can be taken to mitigate these factors, these involve additional costs, which become more difficult to recover given a lower load factor.

With regard to revenue that conventional plants can capture, our analysis suggests that overall prices may decline slightly, due to that significant level of generation that has a negligible marginal cost. While there are likely to be significant price spikes, there is no guarantee that a CCS unit with significant technical constraints will be able to capture them, nor even if they were that they would be sufficient for them to recover their costs.

These factors will add to the risks associated with investing in a CCS plant, making it more challenging to develop successful business cases. Project developers will to look to mitigate these risks, through, for example:

• finding other sources of value, either in the products they provide or through the market rules and balancing arrangements; and

• enhancing the flexibility of their CCS plant.

With regard to other products CCS plants can examine options for providing heat and desalinisation of water as well as power, while gasification units could provide hydrogen for industrial purposes, and potentially transport and fuel cells.

In terms of increasing flexibility, in the case of a post combustion plant the simplest approach would be to by-pass the capture process, so the unit operates unabated and the CO2 is vented with the operator needing to submit additional carbon allowances. Another option could include designing a process to minimise the parasitic load associated with CO2 capture during times of peak prices and using off peak power for amine regeneration. This would require storage facilities and significant volumes of amine that is at times not in use.

Clearly flexibility will become an important feature for CCS technology going forward and is the subject of our next article.

Our Intermittency Study paints an alarming picture for developers of conventional power plants. However, electricity systems will evolve and it is likely that developments such as increased the interconnection of power markets, demand-side management measures, such as smart grids, and energy storage, are likely to lessen the impact of intermittency, and hence reduce the risks associated with investing in conventional generation.

The key message of this article is that a power system with a high degree of intermittent generation will pose additional risks to future developers of CCS projects but there are a significant number of ways in which these risks can be mitigated. This paper has touched on a number of these mitigation actions and we will explore these in more depth in our following articles.

More information

Pöyry Energy Consulting is Europe's leading energy consultancy providing strategic, commercial, regulatory, and policy advice to Europe's energy markets. Our team of 250 energy specialists, based in fifteen offices in twelve European countries, offers unparalleled expertise in the rapidly changing energy sector.

Our Carbon Capture and Storage practice is recognised as one of the leading consultancies in CCS. Recent projects include policy advice to Governments, economic assessment of several potential CCS projects and strategic advice to many leading industry participants.

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A framework for the future development of CCS

In the last edition of CCJ, Calum Hughes of Yellow Wood Energy considered whether and to what extent the recipients of public funding to support CCS should be required to ensure that the projects they develop create a foundation of infrastructure that will promote subsequent growth of the UK's CCS industry.
In this follow-up article, Richard Haigh, also from Yellow Wood Energy, considers the need for additional clarity on the future commercial and regulatory framework surrounding CCS and the way in which the industry is to be funded.

Richard Haigh, Principal Consultant for CCS and Electricity Market Regulation, Yellow Wood Energy

In its October 2009 report, the Committee on Climate Change (CCC) highlighted the need for a "substantially decarbonised" power sector in the UK by 2030 if Government targets for an 80% reduction in greenhouse gas (GHG) emissions by 2050 are to be met.

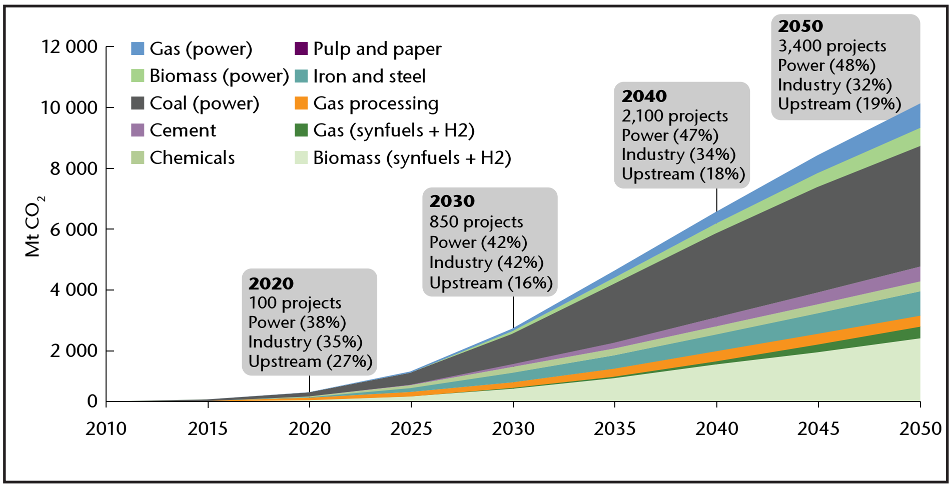
Notwithstanding substantial investment in renewables and nuclear power, under all credible predictions up to and beyond 2030, the power sector will also continue to rely upon substantial quantities of fossil fuel based plant to deliver security of supply and to support intermittency in renewables and a lack of quantity, and potentially a lack of flexibility too, of nuclear power. Hence in order to deliver the required decarbonisation by 2030, it appears that, in the electricity industry at least, the question is not whether widespread use of CCS will need to be introduced in these timescales, but in what form it will be introduced.

The timescales for delivering the required substantial decarbonisation of the power sector by 2030 are already pressing. Whilst the Government is taking further steps to support CCS demonstration projects, there are questions over the rate at which the roll-out of subsequent CCS projects will progress.

For example, in its March 2010 strategy document "Clean Coal: An Industrial Strategy for the development of carbon capture and storage across the UK", the Government makes reference to the IEA technology roadmap for CCS which suggests that up to 850 CCS projects will be needed worldwide by 2030.

However, of these 850 projects only around 11% are expected to be in European OECD countries and of these only 42% are expected to be in the power sector (see figure). This means that based on this roadmap, around 40 power-sector CCS projects will be developed in the EU by 2030.

Given the UK's share of the European OECD energy market, this equates to approximately 7 power-station CCS projects in the UK by 2030, which falls considerably short of the number required to deliver the vision of a substantially decarbonised UK power sector in these timescales.



Global deployment of CCS 2010-2050 by sector. Power generation accounts for 42% of projects in 2030 (source ©IEA CCS Roadmap)

If we assume that, despite this apparent conflict in the rate at which the introduction of CCS needs to take place, there is genuine government volition to meet the CCC's timetable, a considerable CCS industry will need to develop in the UK in the next few years, probably driven primarily from decarbonisation of electricity generation, but providing the opportunity for other industries to participate also. There remain, however, a number of crucial pieces of the policy and regulatory jigsaw to be completed before the UK CCS industry can be expected to begin to develop at the required rate and in an appropriately coordinated manner.

Economic drivers

The first missing piece is the clarification of the economic drivers for the development of CCS and other carbon abatement technologies. Ideally, the development of efficient carbon abatement technologies should be driven by the prices of emissions trading permits (EUAs) emerging from the EU Emissions Trading Scheme (ETS). In practice, however, the current price of EUAs is generally considered to be insufficient to drive the development of CCS in the UK in the required timescales. There are a number of reasons for this.

First, the current EU ETS only operates out to 2020 and there is therefore considerable uncertainty over how carbon abatement measures requiring a payback over longer timescales will be funded (this issue continues to be compounded by the ongoing failure to agree a successor to the Kyoto Protocol).

Second, the UK Government's targets for carbon abatement of 80% by 2050, upon which the CCC's targets are based, exceed the reductions upon which the ETS EUA cap levels are based and hence the current ETS alone cannot be expected to deliver the level of reductions required to meet the UK's targets unless the currently planned EUA cap levels are reduced, on an EU-wide basis, to bring them in line with the requirements of the CCC's targets. Furthermore, governments across the EU are themselves 'picking the winners' insofar as carbon abatement technologies are concerned by subsidising abatement measures such as wind and energy efficiency.

This may seem laudable, but, because the total number of EUAs issued, and hence CO2 emissions across Europe, are fixed un-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der the ETS, these subsidies do not reduce the total amount of CO2 emissions across Europe, but instead, depress the demand for, and consequently the price of, EUAs, suppressing the development of potentially more efficient abatement technologies, such as CCS, which depend upon high EUA prices to drive investment.

In light of this, and absent substantial reform in the EU ETS, in order for CCS to develop within timescales that will facilitate the delivery the CCC's vision of a substantially decarbonised power sector by 2030 on the path to an overall 80% reduction by 2050, it will be necessary for additional measures to be taken within the UK in order to support the development of CCS over and above the level that would be delivered through relying upon EUA prices alone. Precisely how such additional measures will operate to deliver an 80% reduction in the UK, against the back-drop of an EU-wide ETS remains to be seen.

Regulatory framework

A second missing piece of the jigsaw is what regulatory and commercial framework will govern the future CCS industry. In its March 2010 strategy document on the development of CCS across the UK, the Government highlights the fact that the current regulatory framework supporting the development of CCS focuses primarily on demonstrating CCS at a commercial scale, rather than facilitating general commercial deployment of CCS.

It may be argued that to currently be analysing the development of regulatory and commercial framework for the future industry is premature and that it is instead appropriate to wait until CCS has been demonstrated on coal before considering its roll-out to other forms of electricity generation and other sectors.

However, as has already been explained, there is no real alternative to widespread CCS development for the power sector if Committee on Climate Change's glide path is to be met, and consequently some form of framework to support wider commercial deployment will ultimately be needed. In addition, delay in the development of this framework raises a number of material issues.

The first of these is that, in combination with a lack of clarity over what will drive the economics of CCS, a lack of clarity over the future regulatory and commercial framework has the potential to stifle CCS development and innovation outside the demonstration projects themselves. It is, for example, not clear who will be responsible for installation, ownership and operation of onshore and offshore pipelines, and CO2 storage facilities, whether common pressure specifications and CO2 assays will be developed, or how a commercial "market" in sequestered CO2 might operate on a clustered or wider basis.

There is also a substantial danger that any commercial arrangements that are put in place in the short-term will have to be dismantled when a wider regulatory and commercial framework is introduced. In fact, this is not only possible but highly likely, and is an issue not just for would-be CCS developers outside the demonstration projects, but a material risk for the demonstration project developers themselves.

The existing CCS demonstration project funding is aimed at the demonstration and assessment of CCS technology through its use in commercial electricity generation. The effect of this policy thus far has been for consortia to develop vertically integrated demonstration projects led by electricity generators and delivering the entire CCS

train from extraction, through compression and transportation to storage.

Whilst neither the details of the intra-consortium contracts nor conditions the government is seeking to impose in exchange for funding are in the public domain, it is highly unlikely that either will stand the test of time. One of the principal drivers of structural reform in the European energy and gas sectors over the past decade has been a series of European Directives requiring unbundling and independence of the activity of transmission system operation. In electricity, for example, the effect of these directives is to ensure that generators and suppliers who use the transmission system can be assured non-discriminatory access because the person responsible for operating the system, and with whom they contract for access, is not itself permitted to generate or supply electricity.

This requirement forms one of the fundamental bases of the development of internal markets for both gas and electricity across the EU and is potentially undermined by the structure of the CCS demonstration projects, whereby an independent electricity generator wishing to connect to existing CCS infrastructure may be required to contract with consortia that include their competitors in the electricity generation market. In order that CCS arrangements do not undermine those in gas and electricity therefore, a disaggregated CCS industry is likely to be required, in the fullness of time, by the EU legislature as part of their remit to prevent market distortion within the European Union.

Sharing infrastructure

Another factor that suggests that the regulatory and commercial framework of the CCS industry should be developed now and not later is that of transactional efficiency. The fixed costs of CO2 pipelines and storage facilities are large and materially, although not entirely, independent of the size of the pipeline or storage facilities involved.

Given this, it is highly unlikely that it will be economically viable for relatively small CO2 emitters such as a single chemical plant to be able to fund a dedicated CO2 pipeline and storage facility for each site. In fact, this is likely also to be the case even for larger point source emitters such as fossil fuelled power stations. Instead, in order to achieve economic efficiency, it will be necessary for CO2 emitters to co-operate to jointly fund CCS infrastructure.

If CCS is to develop on a material scale, as will be required, this means that the contractual arrangements governing joint use, funding and risk allocations for CCS transportation and storage will need to be negotiated and developed by multiple parties, probably including groups of consortia. Furthermore these parties would each need to take into account the fact that changes to the regulatory and commercial framework might be imposed centrally at some time in the future.

There is therefore a strong case for standardisation of these arrangements at an early stage in order to avoid the need to develop them many times over in different projects. Similar considerations apply to the technical development of the CCS network. Standardisation of CO2 assays, pipeline pressures, compressor specifications etc. would go a long way to ensuring that different elements of the initial system can be linked together to form a more efficient network as the industry progresses. There may even be a case for technical standardisation on a wider scale, for example across the EU if wider CCS networks are anticipated in the future.

Finally, the arrangements for third party access to demonstration project CO2 pipelines seems to be developing along the lines of that applying to the petroleum industry with the addition of an "open season" as part of the construction consenting process, permitting third parties to fund additional pipeline capacity and stab-in points at marginal cost.

However, without an understanding of how non-demonstration project CCS is to be funded in the future it is unlikely that many, if any, such potential users will come forward in the demonstration project timescales. Furthermore, the arrangements for access to, and charging for, storage infrastructure remains unclear and there is therefore further uncertainty over where, and on what commercial terms, the additional CO2 using any enhanced pipeline capacity might be stored.

Because the size of many CO2 emitters is likely to be small compared to the capacity of a typical pipeline or capacity of a storage facility, the requirement to share CCS infrastructure assets is likely to be widespread. Hence, rather than being an exception, the requirement to develop commercial arrangements governing third party use is likely to be the norm and investments will need to be coordinated among many participants rather than just two or three. Precisely what form the access arrangements take will be an important consideration for those wishing to invest in and use such facilities.

In summary, in order for the CCS industry to develop in a timely manner to meet Government targets for decarbonisation, it will be important to set out not just the economic arrangements that will be required over and above the EU ETS but also, from the perspective of CCS, to set out the regulatory and commercial framework for the industry. Absent these two missing answers, it is unlikely that commercial development of CCS outside the demonstration projects can begin in earnest.

Even, for the demonstration projects themselves, these considerable future uncertainties could result in higher demonstration project costs and with the likelihood that many of the arrangements put in place now will need to be undone in the future. Neither of these outcomes would seem desirable.

Partnership offers support for future Carbon Capture and Storage projects

To create a unique single point supplier for CCS advice, law firm Martineau, which has a particular expertise in the energy sector, has joined forces with Yellow Wood Energy, the specialist consultancy focusing on the electricity and CCS industries, and Arup, international consulting engineers and project managers. The collaboration enables Martineau, Yellow Wood Energy and Arup to provide an holistic service across the whole supply chain, complementing their existing climate and energy offerings.

The new alliance is expected to attract interest from many of the companies involved in the CCS process, from project developers to service companies, equipment manufacturers and technology specialists, all looking for help with the myriad complex issues their projects will face. The team will deliver specialist advice covering: costing & finance; risk assessment support; regulatory & policy design and analysis; project development support including the acquisition of licences and consents; legal support including drafting of agreements for trading, transportation, storage operation, trading of rights, service contracts, planning and environmental issues.

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CCS legal and policy – May / June 2010

Calum Hughes, principal consultant in CCS regulation and policy at Yellow Wood Energy, begins a regular column covering developments in the legal and regulatory aspects of CCS.

Over the past few months the UK has seen developments in both government policy and the legislative framework surrounding its nascent CCS industry. In March, the Department of Energy and Climate Change (DECC) published Clean coal: an industrial strategy for the development of carbon capture and storage across the UK and in April the Energy Act 2010, which introduces a new state funding mechanism for CCS demonstration projects in Great Britain, became law.

The Energy Act

The Energy Act 2010 gives the Government powers to provide financial assistance to projects in Great Britain which demonstrate and assess CCS technology through its use in commercial electricity generation. The Act also provides for the establishment of a levy on electricity consumers to fund this financial assistance.

For those considering whether to progress along a road of investment in CCS, a venture beset with uncertainties and risks, both the new Act and the strategy document provide welcome guidance to help in discerning the surest route. However some of the sign-posts are still confusing.

One observation is that while the Energy Bill, as introduced to Parliament, included a restriction that financial assistance should only go to projects based upon coal-fired electricity generation, this restriction was removed, following some interesting debate at the Commons Committee stage, opening the way for assistance under the Act to support CCS demonstration on power generation fired by natural gas and possibly biomass.

Official policy remains, however, that the demonstration projects receiving support under the Act shall all be coal-fired (the title of the strategy document is testimony to this). Policy also states that a maximum of four projects will be supported and that the total funding raised by the levy will be between £7.2bn and £9.5 bn, a sum that has been calculated as that required to support those four projects. However, these facts are hard to reconcile with the removal of the restriction in the Act; if the money raised is to be allocated entirely to the four projects, and these are to be coal-fired, why expand the ambit of the scheme?

The debate rationale in favour of the amendment centred around the need to build flexibility into the law but this flexibility would only be required if policy were to change, either with regard to the number of projects to be supported, or their fuel type, or both. Hence a seemingly certain policy objective now appears a less sure guide even if it has not been explicitly changed.

CCS clusters

A second area in which the alignment between the new law and policy is less than clear is that of CCS ‘clusters’. The strategy document recognises the potential for clusters to offer increased value for money as well as attracting businesses and jobs to cluster regions and expounds a fair amount of support for ‘co-located’ demonstration projects. Accordingly, it is explicitly stated that two projects sharing infrastructure would be considered as separate demonstrators and would therefore, presumably, be eligible for two lots of funding.

What is less clear is whether this policy would include the support of co-located projects where one is based upon a non-electricity generating plant. Funding could be allocated to such a project if the restriction in the Act that financial assistance shall only be applied to projects based upon commercial electricity generation were construed as being satisfied by the inclusion of one power plant within the cluster project as a whole.

A project of this nature has the potential to deliver unique insights into the way in which a CCS network which includes power and non-power generation CO2 exporters would operate. This would potentially provide valuable lessons, not only for the way in which the operational constraints applied by the need to balance an electricity network would interface with those of the rest of the components in the CCS chain, but would also demonstrate how this scenario would operate when a non-power generation emitter, with wholly different operational requirements, were inputting CO2 into the same system.

Given that the central aim of the subsidised programme as a whole is to demonstrate CCS at a commercial scale, and that a large part of this is the acquisition of operational expertise, it is not unreasonable to suppose that policy would be to support such a co-located project, but whether this is actually the case is not clear.

For those considering whether to progress along a road of investment in CCS, a venture beset with uncertainties and risks, both the new Act and the strategy document provide welcome guidance to help in discerning the surest route - Calum Hughes, principal consultant in CCS regulation and policy, Yellow Wood Energy

These two examples demonstrate how easy it can be for messages delivered by policy and legislation separately to be confusing; I suspect that clearer, and more permanent, route-markers will be required before enough decision-makers feel secure enough to commit the levels of private investment required to fund CCS development at the speed which is apparently required by the Climate Change Act 2008.

More information

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Carbon financing of CCS in the developing world

Lodewijk Nell, business development manager at EcoSecurities, speaking at the CCS Ready to Go? conference in Rotterdam, talked about how the CDM could be used for carbon financing of CCS projects.

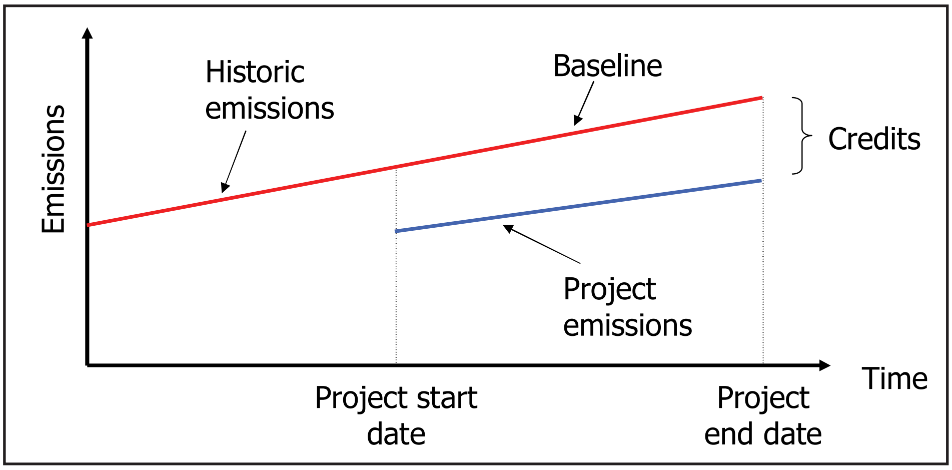
"I left TNO [Dutch research organisation] about a year ago and since then carbon financing has gone through some big changes," began Mr Nell. "At that time we had a visit from the UK foreign secretary David Miliband. He was preparing for the Copenhagen summit and he asked me about CCS and what it could mean for the developing world, principally China."

"CCS was really on the agenda looking forward to Copenhagen and what was going to happen there. Well we know now what happened, a lot of breath was spent trying to get a commitment on targets. CCS was not really spoken about there and nothing really happened."

"Because of that we got a lot of stagnation and a lot of uncertainty in the market and that's what you see with carbon financing, it has not really done us any good."

"Still we did not stop at Copenhagen and we still carry on – carbon financing can really get things going and that's what I am going to talk about today."

"Eco Securities is based in South Africa but was started in Oxford in the UK pioneering many things to do with carbon financing. Now we have been sold to JP Morgan which is a big change. The company is involved with 10% of all the projects registered under the CDM (Clean Development Mechanism)."



Earning credits for emissions abated through the CDM

The CDM

"The CDM is really a very complicated system. Someone told me that it is the most efficient mechanism in the UN! Well you can draw your own conclusions about that."

"The system under the Kyoto protocol divides the world into two regions. Annex one countries have binding emission targets and include the industrialised countries: Western and Eastern Europe, Canada, Japan, New Zealand, Russia, Ukraine."

"Non-Annex one countries have voluntary participation and include the developing countries: China, South Korea, India, South Africa, Philippines, Uruguay, Brazil, United Arab Emirates, etc."

"In Annex one regions like Europe it can be hard to squeeze the last bit of energy performance out, to get even more efficient than you already are. So it can be the best deal to do it in countries where emission performance has not been worked at that much. It can be cheaper or you can get more emission reductions for the same money."

"If you have in a non Annex one country emissions and you get a certified emission reduction (CER) from that you can bring it into the trading systems of the Annex one country for example the ETS (Emissions Trading Scheme) and this tradable unit brings financing into the Annex one country. This is the basis of the CDM."

"Most important to qualifying for a CER is to register your project baseline, to show what would have happened if you had done nothing and what you have done by implementing the project. This gap between the two is what you are going to prove with your monitoring methodology in order to get the credit for the emissions reduction." (see figure above)

"The CDM process starts with submitting a proposal to the UN panel which sits in Bonn every two months to discuss new projects. They judge the proposal against a methodology and decide if it qualifies and then you can start monitoring your emissions reductions."

CCS in the CDM

"It would be excellent if we could do this for CCS but at the moment there is no methodology for CCS and it has been a hell of a process trying to get it included in this system."

The process started in 2005 with three complete projects two of which are true CCS projects, said Mr Nell. The White Tiger oil field CCS project in Vietnam, which is about EOR with CO2 from a CCGT involving Vietsovpetro, MHI, Marubeni Corp, 5-11 million ton CO2/year. Secondly an LNG project in Bintulu, Malaysia involving injection of CO2 into an aquifer offshore by Petronas, 3 million ton CO2/year.

In December 2005 the COP/MOP 1 meeting was held in Montreal but the CDM Executive Board (EB) was unable to reach a decision on the inclusion of CCS. The EB then requested guidance from CMP (conference of the parties to the Kyoto protocol) on whether CCS can be a CDM activity.

"Now in 2009 at Copenhagen discussions continued, the EB commissioned a study to provide the requested input to CMP but no decision at CMP 5 in Copenhagen and CMP (once again) 'invites Parties' submissions on implication of inclusion of CCS in CDM.'"

"They identified a few main issues, firstly long term liability on the storage – who will take responsibility for leakage, especially beyond the crediting period. Secondly there is 'a risk of unbalancing the carbon market and the regional spread of projects'." "This one is really puzzling, they are saying that some of these projects are doing so well, they are storing so much CO2 and

meeting climate change targets that it would unbalance the system."

"Regional spread, where would this money go? Probably Africa, there is a lot of emissions from oil and gas and they really need this money, I think it's good if you have a greater regional spread, they deserve it. There is always a spread of opportunities, Europe does not have many forests and Brazil has so there is always going to be a regional spread."

"Thirdly there is a problem with EOR which could make CCS economically viable because of the oil revenues. People don't like that because of the extra production of fossil fuels."

"What we see is that these are mostly not CCS specific issues, for example with long term storage a forest can also burn down. The real thing that is lacking is a good methodology and that has been blocked by the UN up to now."

"Doing an analysis of this it is clear that it is political decisions that are holding the process up."

"CCS would be huge in the CDM and that is what everybody fears because they think if we have too much emissions reductions this could create a problem in the carbon market. No, this is a regulated market and the only thing you have to be certain of is doing the cap and trade in the right way so it creates a shortage, so it is not really a problem."

"CCS can be quite expensive but if you get more emissions reductions on the market by implementing a few good projects that will bring the carbon price down and more expensive ones will not go ahead."

Post Kyoto

"Things do not stop when the Kyoto treaty expires in 2012, it just moves to a new phase. The EU ETS has already indicated it will accept emission offsets via the CDM for 2013-2020."

"The CDM is a recognized gold standard, a project that qualifies for CDM can qualify for others."

"I think we should use this period to make a case for CCS and take this subject along in the negotiations. We need methodologies and specific projects that are well developed and have dealt with all the issues so that this obstacle does not keep coming up again."

"The real thing that is lacking [for CCS in the CDM] is a good methodology and that has been blocked by the UN up to now" - Lodewijk Nell, business development manager at EcoSecurities

Global Carbon Capture and Storage Institute meeting

The GCCSI held its first members' meeting in the US in Pittsburgh on May 13-14.

www.globalccsinstitute.com

James Wolfensohn, President of the World Bank, began by saying that he had met with his colleagues on the international advisory panel to talk about the direction of the GCCSI, and they had decided that the most fundamental aim should be to make sure that there is a first rate system for information interchange that could be used by the Institute, the idea being that if someone had a question related to CCS it would be the first place to go to have access not only to information but also the people that were involved and it could be used not unlike Google for CCS.

"We want to try and dominate that space," he said. "In talking to many of you the area which was seen to be unarguably the most useful was putting together such an information basis of exchange."

It would try to cover policy and regulatory issues, financial and commercial barriers, technological issues and issues of public acceptance.

"The other issue we talked about is the support of the Institute for individual projects. We are looking for projects that are not only interesting in themselves, but where we can generate information that will be useful in terms of our information exchange."

Mr Wolfensohn said that 56 projects had been submitted for consideration of GCSSI funds totalling over $500 million, and discussions were continuing over how to allocate the $50 million that was available.

Nick Otter, the CEO of the GCCSI, said that despite the importance of CCS in the mix of technologies to combat climate change, there was a danger of it being bypassed as a really acceptable solution to the problem if development was not fast enough.

He said there were two imperatives for the Institute, taking the demonstration program forward, and planning for the future to enable commercial deployment, and knowledge sharing underpinned both objectives.

Lord Stern, Chair of the Grantham Institute for Climate Change and the Environment at the London School of Economics, said a market-based approach failed because it did not take account of the cost of climate damage. Policy is needed to fix that market failure. He said policy was "pro-market" and that it was people who refuse to acknowledge the market's failings that are anti-market.

"We are talking about combating the greatest market failure the world has ever seen, including the events of the last two or three years, we're involved in risks much bigger than that."

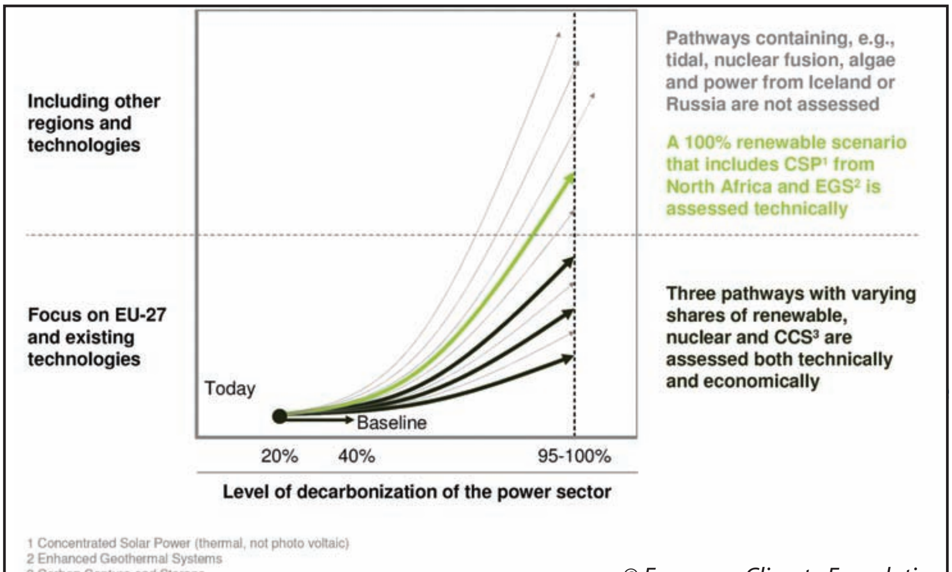
"The reaction to that market failure will involve a fundamental change to how we do industry and energy, this is arguably the biggest industrial revolution the world has seen, and if it isn't our children are in big trouble."

He said overseeing structured learning and dissemination of the data about CCS was a central role that the GCCSI could fulfill.

Report shows path to affordable low carbon power in Europe

"2050: a practical guide to a prosperous, low-carbon Europe," published by the European Climate Foundation (ECF), finds that in a decarbonised power system, the future cost of electricity is comparable to the future cost of electricity in the current carbon-intensive infrastructure.

www.europeanclimate.org



© European Climate Foundation

The Roadmap 2050 scenarios show that with the necessary investments in energy efficiency and Europe's power network infrastructure, a decarbonised power sector using available technologies can provide the same high level of reliability that consumers enjoy today, in all low/zero carbon pathways.

The report was authored by the ECF with technical and economic analysis by Imperial College London, KEMA, Oxford Economics and McKinsey & Company and policy analysis by E3G and the Energy Research Centre of the Netherlands (ECN). AMO, a research and design studio within the Office for Metropolitan Architecture, contributed to the content development through the production of a graphic narrative which conceptualizes and visualizes the geographic, political, and cultural implications of the integrated, decarbonised European power sector.

Roadmap 2050 looks at the economic, service reliability, infrastructure, energy security and policy implications of the European power system in 2050 in four decarbonised scenarios. The pathways do not rely on imported electricity and are based on existing or late stage development technologies including renewables such as solar, wind, biomass, geothermal and also non-renewable low-carbon resources such as carbon capture and storage (CCS) and nuclear:

1. 40% renewables, with the remaining 60% supplied evenly between non-renewable low-carbon technologies: CCS and nuclear

2. 60% renewables, with the remaining 40% supplied evenly between non-renewable low-carbon technologies: CCS and nuclear

3. 80% renewables, with the remaining 20% supplied evenly between non-renewable low-carbon technologies: CCS and nuclear

4. The study has also assessed the technical and economic feasibility of a scenario with 100% renewable electricity, requiring no nuclear power and limiting CCS application to heavy industry, including solar power from North Africa and breakthroughs on enhanced geothermal power generation.

When the Roadmap 2050 project started, a number of widely shared assumptions dominated the debate on the future of the European power sector. These included assertions that high-renewable energy scenarios would be too unstable to provide sufficient reliability, that high-renewable scenarios would be uneconomic and much more costly, and that technology breakthroughs would be required to move Europe to a zero-carbon power sector. Roadmap 2050 has found all of these assertions to be incorrect.

With the exception of existing hydroelectric facilities, almost all of the power generation capacity required to supply Europe in 2050 will need to be built in the next 40 years. This is a major undertaking regardless of the energy mix, and would pose a massive challenge even in a high-carbon scenario.

The key finding of the Roadmap 2050 project is that the challenge is basically the same in either a high-carbon, low-carbon or zero-carbon energy scenario, in terms of overall cost and scale.

What does change significantly is the required level of investment early in the cycle. Capital expenditure on energy infrastructure will need to double in the next 15 years to deliver a zero-carbon power sector by 2050. But in that scenario, the overall energy bill for the economy will be heading downward by 2020, and the day-to-day running costs fall fast throughout the period.

As well as studying the technical requirements of the grid and power infrastructure and the economics of the various scenarios, the Roadmap 2050 project has also delivered an analysis of the policy requirements for decarbonisation of the power sector by 2050.

Action before 2015 is a prerequisite for decarbonisation by 2050. Immediate policy development and implementation should focus on:

• Energy Efficiency measures, creating cost savings and reducing demand.

• Investments in regional networks and local smart grids and coordination of power market operations among member states, maximizing the value of low-carbon investments and minimizing back-up supply and load-balancing requirements.

• Market reform to ensure an effective investment scenario.

Roadmap 2050 shows that existing policy frameworks can be adapted to support decarbonisation of the European power-sector, but that an holistic approach is needed, with rapid action at both regional and national level required.

The Roadmap 2050 project shows that the benefits of the low-carbon transition by far outweigh the challenges and that a commitment now to a systemic low-carbon transformation of the energy sector is ultimately the winning economic strategy for competitiveness, jobs and low-carbon prosperity. Achieving at least 80% greenhouse gas reductions in 2050 based on zero carbon power generation in Europe is technically feasible and makes compelling economic sense.

AMEC - developing CCS clusters

Alastair Rennie, project director – renewable energy at AMEC, talked about how the development of a CCS cluster in the Humber region in the UK can offer significant cost advantages and how CO2 shipping can add value to the CO2 transport network at Riviera Maritime Media's inaugural CO2 Shipping Conference on May 6 in London.

Mr Rennie said he was concentrating on the Yorkshire and Humber cluster as a good example of the cluster concept and the added value that CO2 shipping can provide.

"The Humber is the largest cluster in the UK but it is by no means the only one; each has subtle differences and AMEC has done a lot of work looking at network design and how you would access emitters and storage sites," he said.

"The Humber region has a total of 90 million tonnes of CO2 emissions per year and we are looking at tackling 60 million of that through CCS, which would turn the region from being one of the highest per capita emitters in the UK to one of the lowest."

"The emitters are in a tight geographical area and we are looking at mainly big power stations with over 1M tonnes CO2 emissions per annum; 90% of the emissions come from these sources. Other sources include a large steel plant which is well suited to CCS."

"Offshore there is a mixture of depleted gas reservoirs and saline aquifers close to shore. The combination of gas fields in the short term and aquifers in the longer term is very important giving multiple storage options. As a cluster we are looking to take advantage of the local storage sites first before venturing further afield."

"The connection is from Ferrybridge which is at the far West of the cluster to the coast which in more or less a straight line connects all the major emitters. We are proposing to pick it up at 125 Bar probably maxing at 140 Bar. We looked at a lot of structures and decided that a tree structure was the way to go, with a phased development from 2012 up to 2030."

"The work we are currently doing is under the auspices of a regional partnership which is open to anyone with an interest in low carbon technologies and is facilitated by CO2Sense which is an offshoot of the regional development agency."

"We are currently doing work within a steering group on a pre FEED study looking at a range of options for transport and storage so that the FEED work can be more focused. The outcome of that report will be a schematic for a pipeline network where we are looking at a project by project cost reduction of 44% and by integrating phases a further 27% reduction."

"So the overall cost reduction for being part of an integrated network is around 70% in terms of cost per capacity tonne."

AMEC is able to transfer and integrate their collective capabilities from their onshore and offshore gas business, environment, health and safety consultancy service, involvement with new technologies and pipeline expertise directly into the expanding world of carbon capture and storage.

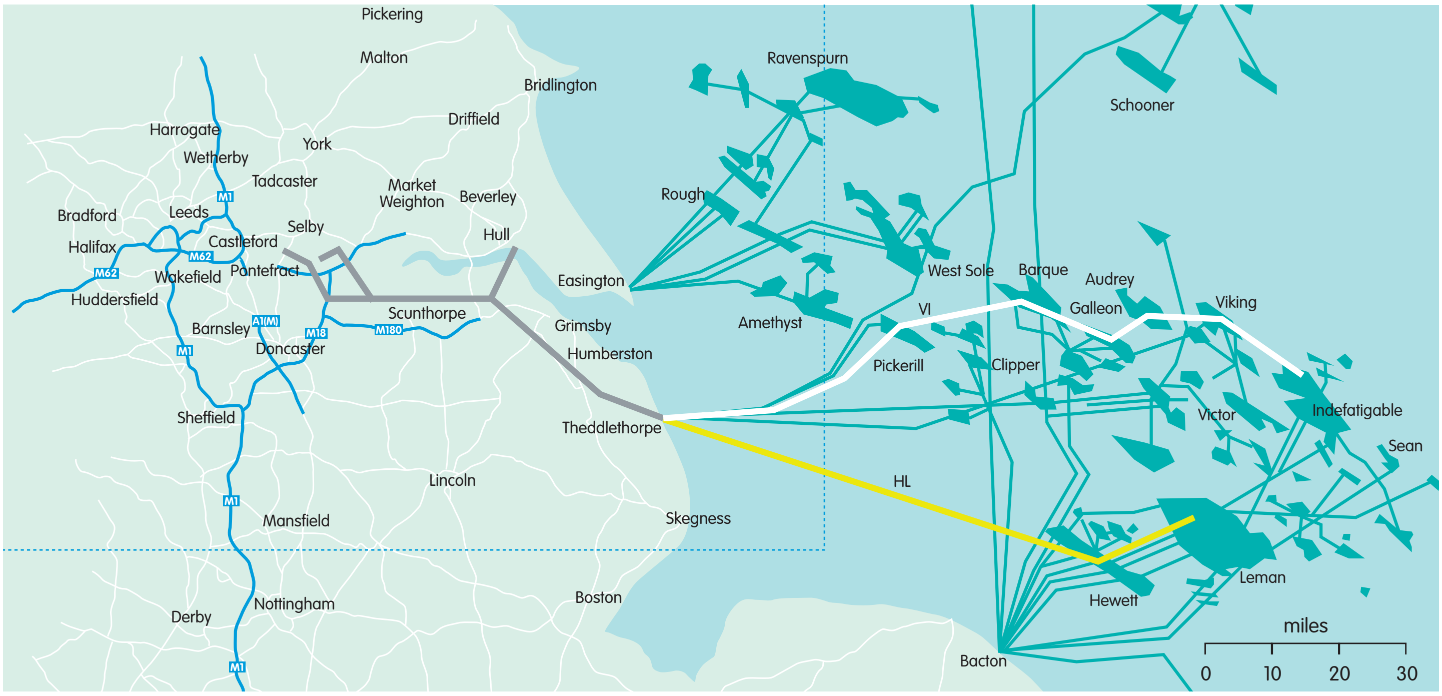
In the US AMEC has showcased its work in this field through their work with oil companies such as ExxonMobil, Chevron, Shell and Kinder Morgan in both CO2 pipelines, CO2 compression and injection projects for enhanced oil recovery. Our services range from concept and consultancy services, pipeline design to full project management and engineering, procurement and construction.

In the UK, AMEC's focus has been on full service carbon capture and storage (CCS). They are applying their gas treatment experience both on and offshore to capture and store carbon dioxide and their proven track record on brown and green field sites to integrate these schemes into new and existing facilities.

AMEC continues to work with academic and industrial institutions, such as the International Energy Agency, on studies and research into distributed transmission, capture of CO2 and cost modelling. In the UK they have undertaken studies for a number of CCS clusters, usually with the Regional Development Agency and a Steering Group of stakeholders.

Led by CO2Sense in the Yorkshire & Humber area the results demonstrate how Britain could capture and store CO2 from industrial sources at and reduce its total emissions by over six per cent. In overall and pre FEED studies the work shows how costs are materially reduced by a co-ordinated phasing of CCS projects.

Such a network would connect plants to storage facilities in the depleted gas fields off the adjacent coastline in the Southern North Sea with the least planning, technical and economic impacts. The network would be the first of its kind in the UK and is designed to support projects built for the UK demonstration competition which we all hope is on track with the new UK coalition Government.



The CCS cluster in Yorkshire and the Humber showing the possible transport system layout on and offshore (map courtesy of CO2Sense Yorkshire)

"The shipping option can add value to the pipeline concept. There would be the ability to pick up ad hoc cargoes from the network for example for EOR requirements or when local storage options are disrupted."

"There are also options for importing CO2 into the system. There are a number of CCS projects around the coast of Ireland, UK and southern Europe coasts who will be able to evaluate the Humber as a storage solution linked by ship. Similarly northern European emitters should evaluate the Humber option."

"Short term agreements for sequestration of pilot and demonstration CO2 and ad hoc imports to alleviate problems at other storage locations are also possibilities. For example an agreement enabling an EOR offtaker to meet all or part of their contract with an emitter despite reservoir or well problems, or for planned maintenance."

"This is essentially enabled by the imported incremental volumes being relatively small compared to the design capacity of the system."

"In the immediate future we are supporting the developers who are considering NER (New Entrance Reserve) funding bids. There is ongoing work to further define the storage options and to support storage licence applications."

"The aim is to initialize the network in 2015 with the second stage coming online before 2020 or in 2018 ideally. Then we can offer a shipping import and export facility."

"The most important thing for us is to be able to offer a low cost base option for CCS by 2020 and that could be a guiding light for other clusters around Europe."

"In conclusion we think that these projects operating in clusters are much more cost effective than individual emitters going it alone, and we need to start developing them now so that public money is not wasted on expensive stand alone projects."

Research at Scottish Carbon Capture and Storage

Scottish Carbon Capture and Storage (SCCS) based in Edinburgh has expanded its remit to include capture plant engineering and CO2 separation technologies, in addition to the energy systems and geological storage R&D for which the centre for CCS technologies was previously renowned.

www.sccs.org.uk

Most of the costs and additional energy consumption required for carbon capture and storage are incurred in the processes separating carbon dioxide from the flue gas and its subsequent compression. In response, the Edinburgh based SCCS has been building their expertise in this area. Now moving into its second phase, SCCS brings together engineers, geologists, geophysicists, chemists, economists and technology analysts and social scientists as dedicated researchers in the field of CCS. A multi-disciplinary MSc programme on Carbon Capture and Storage, the first of its kind in Europe, is now offered at the University of Edinburgh.

New appointments

Professors Jon Gibbins and Stefano Brandani have been recruited to the centre from leading London universities and, along with their research groups, focus on carbon capture, power plant engineering and economics, and adsorbent technologies.

Jon Gibbins has worked on coal and biomass gasification and combustion for over 25 years, firstly at Foster Wheeler and then Imperial College London. He now holds the position of Professor of Power Plant Engineering at Edinburgh and the role

of Principal Investigator for the UK Carbon Capture and Storage Community. His group's work centres on research, teaching, and policy advice for Carbon Capture and Storage with fossil fuels and biomass, plus the use of low-carbon electricity, in the UK, China and other countries, directed towards developing effective global strategies for avoiding dangerous climate change.

The strategy behind Jon's CCS activities is helping to deliver the combination of technical, policy and economic advances that are required to progress CCS rapidly to the stage where it can make an effective contribution to global climate change mitigation. His work already helped to get post-combustion established as a competitive option for CO2 emission reductions from coal power plants.

International guidelines for post-combustion capture-ready plants, drawn up with his participation, now form part of the G8 programme to deploy CCS globally.

Joining Jon from Imperial College is **Dr Mathieu Lucquiaud**, specialising in the design of power cycle and steam turbines for both CO2 capture-ready coal and gas plants, including technology upgradeability of post-combustion capture systems.

The third group member is **Dr Hannah Chalmers**, who's work combines improving the technical understanding of CO2 capture technologies for power plants, with the development of economic models that can be used to identify operating patterns to maximise value of power plant operating with CO2 capture. The Gibbins' group hosts students working on dynamic modelling of power plants with operational CCS, and is establishing a brand new laboratory to verify and enhance the groups' capture plant models.

Professor Stefano Brandani joined the Institute for Materials and Processes at Edinburgh in 2007 from his post at University College London, where in 1999 he previously established the Centre for CO2 Technology. Stefano and his group now have been very successful in building a research portfolio in next generation carbon capture technologies, based on the use of novel nanoporous materials for adsorption and membrane processes.

Major grants include the EPSRC Science and Innovation Award on Carbon Capture from Power Plant and Atmosphere, in collaboration with Geosciences and Heriot-Watt University, the EPSRC consortium on Innovative Gas Separations for Carbon Capture led by Edinburgh with 5 collaborating institutions across the UK, and the US Department of Energy funded project on Carbon Dioxide Removal from Flue Gas Using Microporous Metal Organic Frameworks.

The group's laboratory hosts a range of experimental apparatus designed for exploring new types of adsorbents; screening novel micro porous new materials; and rapid pressure cycling to predict process performance of the best candidates materials. Brandani's work focuses on so-called second-generation solutions.

"We are confident that these solutions work but we need to improve them," says Brandani. "We will need a significant research effort to optimise first-generation amine-based systems, and also get them working on a much larger scale. In parallel, we must develop second- and third-generation solutions to address the limitations of the first generation."

"We are working on novel adsorbents and processes, to develop the underpinning science for these technologies, and all of this takes time and money" - Prof. Stefano Brandani joined the Institute for Materials and Processes at Edinburgh from his post at UCL

Stefano's group have also developed a semi-automated measuring device and a set of numerical tools to analyse the properties of various nanoporous materials, and a novel type of apparatus that will be used to "characterise the performance of adsorption columns with several grams of solid material."

Professor Jon Gibbins, who joins the SCCS from Imperial College London, is the Principal Investigator for the UK Carbon Capture and Storage Community

The new technique makes it possible to screen more materials and more variants than ever before. "We are working on novel adsorbents and processes, to develop the underpinning science for these technologies, and all of this takes time and money" says Brandani. We can only test so many new materials a day, but we must do it if more efficient capture methods are to be established."

The experimental data is used to validate complex dynamic models that can be used to predict the behaviour of carbon capture processes under variable load conditions and at start-up. **Dr Hyunwoong Ahn** has recently joined the group from SK Energy, South Korea's largest refinery company, adding to the team's significant experience in process plant technology. Hyungwoong has developed the first UK MSc course on Separation Processes for Carbon Capture, taking engineers and geologists through the steps of designing capture plants using commercial process simulation software

SCCS is the largest carbon storage grouping in the UK, comprising in excess of 65 researchers, and is unique in its connected strength across the full CCS chain and unique in its biochar capability.

Policy, company and regulation news

Canada opens CO2 technology research centre

canmetenergie.nrcan-rncan.gc.ca

The Honourable Christian Paradis, Canadian Minister of Natural Resources, officially opened the CanmetENERGY CO2 Research Facility (CanCO2) located at the Natural Resources Canada Ottawa Research Centre.

CanCO2 is an integrated pilot-scale carbon dioxide (CO2) capture facility that simultaneously removes pollutants while purifying and compressing CO2 for transport, storage or use.

The Zero Emission Technologies group at Natural Resources Canada's Ottawa Research Centre has developed a CO2 capture and compression unit suitable for separating CO2 generated by an oxy-fuel power plant or from other industrial sources. The CanCO2 is a trailer-mounted modular unit that is transportable and suitable for field testing and pilot-scale demonstrations.

As a portable near-zero emission test platform, the facility is used by industry and research organizations to optimize, reduce costs, evaluate and test technology options for CO2 capture from fossil fuel-fired plants.

Research Scientist Dr. Kourosh Zanganeh (left) shows the Honourable Christian Paradis, Minister of Natural Resources around the CanmetENERGY CO2 Research Facility at its official opening on April 19, 2010. This integrated and efficient pilot-scale carbon dioxide (CO2) capture facility simultaneously removes pollutants while purifying and compressing CO2 for transport, storage or use. The CanCO2 is located at the Natural Resources Canada Ottawa Research Centre in Bells Corners.

ETI seeks bids for CCS demonstration

www.energytechnologies.co.uk

The Energy Technologies Institute (ETI) is looking for organisations or consortia to bid for a major project which could establish an advanced CO2 Capture Technology demonstration.

The ETI is planning to invest £25 million in the project. Bidders would need to demonstrate and justify how their approach would enable their technology to reach a state of development that would allow future investors to start engineering the design of a power station using this next generation technology in 2015, with operation commencing in 2020.

Following an extensive analysis of likely future UK requirements for CCS new build and retrofit power generation, the ETI has identified a specific opportunity to develop capture technology for new-build, pre-combustion capture coal based on physical separation of CO2 from synthesis gas. As part of its wider portfolio of CCS developments, the ETI is seeking detailed and specific proposals for a validation and demonstration project to accelerate development of this technology.

A two-stage bidding and selection process will be used, with a deadline of 23rd June for Stage 1 proposals.

Peabody Energy - clean coal with CCS solution to climate change

www.PeabodyEnergy.com

Peabody Energy Chairman and Chief Executive Officer Gregory H. Boyce has outlined a technology and regulatory path forward to achieve near-zero emissions from coal before the U.S. House of Representatives Select Committee on Energy Independence and Global Warming.

"Clean coal plays an enormous role in meeting three vital needs that Americans face: energy security, economic stimulus and environmental solutions," said Boyce, who was one of four panelists invited to address the 111th Congressional committee. "So, while some others call coal a bridge to the future, I say that coal is the future."

Boyce outlined six steps that would allow coal use to continue in a carbon constrained world:

• Build supercritical combustion plants with improved efficiencies, which in the United States typically have CO2 emissions that are 15 percent below the existing fleet, and more than 40 percent below the oldest of plants being replaced.

• Demonstrate CCS. The technology works. Statoil's Sleipner project in the North Sea has been storing 1 million tons of CO2 annually for 15 years.

• Complete large-scale CCS demonstrations. World leaders increasingly are calling for rapid CCS deployment.

• Develop coal-to-gas with CCS. One of the benefits of coal-to-gas technologies is the inherent ability to capture a pure CO2 stream, so the ultimate cost of capturing and storing CO2 is reduced.

• Deploy commercial-scale IGCC technology with CCS.

• Retrofit the world's existing fleet of coal plants with CCS technologies to improve CO2, just as the nation has done successfully for many other emissions.

"The only path to meet CO2 goals is through technology. A strong energy bill that advances CCS is the best way to achieve both our energy and environmental goals," said Boyce. "Greater deployment of advanced energy technologies including coal with carbon capture and storage would create tremendous economic stimulus, reindustrializing our economic base and putting people to work."

Peabody buys $15M stake in Calera

Calera's technology captures CO2 from industrial processes and converts it into carbonates which can be used as building materials.

California-based Calera recently completed a demonstration project near Moss Landing, California, which used the emissions from a natural gas-fueled power plant.

Every ton of the resulting synthetic limestone building material is expected to store as much as half a ton of CO2. Calera's process also removes minerals and other constituents from water, acting as a freshening system to produce fresh water.

U.S. and UAE to cooperate on Masdar clean energy project

www.masdar.ae

The U.S. Department of Energy (DOE) and Masdar, Abu Dhabi's renewable energy initiative, have signed a Memorandum of Understanding (MoU) to promote collaboration on clean and sustainable energy technologies.

The agreement, signed at DOE by U.S. Deputy Secretary of Energy Daniel Poneman and Dr. Sultan Ahmed Al Jaber, CEO of Masdar, establishes a framework for cooperation in three key areas - carbon capture and sequestration, water and bio-fuels, and building technology.

The agreement will enable scientific and technical exchanges and joint research and development of clean energy technologies.

Masdar also recently signed a similar agreement with Canada, setting out a strategic agreement between the two governments for the sharing of research and evaluation and analysis on non-confidential CCS projects and technologies.

illustration of the Masdar clean energy initiative in Abu Dhabi (image ©Masdar)

DOE supports CCS research partnerships for students

fossil.energy.gov

Students and early career professionals can gain hands-on experience in areas related to CCS by participating in the US Research Experience in Carbon Sequestration (RECS) program.

The initiative is supported by DOE's Office of Fossil Energy (FE), and is currently accepting applications for RECS 2010, scheduled for July 18-28 in Albuquerque, New Mexico, and the deadline to apply is May 15.

The course combines classroom instruction with field activities at a geologic storage test site and visits to a power plant and coal mine. Topics cover the range of CCS deployment issues, and participants will gain hands-on experience designing a carbon storage pilot project and using CO2 monitoring equipment.

Applicants should be early career professionals, Ph.D., graduate and exceptional undergraduates with backgrounds in geology, chemistry, hydrology, physics, engineering, climate science and related fields. Participants are expected to attend the full 10-day program. Enrollment is limited to 25 participants and applicants are welcome from throughout the U.S. and all other countries.

RECS is tuition-free through support by the U.S. Department of Energy, FE's National Energy Technology Laboratory and corporate sponsors, Alstom and the Global CCS Institute, and the program covers all housing and meal costs. In addition, a travel allowance that should cover all or most travel costs will be provided.

US scientists' plan to eliminate coal power CO2 emissions by 2030

A team including members from NASA Goddard Institute for Space Studies and Columbia University Earth Institute have outlined a way to phase out US CO2 emissions from coal use by 2030.

The global climate problem becomes tractable if CO2 emissions from coal use are phased out rapidly and emissions from unconventional fossil fuels (e.g., oil shale and tar sands) are prohibited, says the paper in the June edition of the American Chemical Society's journal Environmental Science & Technology.

The paper focusses on coal, "for physical and practical reasons and on the U.S. because it is most responsible for accumulated fossil fuel CO2 in the atmosphere today, specifically targeting electricity production, which is the primary use of coal."

The paper concludes that elimination of fossil fuel subsidies and a substantial rising price on carbon emissions are the root requirements for a clean, emissions-free future.

The current U.S. electric grid incorporates little renewable power, most of which is not base load power, however this can readily be changed within the next 2-3 decades, says the paper.

Eliminating coal emissions also requires improved efficiency, a "smart grid", additional energy storage, and advanced nuclear power. Any further coal usage must be accompanied by carbon capture and storage (CCS).

"We suggest that near-term emphasis should be on efficiency measures and substitution of coal-fired power by renewables and third-generation nuclear plants, since these technologies have been successfully demonstrated at the relevant (commercial) scale."

"Beyond 2030, these measures can be supplemented by CCS at power plants and, as needed, successfully demonstrated fourth-generation [nuclear] reactors."

"We conclude that U.S. coal emissions could be phased out by 2030 using existing technologies or ones that could be commercially competitive with coal within about a decade."

EU storage report - Europe has capacity to store CO2 emissions

www.zeroemissionsplatform.eu

Scientist writing for the EU's Zero Emission Platform (ZEP) have reiterated that Europe has sufficient capacity to store CO2 emissions from CCS.

A statement refutes recent claims from Christine Ehlig-Economides & Michael Economides (E&E) of Texas University, that geological reservoirs would have much less capacity than previously estimated because they are closed systems.

The authors assert that E&E's statement that "underground carbon dioxide sequestration via bulk CO2 injection is not feasible at any cost," is, "inconsistent with the experience gained from a number of varied CO2 injection projects around the world and countless other fluid injection projects over the last several decades such as the injection of hundreds of billions of gallons of waste fluid into the subsurface under the auspices of the U.S. EPA Underground Injection Control Program (EPA, 2002)."

They also said that E&E's central premise that CO2 storage requires a closed storage container, sealed on all sides by impermeable boundaries, to prevent leakage, is "demonstrably untrue".

"Let's be in no doubt, there will be suf-

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ficient geological capacity to store CO_2 capture from CCS in the EU and the UK," said Dr Jeff Chapman, Chief Executive of the Carbon Capture and Storage Association.

"According to the EU's GeoCapacity survey, the EU has the geological capacity to store at least 117 billion tonnes of CO_2 storage; that equates to enough capacity to store CO_2 from CCS over the next 60 years, and is over 100,000 times the capacity for CO_2 as is currently stored on a yearly basis by the Sleipner plant in Norway."

"The UK has been fortunate in its natural endowment of oil and gas resources," added Professor Stuart Haszeldine, Professor of Geology, University of Edinburgh. "The endowment of CO_2 storage is also fortunate, and far outstrips the domestic need. This means that the UK can offer large, safe and secure CO_2 storage to much of northwest Europe for the next 100 years."

UK Universities get £1.4M for CO2 to fuel research

www.bath.ac.uk/i-see/

The research is into porous materials that could remove CO_2 from smoke stacks and convert it into chemicals to make car fuel or plastics.

The research is led by the University of Bath, in collaboration with scientists and engineers from the University of Bristol and the University of the West of England. It is supported by a £1.4 million grant from the UK Engineering & Physical Sciences Research Council (EPSRC).

The process would be powered by solar energy and would combine a range of different methods, including micro-organisms that naturally capture CO_2. The material could be used to line the inside of factory chimneys.

"Current processes rely on using separate technology to capture and utilise the CO_2, which makes the process very inefficient," said Dr Frank Marken, Senior Lecturer in Chemistry at Bath.

"By combining the processes the efficiency can be improved and the energy required to drive the CO_2 reduction is minimised."

UCL legal programme updates

www.ucl.ac.uk/cclp

New material is available on the the UCL Carbon Capture Legal Programme (CCLP) website, which aims to provide a dedicated, up-to-date, open access and independent resource for the analysis of legal aspects of CCS.

The main output of the CCLP is its website, which is designed to provide an easily accessible source of legal and policy material, as well as succinct analysis of the legal developments and issues arising from changes in the law and policy concerning CCS.

Recent developments to date on the CCLP website include:

- New legal material on regulatory regimes governing CO_2 transportation for storage (International, European and Regional, and National) is now available, both in the Onshore and Offshore sections.
- A new section of its website dedicated to liability for CCS under the provisions of the EU Directive on the Geological Storage of Carbon Dioxide. This new section can be found in the Environmental Liabilities section of the CCLP website.
- A new Think Piece from Baker & McKenzie discussing the Natural Gas Gorgon Project in Western Australia.
- The CCLP recently held a Global Legal Symposium on CCS at New York University and the presentations from this event are now available.

Study launched to find CO2 purity requirements for CCS

www.ico2n.com

www.ptac.org

Two industry associations - the Integrated CO_2 Network (ICO2N) and the Petroleum Technology Alliance of Canada (PTAC) - together with international partners and the Alberta Department of Energy have joined to undertake a study for determining the purity needs for capture, transport and storage of CO_2.

The study will be facilitated by PTAC to secure funding from provincial and federal governments, issue the RFP, manage the contracts, and disseminate the information.

Determining the overall level of CO_2 purity is necessary for establishing the optimal conditions under which CO_2 capture, transportation, long-term storage and enhanced oil recovery can occur. Capture processing costs increase to meet higher quality CO_2 specifications, and capture purity varies by industry and the choice of CO_2 capture technology. Enhanced oil recovery markets can be compromised by poorer quality specifications. In addition, pipeline specification standards designed to protect CO_2 pipelines will also influence the optimal CO_2 purity determination.

The study will examine CO_2 purity, contaminants, temperature and pressure and looks to build on Alberta's extensive CCS knowledge. It seeks the balancing point for purity requirements and cost effectiveness as it pertains to all stages of a CCS system - capture, transportation, sequestration, as well as enhanced oil recovery use. There has been a lot of research on CCS in Alberta and the development of a CO_2 purity standard will serve as an essential piece of information in developing Alberta's CCS infrastructure.

"ICO2N is very fortunate to have access to proprietary CO_2 capture information, from its members, on which to build this analysis," said Robert Craig, Director of Strategy & Technology for ICO2N. "We are pleased to be able to collaborate with organizations locally and globally in understanding this significant technology, its effectiveness and financial costs."

The CO_2 purity study is expected to be completed in early 2011.

New online CCS resource launched

www.ccs101.ca

The CCS101.ca website was funded through the IEA GHG Weyburn - Midale CO_2 Monitoring and Storage Project and Canada's CCS Network.

The CCS101.ca website has three main navigation areas: CCS Basics informs people of the technology fundamentals, while the CCS Pro area has detailed project listings, RD&D projects and funding, the Canadian CCS Technology Roadmap, and virtually all public information on CCS. The CCS Communities section features videos of people living in injection areas and seeks to show how projects are perceived by the people who actually live in areas with CCS development.

US Interagency Task Force on CCS meets for first time

fossil.energy.gov

The meeting on May 6 gave members of the public the opportunity to provide ideas for moving forward with carbon capture and storage projects.

Energy Secretary Steven Chu, Council on Environmental Quality Chair Nancy Sutley and EPA Deputy Administrator Bob Perciasepe attended the meeting and delivered brief remarks.

The task force, co-chaired by DOE and EPA, is charged with proposing a plan to overcome the barriers to the widespread, cost-effective deployment of carbon capture and storage within 10 years, with a goal of bringing five to 10 commercial demonstration projects online by 2016.

The task force is comprised of 14 executive departments and federal agencies and was established by a presidential memorandum on February 3, 2010. The task force's plan is due to the president in August 2010.

Presentations from the meeting are available on the US DOE website.

Sulzer - lifetime cost analysis of post-combustion CO2 capture

Sulzer presents a case study of a generic amine-based absorption process. A lifecycle cost analysis for a power plant over a 40-year span shows the advantages of structured packing over random packing.

Abhilash Menon, Markus Duss and Christian Bachmann, Sulzer Chemtech

The past few years have seen an unprecedented interest in proving the techno-economic viability of CO2 capture technologies from power plants flue gas streams. The main challenge is removing concentrations of CO2 (typically 3.5–14 vol%) from large volume gas streams, which leads to very large column sizes.

An important cost factor is the pressure drop per metre that can be saved inside the absorber. Structured packing offers an excellent solution in terms of both reducing the column's dimensions (Capex) and providing a low pressure drop (Opex) over the absorber. The correct choice of gas and liquid distributor devices is also critical in the success of such large-scale industrial applications.

CO2 control initiatives

The past few years have seen significant interest worldwide in the handling of carbon dioxide (CO2). This is primarily linked to responsible utilisation of fossil fuels. Climate change and greenhouse gases (GHG) emissions have become a daily topic of discussion as world governments, politicians, industries, NGOs and the general public contemplate how to tackle this global problem. CO2 emissions from fossil fuel combustion are considered to be the primary contributor.

As a result, there has been considerable international interest in the development of technology for capturing and storing CO2. The current available technology is highly expensive, and there are many uncertainties linked to the costs and operation of a CO2 chain.

For example, the cost of capturing CO2 from a coal-fired power plant amounts to approximately two-thirds of the cost of the entire CO2 chain, while transport and storage amount to approximately one-third (Norwegian Ministry, 2008).

Capturing CO2 requires a lot of energy. The IPCC report (Norwegian Ministry, 2008) assumes that, if 90% of the CO2 from a power plant is captured, fuel consumption will increase by 11–40%, depending on the technology and the fuel. The report estimates that CO2 capture increases the production costs associated with power production by 20–85%. If the current level of research and development is maintained, the cost of capturing CO2 could be reduced by 20–30% over the next ten years.

Technically, there is no problem in separating CO2 at very low concentrations from flue gas streams. This is a well-established process within the gas processing, petrochemical and fertiliser industry. Gas absorption into chemical solvents such as amines is the most promising technology due to its capacity to handle large volumes of flue gas, plus it can be operated at a low temperature and pressure.

Flue gases from gas or coal-fired combustion plants typically contain some oxygen. Monoethanolamine (MEA)-based solvents with additives and corrosion inhibitors are commonly used in applications for flue gases. MEA-based processes look attractive due to their fast reaction rate with CO2 and the low cost of raw materials compared with other amines. However, MEA absorption processes are associated with high operating costs because of the significant amount of energy required for solvent regeneration, and severe operating problems such as corrosion, solvent loss and solvent degradation.

Post-combustion CO2 capture technology

Technology for capturing CO2 from gas and coal-fired power plants can be divided into three main categories: post-combustion, pre-combustion and oxy-fuel. Post-combustion entails separating CO2 from the exhaust gas of the power plant using chemical scrubbing. This technology, in principle, can be utilised in existing power plants without major modifications.

Post-combustion is the most mature technology, although there is still significant uncertainty surrounding its use. The main problem is the low partial pressure of CO2 in the flue gas, which also contains other gases such as oxygen, water vapour and nitrogen. Separation methods are required to trap CO2 preferentially, so it can be compressed and stored in a sequestration site, complying with regulations for CO2 purity.

So far, none of these technologies have been subjected to large-scale testing in gas power plants. Therefore, there is much uncertainty associated with the use of the available technology for CO2 capture, particularly with regards to costs and performance.

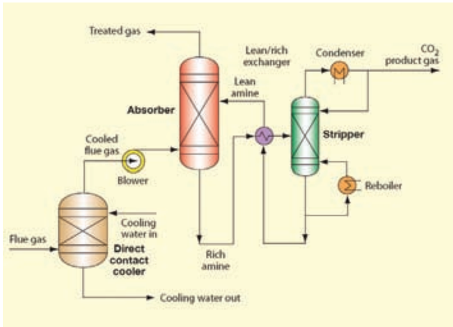

Figure 1 Schematic of CO2 capture plant based on amine scrubbing process

Techno-economic design study

As previously noted, it is important to choose the right technology for mass transfer when it comes to applications such as CO2 capture, where pressure drop can be a significant factor in operating costs. While an industrial case study has been chosen to emphasise this point, it is not our intention to discuss process-specific parameters related to heat duty optimisation, energy/exergy analyses and so on, but rather to convey some essential concepts that must be understood and accounted for at an early stage in the design process.

Case study

Figure 1 provides a schematic overview of the amine-based scrubbing process for CO2 capture from a flue gas stream (eg, coal-fired power plant flue gas stream). The process conditions for this case study have been taken from Alin (2007).

This study is performed on a 800 MW coal-fired power station, which is reasonable for a medium-sized power plant in Europe. The various process conditions, parameters and assumptions are summarised in Table 1.

Simulations presented herein are performed using the commercially available tool ProTreat from OGT (2008). ProTreat is a rate-based modelling tool that uses mass transfer correlations readily available in literature for random packing (Onda, 1967)

and structured packing (Bravo & Fair,1992). The amine selected for this simulation is MEA, which is a widely used generic amine for sour gas treatment purposes.

The simulations were run for a loading of 0.15 mol CO2/mol amine in the lean amine stream entering the absorber. Of course, the CO2 loading is directly coupled with the reboiler heat duty, but that discussion is outside the scope of this article.

The absorber is operated close to atmospheric conditions, which implies that pressure drop within the absorber is a critical factor when designing the column (ie, a higher pressure drop requires higher energy input into the fan, which feeds the flue gas into the absorber). This simple philosophy virtually rules out using trays as a mass transfer device in the absorber because of the significant pressure drop losses.

Therefore, choosing the right mass transfer technology within the absorber can result in huge potential savings in both capital and operating expenses. The comparisons presented are for structured and random packings available in the market.

The simulations are for a standalone composition absorber only, as this is the largest column in a CO2 capture plant (CCP), so has the biggest impact on the economics of the process. An important factor to consider here is the lifecycle of power plant, which tends to be 30–40 years, compared to ten years for a petrochemical plant.

Mass transfer technology for CO2 absorption

Comparison of the various mass transfer devices was based on two criteria: similar metrical surface area for the packing and similar operating capacity of the column. The internal diameter (ID) of the absorber was fixed at 21m. This was arrived at by simulating the process with structured packing MellapakPlus M252Y, which gives a column capacity of around 68%.

If a system factor is taken into account for foaming, this value should be derated. For this study, the design criteria for the column's hydraulic capacity is fixed at 70%. The chosen packing types are listed in Table 2. These mass transfer devices will be compared on the basis of their separation efficiency, hydraulic performance and, most importantly, associated costs (Capex and Opex).

As seen from Table 2, structured packing MellapakPlus M252Y and random packing CMR1" have the same geometrical surface area of 250 m2/m3, and IMTP25 is close at 226 m2/m3, which could make for some interesting comparisons. As will be seen later, CMR1.5" has a similar capacity to M252Y. IMTP40 is also included, as it has a higher capacity than IMTP25, so it will be interesting to see its separation performance.

Separation performance

Based on the results from simulations using ProTreat, Figure 2 shows the separation performance of M25 compared to all the listed random packings. A packing height of around 7.6m for M252Y is enough to achieve a CO2 separation efficiency of 90%. CMR1", with a similar geometrical area to M252Y, requires 13% more packing height, while CMR1.5", with a similar capacity to M252Y, requires 20% more than M252Y.

It is obvious from these results that structured packing offers significant advantages in terms of reducing column heights. Obviously, ProTreat simulates a higher separation efficiency for structured packing than random packing.

Therefore, the packing height for a desired separation performance will be lower for structured packing, which translates directly into a further reduction in total pressure drop, as can be seen in the following section.

Process conditions used in the ProTreat simulation model

Process parameter	Value
Flue gas temperature and pressure at absorber inlet	46°C/1.02 bar
Flue gas composition	
CO_2	12.4 mol%
H_2O	9.9 mol%
O_2	5.0 mol%
N_2	71.8 mol%
Ar	0.9 mol%
Flue gas flow rate at absorber inlet	3.07. 10^6 kg/hr
Treated gas temperature and pressure	60°C/1.02 bar
Lean amine temperature and pressure at absorber inlet	40°C/1.03 bar
Lean amine (MEA) concentration	30 wt%
Lean amine circulation flow rate	7.20.10^6 kg/hr

Table 1

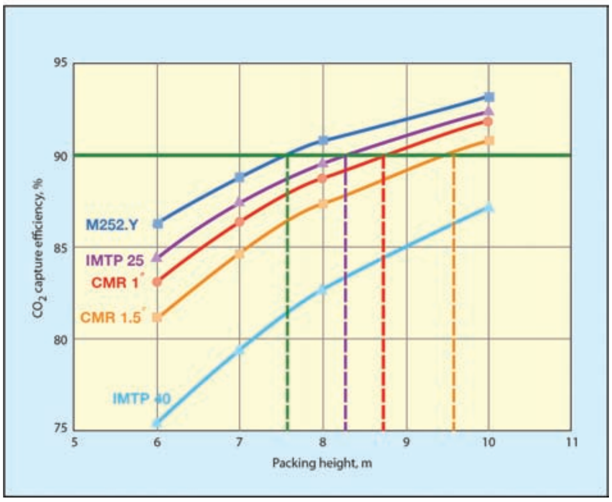

Figure 2 CO2 removal efficiency as a function of packing heights for structured and random packings. A separation performance of 90% is the yardstick for comparison

Hydraulic performance

Structured packings have a significantly lower pressure drop per theoretical stage than random packings when comparing packings of similar efficiency. Pressure drop considerations assume more importance for an application like CO2 absorption from flue gas streams, which are under atmospheric conditions. Every saving in the total pressure drop over the column amounts to significant savings in operating expenses (eg, the energy required for the fan blower).

For a given CO2 capture efficiency of 90%, Figures 2, 3a and 3b show the benefits gained by using M252Y over random packings in terms of separation efficiencies and hydraulic capacities/ pressure drop. An interesting result here (see Figure 3a) is the difference in hydraulics estimated by ProTreat and Sulcol.[3]

For an ID of 21m, hydraulics provided by Sulcol show a capacity of around 57%, which implies that the column is over-designed (whereas ProTreat gives a value around 70%). A quick estimation in Sulcol to match the 70% capacity criteria shows that an ID of 19m is good enough to meet the hydraulic performance requirements. Of course, for this lower ID of 19m, the corresponding pressure drop goes up by around 50% with respect to an ID of 21m (see dotted curve for M252Y in Figure 3b).

Actually, Figure 3b provides an interesting perspective in terms of the overall pressure drop over the packed bed height for various separation efficiencies. M252Y offers the lowest pressure drop among all the packings, with its pressure drop more than halved. It will be shown later how these savings in pressure drop (each mbar saved) can translate into significant cost savings for the end user.

Packing characteristics for structured and random packing used for simulations

Packing type[2]	Geometrical area, m²/m³
M252Y	250
CMR1"[a]	250
CMR1.5"[b]	187
IMTP25[c]	226
IMTP40[d]	151

a Sulzer equivalent C-Ring 1"; **b** Sulzer equivalent C-Ring 1.5"; **c** Sulzer equivalent I-Ring 25; **d** Sulzer equivalent I-Ring 40

Table 2

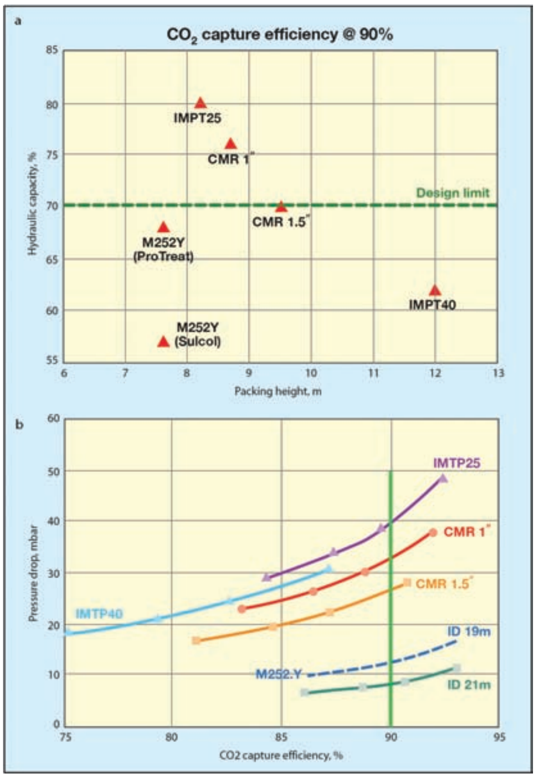

Figure 3 Hydraulic characteristics for CO2 absorber for commercially available packings.The dotted M252Y curve in (b) reflects the hydraulics for an absorber with an ID of 19m. All remaining curves are for an absorber ID of 21m

Savings in capital and operating expenditures

Capex savings

A higher separation efficiency for a given performance target implies that packing bed heights can be reduced. As noted in Figure 2, M252Y can reduce column bed heights by up to 20% compared to random packings, which means the column heights could be correspondingly lowered, resulting in lower capital expenses.

As also observed in Figures 3a and 3b, M252Y offers higher hydraulic capacities (or lower total pressure drop) compared to random packings. Thus, the column internal diameters can be reduced (by up to 10% in this case), which again contributes to a lower Capex.

These benefits go hand-in-hand with the total material weight (cost) of the packings. Random packings require more material for manufacture (in terms of sheet thickness) than structured packings, so depending upon the packing type chosen, random packings can weigh up to two to three times more than structured packing.

Opex savings

Here, a lifecycle cost analysis is presented for possible Opex savings, based on electrical costs (pressure drop). A fan is required to force the large flue gas stream through the absorber. A reduction in the pressure drop across the packing and column internals is a key parameter for saving energy. Each mbar of pressure drop saved results in considerable savings in operating cost.

Table 3 calculates the annual electrical cost to overcome 1.0 mbar of pressure drop and assumes a vapour flow rate of 1 MM 3/h of flue gas. The calculation results in €15 000 saved per each mbar and per

1.0 MM m3/h of gas. The flue gas from an 800 MW coal power station or a 400 MW gas power station is close to 2–3.0 MM m3/h (see Table 1).

Hence, when comparing various absorber designs, attention needs to be paid to the total resulting pressure drop. In order to judge investment costs resulting in pressure drop reduction, the net present value method (NPV) can be applied. Usually, the required investment to achieve a higher cash flow is known and the NPV method is used to judge the economic feasibility.

In this case, the investment is not calculated. Instead, three values are arbitrarily chosen to evaluate the benefit of such an investment. The objective here is to quantify the investments made to reduce pressure drop in terms of the internal rate of return (IRR) and the pay-out time.

Figure 4 shows the NPV curve, assuming an interest rate of 8.5% (WACC, weighted average cost of capital) for three cases, with an invested capital of €75 000, €100 000 and €125 000, respectively, for a reduction of 1.0 mbar pressure drop and a flue gas rate of 1.0 MMm3/h.

Power stations typically have a lifespan of 30–40 years. The IRR indicates the achieved interest on the invested capital over that lifespan. Therefore, the IRR for a power station can be based on a time period that is much longer than the chemical and hydrocarbon processing industry is used to. Table 4 shows the IRR, assuming a lifespan of 20, 30 and 40 years, respectively.

Investments to reduce pressure drop can be as high as €125 000 for each mbar of pressure drop reduction for a flue gas rate of 1.0 MM m3/hr, depending on the required IRR and assumed lifespan. The use of structured packing in the CO2 absorber results in significant pressure drop savings compared to random packing,

Electricity costs for a medium-sized European power plant	
Process parameter	Value
Flue gas rate, G	1 000 000 m^3/h
Pressure drop reduction, Dp	1 mbar
Fan efficiency, h	0.75
Operating time, t	8100 hr/yr
Electrical cost[1], c	0.05 EUR /kWh
Energy per year, E = G x Dp x t/h	$3.0.10^5$ kWh/year
Electrical costs, C = E x c	EUR 15 000/year

1 Average electrical cost in EU25 countries (Eurostat, 2007)

Table 3

Cash flow analysis for investment made to reduce pressure drop			
Invested capital (€) per mbar per 1 MM m^3/hr	75 000	100 000	125 000
Assume life span, years	IRR, %	IRR, %	IRR, %
20	19.4	13.9	10.3
30	19.9	14.7	11.5
40	20.0	14.9	11.9
Pay-out time	7	10	15

Table 4

so structured packing is preferred in this service. For a 800 MW coal-fired power station, a reduction of even 5.0 mbar can be worth more than €1.0 MM, with a pay-out time of seven years and an IRR of around 20%. This definitely needs to be taken into consideration during when designing the CO2 absorber.

Not just the choice of packing must be considered, but also the overall column dimensions and the other column internals, such as liquid distributors and draw-off trays. Alternatively, columns might be built larger in diameter, which is commonly perceived as a means of minimising pressure drop.

Again, it is important to bear in mind that the overall savings will be down to the right combination of Capex and Opex. A smaller diameter implies a higher pressure drop and vice versa. So, essentially, this becomes a trade-off between Capex (smaller ID) and Opex (higher pressure drop) or vice versa, which the process designer should account for in the design phase.

Liquid and gas distribution for large CO2 absorbers

Gravity-type distributors for the distribution of liquid in the absorption sections are recommended. For lower liquid loads, a line distributor can provide adequate distribution.

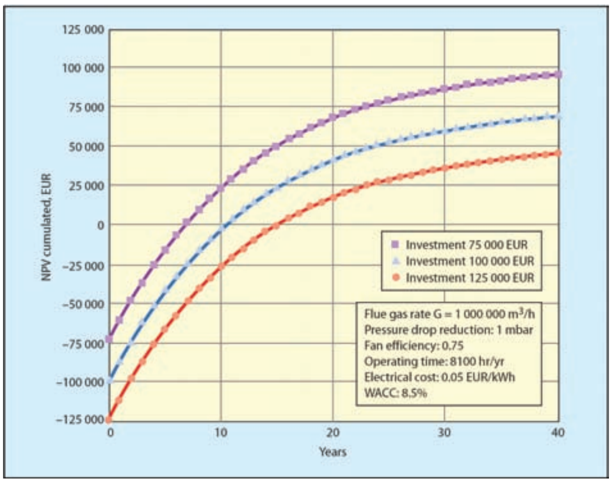

Figure 4 Net present value (NPV) curve for a period of 40 years

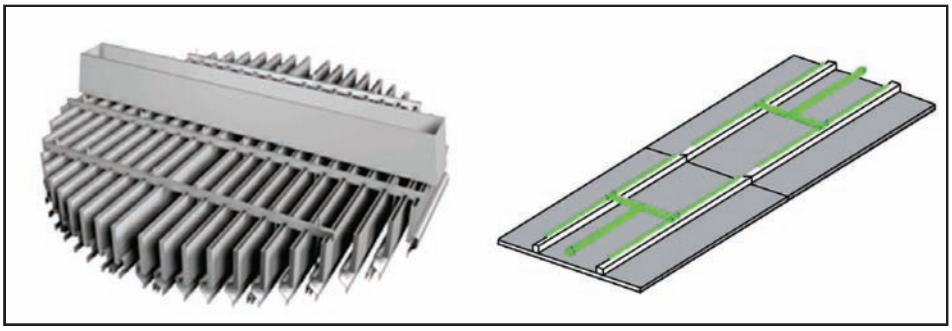

Figure 5 Sulzer liquid distributor configurations: (left) splash-plate distributor (right) rectangular layout of a high load distributor including the arrangement of the liquid inlet

To avoid problems with fouling, the distributors must be equipped with larger orifice sizes and openings on the side walls.

To allow for adjustments in the operation of the column, a turndown range of three to one can easily be realised with gravity distributors. The open area of the distributor influences the pressure drop of the column. A typical open area of configurations (Figure 5).

For higher liquid loads (>10 m3/m2h), high load gravity distributors are used in combination with a well-designed inlet system. The inlet system is designed to allow a proper pre-distribution to the liquid distributor.

The distributors are built in segments to allow them to be installed through manway openings. The distributors have to be level during operation. On structured packing sections, the distributors can be supported by the packing itself. An integrated support system with the capability of levelling the individual parts of the distributor is placed on the packing surface.

The mechanical strength of the structured packing is able to support the distributor, including its liquid load. If random packing is used, the distributor has to be suspended on beams. The distributor layout can be easily adjusted for circular or rectangular column cross-section layouts.

Collect and redistribute

To draw off liquid from a section, the liquid has to be collected by a collecting device. Collectors have to be designed with a minimum pressure drop and, depending on requirements, should be as sealed as possible.

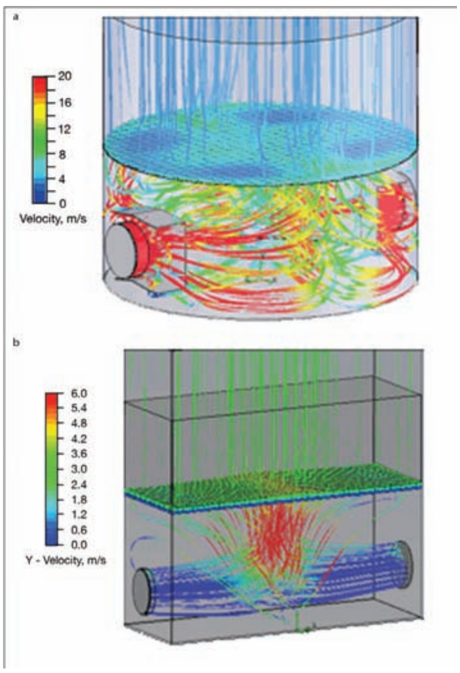

Figure 6 Sulzer vapour distribution configurations: (a) circular (b) rectangular column

The required distribution quality of the vapour flow is not the same as for liquid, but is still important to allow for an even L/V ratio in the packed section. The vapour distribution is mainly influenced by column shape, the configuration of the vapour inlet pipes, inlet devices and the available pressure drop of the packed bed above the vapour inlet (Figure 6).

All these parameters need to be accounted for when the vapour distribution quality is verified. CFD tools allow you to visualise and analyse the vapour distribution quality below packed sections. To allow for a definition of the vapour distribution quality, the variation of the vertical velocity is compared over the column cross-section at the packing inlet. The position of the vapour inlet nozzle in rectangular column layouts has more influence on vapour distribution quality than a circular arrangement.

Conclusions

The right selection of mass transfer technology is crucial to the successful techno-economic feasibility of CO2 capture from post-combustion power plants. Comparing the separation efficiencies and hydraulic performance of the various packings, structured packing is clearly preferred in this application.

Even a 5.0 mbar reduction in total pressure drop over the column can be worth more than an initial investment of €1.0 MM. It is possible to achieve a two to three times greater reduction in pressure drop using structured instead of random packing. On deciding whether to go for a larger diameter with a smaller pressure drop or vice versa, this is purely an economic trade-off between Capex and Opex, which must be accounted for by the process designer.

Also, the liquid and gas distributors must be properly selected, as these are critical in ensuring the successful operation of the packed beds, especially in such large-scale absorbers.

ProTreat is a mark of Optimized Gas Treating, Inc. MellapakPlus is a mark of Sulzer Chemtech AG. M252Y belongs to the MellapakPlus family of structured packing manufactured by Sulzer Chemtech AG, Switzerland. CMR1", CMR1.5", IMTP25 and IMTP40 belong to the random packing portfolio of Koch-Glitsch Inc, USA (www.koch-glitsch.com). Sulcol (SULCOL) is the hydraulic rating tool available from Sulzer Chemtech AG. This article is based on a paper presented at the recent ERTC in Vienna, Austria.

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www.sulzer.com

Capture news

Powerspan releases independent CO2 capture tech review

www.powerspan.com

Powerspan has released the results from an independent review of its ECO2 post-combustion carbon dioxide capture technology, conducted by global engineering firm WorleyParsons Group.

WorleyParsons conducted a detailed assessment of Powerspan's CO2 capture pilot test facility and evaluated the technology's readiness for commercial deployment on existing coal-fired electric power plants.

The WorleyParsons report concludes that the one megawatt (1 MW) equivalent slipstream ECO2 pilot test facility (approximately 20 tons per day of CO2 capture) operating at FirstEnergy Generation Corp.'s R.E. Burger Plant near Shadyside, Ohio, is well-designed and instrumented, with testing results that can be reliably used to design, build, and predict performance of a larger, commercial size plant.

Using design information based on the pilot results, the report concludes that a retrofit project could be implemented at less than $40 per ton of CO2 captured and compressed for a project size of 220 MWe net.

The WorleyParsons cost estimate is based on data derived from the ECO2 pilot for 90 percent CO2 capture with steam extraction for regeneration of less than 1,000 Btu/lb of CO2. This energy requirement is an improvement over previously reported values and results from optimization of the pilot facility process.

As part of the assessment, the WorleyParsons team visited the pilot test facility; confirmed the objectives for the pilot and the testing plan; verified the overall integrity of the ECO2 process; verified that the pilot is constructed and operated as was intended; verified location and operation of critical instruments; reviewed the instrument calibration logs; monitored operator actions and pilot plant response; examined sample testing procedures and documentation of results; confirmed automated data acquisition; confirmed that the data is a meaningful basis for a scale-up design from the pilot; and assessed that the ECO2 pilot is a good representation of a process that can be scaled-up to a larger, commercial size plant.

In addition WorleyParsons assessed the performance and cost implications of commercial scale-up and retrofit of the ECO2 technology to a 220 MWe net coal-fired power plant based on operating conditions provided by Powerspan, and confirmed by the ECO2 pilot facility operation. This high-level scale-up analysis provides estimates on performance, emissions, equipment sizing, and steam cycle modifications.

The study also includes the sizing of the ECO2 process equipment required for scale-up, the impacts of the ECO2 process and CO2 compression on the plant's net generation, and an overview of the reliability and maintenance considerations based on the current status of the process design.

The WorleyParsons assessment will be made available to prospective customers and partners.

Powerspan's ECO2 pilot test facility at FirstEnergy Generation Corp.'s R.E. Burger Plant near Shadyside, Ohio

Powerspan's ECO2 technology is a post-combustion CO2 capture process that uses a proprietary solvent to capture 90 percent of CO2 from the flue gas of coal-fired power plants. Once the CO2 is captured, it is dried and compressed and is ready for pipeline transport and sequestration.

Codexis receives DOE grant for CO2 capture biocatalyst research

www.codexis.com

Codexis has received up to a $4.7 million grant from the U.S. Department of Energy for development of technology to remove CO2 from coal-fired power plant emissions using biocatalysts.

The grant supports development of biocatalysts for more efficient carbon capture from coal-fired power plants. The technology is based on customized carbonic anhydrase biocatalysts that have the potential to enable cost effective, energy efficient capture of carbon dioxide. Codexis is developing this technology in collaboration with CO2 Solution Inc., based in Quebec, Canada.

According to the Department of Energy, the award was announced April 29 by Vice President Joseph Biden and Secretary of Energy Steven Chu as part of a $106 million award through the DOE's Advanced Research Projects Agency-Energy (ARPA-E) program.

Codexis is a leading provider of optimized biocatalysts that make existing industrial processes faster, cleaner and more efficient than current methods and have the potential to make new industrial processes possible at commercial scale.

Codexis has commercialized its biocatalysts in the pharmaceutical industry and is developing biocatalysts for use in producing advanced biofuels under a multi-year research and development collaboration.

CO2 shipping - do the numbers add up?

Large scale CO2 Shipping will support the early deployment of CCS and offshore enhanced oil recovery given that policies and mechanisms are put in place. Managing offshore cargo operations and coping with the mere scale of CCS are key success factors. The business case builds on an analysis of potential market segments, volume forecasts, transport services supplies and margin impact factors.

Per Arne Nilsson, Owner and Senior Consultant, panaware ab. This paper was originally presented at Riviera Maritime Media's inaugural CO2 Shipping Conference on May 6 in London.

Backdrop

The CCS market development is in its infancy and will remain there for still a number of years. The European outlook gives that the EU and a few member states are scrambling to provide funding for some eight to ten Demonstrator projects, to be in operation latest by December 2015. Another three to five projects may follow a couple of years later but still dependent on public funding and other subsidies.

On the global arena, climate mitigation policies still seem remote but the G8 set the target of 20 CCS installations by 2020. For the purpose of this analysis however, we use the bold assumptions that CCS technology will be verified through the demonstrator projects and that policy makers will stimulate a gradual CCS market development from 2025-2030 and onwards. Further momentum will be provided by developments and projects in the rest-of-the-world, with China, Australia and the US as drivers which is why we choose an overall positive outlook for the European market.

Volume Potential

The EU Commission, supported by various studies from a o McKinsey and The European Technology Platform for Zero Emission Fossil Fuel Power Plants (ZEP), forecasts a need for CCS to contribute to the overall emissions reductions, for the Union to stay on the 2 degree curve by 2050. This builds on a rapid ramp-up of the captured volumes to 99 mtpa by 2020 and 400 mtpa already in 2030. Realism or utopia, this is our chosen point of departure for the market potential evaluation for CO2 shipping.

Defining the geographic location of the capture sources and the most likely sinks (sequestration/storages) will assist us in finding the volume potential for marine transportation. Geologists have in numerous programmes mapped most of the globe for possible sinks and the European situation is reasonably clear. Land-locked capture sources in e g Germany, Hungary and Poland may find land-based sinks with sufficient capacity or else costly combinations of pipeline and maybe river transit schemes must be developed to reach coastal hubs. Offshore, in particular the North Sea appears to offer attractive saline aquifers and depleted hydrocarbon fields, promising storage capacity far beyond the region's needs. Also in the Mediterranean some few suitable locations have been mapped.

There are some preferences for offshore storage locations when practically possible and the choice is given. Partly this is a consequence of NUMBY behaviour (Not Under My Back Yard) from local pressure groups, protesting against the unknown underground storage of CO2 near their properties. This is probably most of all a gut reaction but clearly poses an obstacle to developers, which Vattenfall, Shell, Total and others will testify.

Other factors like smoother cross-border transport concepts, shared capacities and storage clustering also speak in favour of offshore sequestration. Therefore, when trying to assess the marine share of storage we apply some "offshore bias". By looking at a few offshore projects and regions, (NSB, Baltic, Rotterdam) we better understand the volume game.

Per Arne Nilsson, Owner and Senior Consultant, panaware ab

The European market potential for CO2 shipping should ideally be defined by the different "market segments", which could be described by time perspective and geography. High uncertainty is attached to any quantification but the examples serve well as indications of a likely development:

- Demonstrator projects, starting 2015-2017, aggregate maximum 20-30 mtpa, of which offshore storage 10-15

- Commercial scale market, commissioned from 2025 onwards, 300-400 mtpa, of which offshore storage 150-200. Marked annual growth up to 2050, when CCS could amount to 0.6 – 1.7 gtpa (source: ZEP, 2008)

- Intercontinental trade, e g CO2 to the Middle East for EOR projects (not included in the assessment)

- European offshore EOR projects, possibly commencing from 2020 and continuing through 30-40 years with volumes being a share of the commercial scale volumes

The potential market volume for marine transportation of CO2 is huge. It should be expected that the ship transport share will be higher early on than when the market begins to reach mature volumes and when scale economics benefit pipelines. For an assessment we assume that the shipping share of the marine transport is 40% for the early projects and thereafter stable 30%, which gives the following coarse CO2 shipping potential volume:

Probably a conservative forecast, by no

(mtpa CO2 transported)	Demonstration projects 2015-17		Commercial Scale 2030+	
	Total	Ship	Offshore	Ship
Low	15	3	100	30
Medium	20	4	150	45
High	30	6	200	60

Table 1 - Potential volumes, CO2 transport market

means verifiable and within only twenty years from now, but it indicates a new and attractive market potential. Comparing to the present volumes of around 110 mtpa oil onboard shuttle tankers from the North Sea, this encourages us at least to pursue the business case analysis. The shipping industry could influence its own potential by taking a proactive, constructive and early approach to supporting the development.

Key Competitive Challenges

There is a spinal reaction in industry to consider pipeline the first choice of marine CO2 transport for CCS and certainly in view of projected volumes and distances this will also be the case. The Euro-per-ton cost of transport will be under heavy pressure and so industry will push for governments to "provide infrastructure" which by all standards will be dominated by pipeline networks.

However, there are a number of complexities attached to the development of large scale pipeline networks, where ship solutions can function as enablers. Without entering into detail, key words are timing (and certainty) of individual CCS project investment decisions, capacity utilization, source clusters, spine (trunk) connections and sink clusters.

Shipping capacity can be near-tailored to demand and can grow near-dynamically with each growth in captured volumes. Therefore there should be more of symbiosis than competition and shipping will enable large scale pipeline investments by supporting volume growth from scratch and up to what is required for these to break even and yield a return.

Ship owners can seize an attractive share of the marine CO2 transport market relying on its long established business model. The frameworks such as insurance, legal, technical and commercial conventions are in place and can be applied with little modification. This will naturally lower the hurdles for power plant investors who venture into unknown terrain already with CCS and even further with gas shipping.

Investing in (or contracting) ship transport capacity to the tunes of CCS will be perceived as low risk compared with pipeline investments. Lower locked-in CAPEX and lower CAPEX share of total cost cushion investors in these overall very capital intensive projects. Constructions will surely also be seen where ship residual values will be secured, either through life-extension projects or by a multi-product design, at least for the earlier projects. Speed-to-market, flexibility and high utilization rate are other key hallmarks for the shipping industry.

Technically, one chief challenge will be to manage offshore cargo operations. Ship transport can be foreseen both as feeder from one source (or source cluster) to a trunk pipeline and as direct point-to-point for offshore discharge and injection. The shipping industry must provide safe, reliable and cost efficient solutions for offshore operations to play a really important role in CCS.

By building on the excellent oil loading track record and technological advances, acceptable availability should be secured. Teekay Corporation as the largest operator of offshore loading shuttle tankers has performed more than 20 000 successful oil liftings in the North Sea, albeit with larger vessels than will be employed for CCS. Conditions vary between the Northern and Southern sectors of the North Sea and even more in the Mediterranean, so there will be more than one technical concept.

As an example, at a North Sea location with a water depth between fifty and hundred metres the APL concept with submerged turret would provide the required robustness. Designing and building ships to this standard is low risk considering the project lifetime. With the experience available it will be possible to design offshore discharge ships and offloading systems that will provide an acceptable operational availability independent of storage location.

CO2 shipping could become a catalyst to offshore enhanced oil recovery. This is technically a more demanding market where shipping innovation and credible performance are required. The nature of projects, like project lifetime, injection patterns and likely combinations of fields and existing infrastructure, harmonize well with the flexibility and speed-to-market of shipping.

The mere scale of the logistics operation is probably more of an operational challenge where all components must ensure an MTBF (mean-time-between-failure) which harmonizes with the complete CCS system where transport shall fit in. Technical design, construction and maintenance must be matched with a robust enough organization with fail-safe procedures built in to a quality assurance environment.

The fall-back for system failures could well be the financial penalties for involuntary emissions. The logistic system should be built to the same standards as the power plant to be able to operate for up to forty years which is unusual but not considered unattainable in shipping. In fact service life of 30 to 40 years is already accepted in the area of LNG shipping.

Margins

The speed of the growth of the clean energy economy is a function of political determination, first on a global arena. Implementation of emission regulating mechanisms must create a reasonable playing field for competing energy technologies to develop.

Combustion of fossil fuels with CCS will compete with wind, wave, hydro, solar and nuclear power generation. In a near-perfect market, margins will eventually balance out with parameters like location, distribution (grid), demand and national policies. It must be expected that energy markets will always be at least partly regulated in many regions and countries. Therefore, ultimately the gross margins for services within the CCS value chain will be limited by both markets (competition) and regulation.

Payability is hard to forecast before climate policies establish the basic rules for and costs of emissions and before functioning commercial markets have been established which could be expected to happen maybe only by 2025-2030. This explains why so far mostly "costs" for CCS rather than "price" have been commonly discussed. Transport services to CCS are today (by many) considered the least technical challenge and hence the most commodity type of service with high expectations for a real price pressure.

Viewing the volumes (in millions of tons per year and project) one must conclude that realistically only pipelines and gas tankers can handle the task. Since these two transport modes are both technically and financially different in nature, comparisons will never be straight-forward. Investors will take hard looks on the financials but always factor in longer term strategies when making their technology choices. Gas tanker margins will be limited by the perceived costs of installing and operating pipelines.

The shipping industry has well established pricing mechanisms, based on an understanding of acceptable returns on capital employed. Prices for new-built tonnage as well as going time charter rates are public. CO2 shipping will over time be no different, in fact maybe even more transparent with certain projects being public tenders. Moreover, ships will have limited proprietary technology content.

From the opposite perspective, CCS Project Developers will analyze projects first from the expected end product net margins (energy or industrial goods). Then for CO2 transport, synergies will be explored, between multiple sources and multiple sinks, in different clusters. Here shipping solutions could play an important role to optimize flows. In the end, the attractiveness of this emerging shipping market will be defined by the above factors. Proactive ship owners looking for early-mover advantages will pioneer development and build substantial good-will but competition will be fast to level out margins. As for most new markets, CO2 shipping will tend

to go from niche pricing towards commodity.

Transporting CO2 to offshore oil fields for enhanced recovery projects may well prove to be the positive extreme on the margin scale. Ship solutions could add substantial value in its superior flexibility, serving multiple projects yet offering investors low financial risk also for projects with lifetime as short as five years. This market segment with attractive oil revenues combined with carbon credits and the benefits of possibly deferred decommissioning costs could well offer (some few) credible and innovative ship owners substantially more than commodity margins.

Cost Analysis

The complete logistic chain for CO2 ship transport is in essence no different than those of other liquid gases. To analyze costs for the pure transport element and to provide some basis for alignment when discussing shipping costs, we suggest including:

- Cargo pump for 12 hours loading time
- Fixed loading arm installation for maximum automation and loading surveillance
- Semi-refrigerated, semi-pressurized ships for 8 bar and -55oC
- Cargo capacity tailored to logistic needs and limited to maximum 40 000 m3
- Dynamic positioning capabilities integrated in original design and construction
- Hull modification and installation for submerged turret loading (STL) as one example of a number of suitable mooring solutions

Other major cost elements to be considered for the complete logistics case are:

- Liquid buffer storage at quay-side, 0.8-1.5*ship cargo capacity
- Onboard cargo plant for re-liquefaction for one-way journeys exceeding seven days
- The required installations at the receiving end will be quite site specific and can hardly be included in any generic cost comparisons
- Ship discharge could range from fast (liquid) to slow (gaseous), requiring different gas conditioning investments

For Demonstrator size projects with 2.5 mtpa CO2 and only point-to-point transport the following table shows transport cost estimates. To imagine transport costs in a commercial market the potential for cost reductions by either source or sink clustering (or both) must be considered. Indeed, projects will be site specific, so there are really no generic transport costs. Therefore, when presenting numbers the basic assumptions should be stated. For this case our logistic model optimizes the ship sizes to 20 000 and 33 000 m3, respectively. The above cost elements are included. Notably, if adding quay-side buffer storage, offshore terminal and gas conditioning offshore, "ship" costs increase by 2.5 EUR/ton.

(EUR/ton)	180 kms	750 kms
Offshore pipeline (excl compression)	10	27
Ship to offshore	5	6
Ship "all-in"	13	14

Table 2 Examples of estimated transport costs, pipeline and ships for EU Demonstrator type of projects

In a wider CCS perspective the battery limits must be made clear when discussing the distinct costs of capture, transport and storage, respectively. The debatable areas are primarily the conditioning after capture, compression and liquefaction, the subsea installations for discharge and conditioning before injection. For the given example compression for pipeline transport is not included but as an indication the energy consumption amounts to around 80-90 kWh/t CO2. An estimate for liquefying 2.5 mtpa CO2 at one site with electricity at typical European market prices is 5.5 EUR/ton.

The cost structures of pipeline and ship transport are significantly different. Pipelines are characterized by high investment, while shipping costs have an OPEX bias. Therefore pipelines have a larger benefit of scale whereas ship investments are not fully locked in and can under certain conditions be redeployed in other product markets. A cost estimation model must integrate dynamics for residual values.

Business Outlook

In conclusion, we summarize some answers to these four critical questions:

- Will there be any business for ship owners and if so
- How big?
- Which will be the margins and finally,
- When?

Even in a low volume scenario ship owners could prepare for an interesting enough market under development. Base conditions are the same as for most other clean tech, i e that stringent climate policies are installed with reasonable determination and speed.

Shipping CO2 in gas tankers at large scale will be a kind of niche market in what most experts today consider a pipeline infrastructure game, possibly with the direct involvement of government investment. Using the known sources across Europe and the perceived suitable offshore storage locations we find a transport demand for ships ranging from 2 mtpa in the low scenario for 2015 to 60 mtpa in the high scenario for 2025. In comparison, the volumes of crude oil shipped in tankers today from the North Sea account for around 110 mtpa. In effect this means that a number of projects and tenders will enter the market from 2020 but that real market revenues and profits will not be seen before 2030 but by then the scale will likely overtake current North Sea oil cargo operations.

Margin intervals will be limited by both the general payability for CCS, in turn a function of climate policies and by the expected long term transport costs for a near-functional market where source and sink clusters respectively exploit all possible synergies in pipeline networks. Ship-owners' overall returns in CCS projects will essentially be measured in return-on-investment for new-and-dedicated CO2 tonnage.

For the two Demonstrator examples above, the estimated (calculated) and required Time Charter rates are 31 000 and 39 000 USD. These are only speculative indications of how margins will develop, but in summary CO2 shipping is likely to become an interesting new source of revenue for some proactive ship owners.

The first tentative ship transport agreement has been announced for commissioning around 2014-2015. The speed of market growth is affected by both macro-climate agreements and by industrial investment decisions. Ship owners can certainly influence their joint market share already now and will see market potential growing from 2020 onwards. CCS project investments decisions are due within the next five years. The heat is on – or at least, prospects are warming up.

More information

Per Arne graduated as an International Economist and completed post-graduate training at IMD, Lausanne and the Gestalt Institute, Cleveland, US. He has been stationed in Europe, Middle East and Far East. Joining Norsk Hydro in 1986 he first headed sales in the downstream sector before relocating to Asia to pioneer the expansion of the industrial gas division from where he was appointed President, South Europe of Hydro's (later Yara) Industrial Chemicals Division. Since 2005 he is an independent management consultant, with key focus on Climate Change mitigation.

For IM Skaugen, Norway he developed a business model for large scale CO2 shipping. He has executed a number of CO2 logistics studies for European clients and is currently heading the Zero Emissions Platform Expert group on CCS Transport Cost.

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Transport and storage news

EPA proposes emissions reporting for CO2 storage sites

www.epa.gov

The U.S. Environmental Protection Agency (EPA) is proposing to include CO2 injection sites in the mandatory reporting of greenhouse gas emissions.

EPA finalized its mandatory greenhouse gas reporting requirement in October 2009. That rule required 31 industry sectors, covering 85 percent of total U.S. GHG emissions, to track and report their emissions.

In addition to those 31 industries, the agency is now proposing to collect emissions data from the oil and natural gas sector and from facilities that inject and store CO2 underground for the purposes of geologic sequestration or enhanced oil and gas recovery.

Data collected from facilities that inject CO2 underground would enable EPA to track the amount of CO2 that is injected and in some cases require a monitoring strategy for detecting potential emissions to the atmosphere.

The data will also allow businesses to track their own emissions, compare them to similar facilities, and identify cost effective ways to reduce their emissions in the future.

EPA is also proposing to require all facilities in the reporting system to provide information on their corporate ownership.

Under these proposals, newly covered sources would begin collecting emissions data on January 1, 2011 with the first annual reports submitted to EPA on March 31, 2012.

These proposals are open for public comment for 60 days. The agency will also hold public hearings on these proposals on April 19, 2010 in Arlington, Va. and April 20, 2010 in Washington, D.C.

DNV releases CO2 storage guideline

www.dnv.com/co2qualstore

DNV and the energy industry, with contributions from government agencies, have developed a comprehensive guideline for safe and sustainable geological storage of CO2.

The CO2QUALSTORE Guideline for Selection, Characterisation and Qualification of Sites and Projects for Geological Storage of CO2 has been developed in response to a perceived lack of tailored regulatory frameworks and established industry practices.

The guideline provides a comprehensive and systematic process that covers the full lifecycle of a CO2 storage project, from screening and site selection to closure and transfer of responsibility from the operator back to the national state, taking into account the unique characteristics of each potential site.

The aim is to accelerate the implementation of CCS by providing a common, predictable and transparent basis for decision-making between project developers, operators and regulators.

Project developers will benefit from a procedural framework to select and manage sites, delivering consistency and efficiency based on best engineering practice and technology, said DNV. Regulators can use the guideline to verify that sites have been selected and assessed as suitable for geological storage of CO2, following a standardized and globally recognised procedure.

Verified implementation of CCS projects in compliance with this guideline should also help provide assurance to the general public that a storage site is selected based on a recognized process, will be safely and responsibly managed according to recommended practices for sustainable CO2 storage, and is in compliance with regulations, codes and standards.

Leading engineering, oil & gas companies and government bodies were brought together by DNV to develop the CO2QUALSTORE guideline 18 months ago. The procedural framework that was developed mirrors best practices within the oil & gas industry, reflects existing and emerging regulations, standards and directives relevant for geological storage of CO2, and draws on learnings from R&D and pilot CCS projects around the world.

The guideline will be updated periodically to keep pace of changes.

Petrofac acquires CO2Deep Store

www.co2deepstore.com

CO2DeepStore, the UK-based developer of CO2 storage projects, has been acquired by international oil & gas facilities service provider Petrofac.

The company will continue to trade as CO2DeepStore and will retain its full management team as part of the Petrofac Group where it will have access to financial backing for investment in major CO2 storage projects in addition to using the engineering and project development capability of Petrofac in such projects.

The current phase of CSS demonstration projects, underwritten by government funding in various countries, will be the focus of early investment attention.

Petrofac says the acquisition is a key part of its diversification into the low carbon energy sector and the development and operation of CO2 transport and storage facilities complements Petrofac's Offshore Engineering & Operations and Energy Developments businesses.

Global network for CO2 geological storage launched

www.ipac-co2.com

The International Performance Assessment Centre for Geologic Storage of Carbon Dioxide (IPAC-C02) has established a global network linking organizations in eight countries which conduct research into the geological storage of CO2.

Pennsylvania government reports on CCS storage regulations

www.dcnr.state.pa.us

The Department of Conservation and Natural Resources has published two reports online that conclude that with the appropriate changes in laws, Pennsylvania's geology could store carbon dioxide in a cost-competitive and manageable way.

Creating such a system would bring with it jobs and a cleaner environment, but it cannot be accomplished without substantive changes to laws governing subsurface ownership rights and long-term liability issues, the reports say.

The reports conclude that the next step is to identify specific geographic areas where storage could be evaluated, but note that this technology cannot be deployed at power plant scale in Pennsylvania now or in the foreseeable future because ownership of adequate underground storage cannot be assembled.

An assessment prepared by Tetra Tech of Pittsburgh suggests that favorable geologic conditions exist for a CCS network in Pennsylvania, which mirrors the findings of an initial report issued in May.

The technical and economic analysis, which examined the potential of retrofitting six coal-fired power plants in central and southwestern Pennsylvania, was prepared by WorleyParsons Group Inc., Spectra Energy, Climate Change Capital, and the Clinton Climate Change Initiative.

Clarification

In the last issue we stated that, 'The first comprehensive study of carbon capture and storage to be undertaken in the UK ....was published in May 2009'.

This was incorrect, the first study of this type was published 12 months previously by Yorkshire Forward. We apologise for the mistake.


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