INTERNATIONAL ENERGY AGENCY

WORKSHOP REPORT 2013

CCS in industrial applications

A workshop of the CCUS Action Group in preparation for the 4th Clean Energy Ministerial

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INTERNATIONAL ENERGY AGENCY

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Executive Summary

At the 3rd Clean Energy Ministerial (CEM 4)[1] meeting in London, UK in April 2012, the Carbon Capture, Use and Storage (CCUS) Action Group – which brings together thirteen countries that recognise the potential importance of CCS to decarbonising their economies – requested that a paper on how to make progress on CCS solutions for industrial applications be prepared and presented at CEM 4 in New Delhi, India in April 2013. The IEA and the CCSA jointly organised a workshop to discuss the key messages and policy conclusions that might be included in the requested paper. The workshop was held in London, UK on 30 January 2013. It convened participants from the steel, cement, refining and chemicals sectors with other experts from CCUS governments and the research, financial, environmental and policy communities. Discussion centred on the policy recommendations to be made to governments and ranged from the technology readiness of CCS in individual sectors to possible project development models and supportive policy regimes for trade exposed industries.

Transforming energy-intensive industrial sectors so that they can be compatible with the transition to a low carbon economy, while maintaining production volumes, requires concerted, collaborative efforts to develop and invest in novel process designs and solutions that can reduce emissions intensities by over 50%, but which are not yet on the market. In this context, IEA analysis suggests that CCS could be an indispensible tool to which insufficient attention has been given to date in some of these sectors.

The CCUS Action Group's Industrial CCS Working Group has the following aims:

- To raise awareness among CEM governments of the potential of CCS for significantly reducing emissions in industrial applications, including an improved level of differentiation between the sectors and processes concerned.
- To analyse, on the basis of existing studies and expert input, the potential and challenges for CCS in the industrial applications that offer the greatest opportunities for: reducing overall CO_2 emissions (i.e. long-term large contributors of CO_2 emissions); or near-term CO_2 emissions reduction (i.e. low cost opportunities for application of CCS).
- To provide CEM governments with a succinct set of near-term actions required to advance industrial CCS towards deployment consistent with lowest-cost climate change mitigation and industrial competitiveness.

Workshop participants were invited to comment on a draft version of the requested CEM 4 paper, prepared in advance by the IEA. Supporting information was provided by a background paper, prepared by the IEA with support from the CCUS Action Group and an expert working group convened for the purpose. The background paper and other supporting materials can be found online at the workshop web page:

www.iea.org/newsroomandevents/workshops/workshop/name,34219,en.html

This report presents a synthesis of the discussions that took place.

[1] www.cleanenergyministerial.org

1. Scope of workshop

CCS in industrial applications refers to the capture, transport and storage (or utilisation) of CO_2 that would otherwise have been emitted to the atmosphere from commercial facilities, excluding the power sector[2]. CCS is currently the only large-scale mitigation option available to achieve emissions reductions of over 50% of their current levels in some sectors. Without CCS it may not be possible to decarbonise these sectors and therefore economies where CCS is available may be better placed to host and benefit from industrial production in the future. The reason for this is that certain industrial processes unavoidably generate CO_2 as a result of chemical reactions that are integral to the formation of the final product.

In the sectors studied in preparation for the workshop, common challenges were identified. Of primary importance is the fact that these sectors are exposed to global trade. Unlike the power sector, their products compete on truly global markets. Output from regions that fully internalise the climate costs of production could be competitively disadvantaged. Among these sectors, four stand out in terms of their overall total CO_2 emissions and the future difficulties of avoiding CO_2 emissions from the production or substitution of their material products without CCS. These sectors are: iron and steel, cement, refining and chemicals.

The workshop agenda covered three main themes.

- Existing recent work in the area of CCS in industrial applications that has sought to understand where opportunities lie for the development of projects and policies that can create momentum towards low carbon industrial production.
- Identification of the challenges associated with both the development of the necessary technologies and the necessary policies, to which solutions would need to be presented in the recommendations of the requested CEM 4 paper.
- The recommendations themselves: What are the priorities? What has been omitted? How can the recommendations most effectively inform policymakers about the challenges and their potential solutions?

The workshop was co-chaired by Mr. Juho Lipponen, Head of the IEA's CCS Technology Unit and Dr. Luke Warren, Deputy Chief Executive, CCSA. This report presents a synthesised summary of the discussions and is built around the themes listed above. The following sections reflect views expressed by participants at the workshop, and do not necessarily represent those of the IEA, CCSA or CCUS Action Group.

[2] CCS for power - or combined heat and power (CHP) – generation, for local consumption by a sector's industrial processes could be an important element of decarbonising industry and is included in the policy recommendations in this paper.

2. Introduction

The workshop was opened by Mr Juho Lipponen of the IEA, who reviewed the recommendations of the CEM in relation to CCS and introduced the objectives of the meeting as follows.

- Explain the Clean Energy Ministerial concept
- Learn from current experience from different countries and sectors
- Receive feedback on the draft recommendations
- Facilitate a discussion on challenges and messages for policymakers

In recent publications, the IEA has highlighted CCS in industrial applications because of its significant potential to contribute to emissions reductions across the global economy and also because of its potential role as a first-mover for CCS commercialisation. In several cases industrial applications offer lower CO_2 mitigation costs than CCS in power generation and could play a facilitative role in advancing CCS towards subsequent deployment in all sectors. CCS in industrial applications deserve special emphasis because it has received little political attention and few incentives exist around the world for firms to set out on the road towards achieving deep CO_2 reductions using CCS.

The CEM offers a particular opportunity to communicate this situation to policymakers and clarify the challenges that will need to be overcome. CCS in industrial applications must be understood in the context of a diverse set of different industrial sectors that will require tailored policies. These policies will need to manage the impact on the global competitiveness of firms within these sectors. Given the possible timescales for wide deployment of CCS as envisioned by IEA modelling, and that of several CEM governments, it is imperative that these concerns are addressed in the short term and a pathway charted to 2050 for CCS. In this perspective, CCS in industrial applications could play an important role, not just in delivering emissions reductions, but also in demonstrating the breadth of application of CCS. CCS is not just a technology for application to coal-fired power plants. In fact, by 2050 almost 50% of the CO_2 captured and stored may need to come from industrial applications – three quarters which would be in non-OECD countries.

According to IEA analysis of current emissions levels and the need for CCS to deliver deep emission reductions, four sectors have been identified as priorities for the CEM paper: iron and steel, cement, refining and chemicals (including petrochemicals). Mr Lipponen requested that participants focus on practical policy recommendations that will be relevant today. The following key questions were outlined.

If CCS needs to be a technically proven option for the iron and steel, cement, refining and chemicals sectors:

- What are the strategic challenges for industry?
- What are the challenges for policy?
- What needs to be done in this decade to ensure this outcome?

If CCS needs to be a commercial solution for the iron and steel, cement, refining and chemicals sectors:

- What types of policies will create momentum this decade?
- And what types of policies will deliver deep emissions cuts?

Mr. Chris Barton, Deputy Director, International Energy Security at the UK Department for Energy and Climate Change (DECC) agreed that CCS is seen by the UK as absolutely critical to energy and climate change goals. CCS will be important for emissions and energy security alike, by facilitating the continuing use of widely available coal and gas resources. CEM countries, in his opinion, remain a significant distance from having CCS available to deliver the reductions in industrial emissions that will be needed in the first half of this century.

The CEM process is grounded in practical collaboration between major economies and, as such, is complimentary to the United Nations Framework Convention on Climate Change (UNFCCC) mechanism. Mr Barton stressed that the strength of the CEM process is its ability to target specific practical and achievable recommendations to Ministers and he urged all participants to contribute suggestions and constructively develop strong recommendations on CCS in industrial applications.

3. Existing recent work in the area

In recent years policymakers have become increasingly aware of the scale of greenhouse gas emissions associated with industrial production and the limitations to reducing these emissions through efficiency gains and greater use of renewable or other low carbon energy sources. At the same time, modelling exercises such as the IEA's Energy Technology Perspectives (ETP) have indicated that production of energy-intensive commodities such as steel and cement will continue to expand during the twenty first century as growing economies invest in infrastructure. The ETP models one lowest-cost scenario for managing emissions in line with a maximum 2°C rise in global temperatures. This scenario envisages that 55 billion tonnes of CO_2 would need to be captured from industrial applications and stored in geological formations between now and 2050. Other exercises[3] have reached similar conclusions about the central importance of CCS if the world is serious about moving to a low carbon pathway, not just in the provision of electricity and transport, but also in the provision of material goods.

Although the development of policies that can effectively support CCS in industrial applications is relatively young, several good technical reference documents exist. Many of these are sector-specific and consider the costs or technical configurations that could be deployed. The three recent pieces of work that were presented at the workshop were chosen for their breadth – they cover all relevant energy-intense industries in their jurisdiction – and their regional policy focus. These pieces of work consider where the opportunities might be for cost-effectively capturing emissions from industrial applications in the UK, the EU and China's Shaanxi Province. In addition, some of the preliminary work for the CCUS Action Group in preparation for the requested CEM 4 paper was presented by the IEA.

3.1. UK perspective on industrial CCS - technology readiness and costs

In the context of the UK Government's legal requirement to deliver a reduction of greenhouse gas emissions by 2050 of 80% compared to 1990 levels, it is anticipated that industrial emissions would need to be reduced by 70% over this period. In the development of the Fourth Carbon Budget, which was legislated in June 2011, it was concluded that CCS could be both widely applicable in energy intensive industries and cost effective within projected carbon prices over the period to 2030, reducing emissions from energy intensive industry by 5 $MtCO_2$ in 2030 and 37 $MtCO_2$ in 2050[4]. By 2050 up to one third of CO_2 emissions from UK energy intensive industries could be avoided through CCS.

Ms. Jane Lumb of the Green Economy Team at the UK Department for Business, Innovation & Skills, presented work that began in 2012 in response to the anticipated need for CCS to provide compliance with climate change legislation in energy intensive industries. The UK has a GBP 1 billion commercialisation competition that primarily targets the power sector, but for which industrial CCS is also eligible where it can link to a power emitter, and contribute to the objective of reducing the costs of fossil fuel power with CCS. The GBP 125 million CCS R&D programme is set to fund around 85 projects; including some which relate to industrial CCS. In general, however, policy for energy intensive industries has so far focused on developing some compensation to help these sectors to manage the rising costs of CO_2 emissions. A longer-term solution is sought.

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[3] Such as the European Commission's 'Roadmap for moving to a low-carbon economy in 2050'.

[4] The Fourth Carbon Budget. Reducing emissions through the 2020s. Committee on Climate Change. December 2010

The work to date has looked at the technological readiness and the available information on costs.

A review of the technical aspects of CCS for industrial applications in the UK was undertaken in late 2012 by the UK CCS Research Centre (UKCCSRC), which organised a series of workshops with the relevant industries: iron and steel; cement; glass and other industrial heat users; chemicals and refineries [5]. A further work stream on clustering CO_2 sources for CO_2 transport and storage purposes was also developed.

The main findings from these workshops are summarised in Table 1.

Table 1 • Findings from the 2012 UKCCSRC workshops on CCS in industrial applications

	Technological readiness	Remaining issues and barriers
Iron and steel	• Several capture choices, option will be site specific • Pilot ready for some applications • Some knowledge transfer from power capture technologies	• Multiple sources of CO_2 – blast furnace, stove, coke, power station • Impurities in gas streams • First Of A Kind risk • All solutions need to be retrofit – very unlikely will invest in new build in the UK
Cement	• Technology is pilot ready with several pilots planned around the world (none in UK)	• Multiple sources of CO_2 • Air leaks in existing plants (for oxy-fired CCS) • Unknown impact on the quality of the cement of the most highly-integrated methods, though this is not an issue with post-combustion capture.
Glass and other industrial heat users	• CCS one option, but could also reduce CO_2 onsite through fuel switching (electric or H_2) but electric heating thought more expensive than CCS. • Oxy-firing used to some extent now for process improvement. • H_2 firing and post-combustion capture thought technically feasible.	• Oxy-firing would require new or substantial rebuild – big cost implication. Some gaps where knowledge is very low. • There is no experience in the UK with H_2 firing or post-combustion capture in these sectors.
Chemicals and refineries	• Mixture of well developed technologies already in operation (e.g. hydrogen) through to very early stage research (e.g. olefins)	• Main barriers where technology is developed are commercial - cost, fuel uncertainty, payback

CCS in industrial applications is viewed positively in the context of clustering CO_2 sources to reduce overall mitigation costs. The availability of an existing pipeline with known costs greatly reduces project risks for additional sources investing in CO_2 capture equipment. The approach that could be envisaged in the UK would be the use of power generation CCS projects as 'anchors'. The industrial sources would provide the additional benefit of steadying the supply of CO_2 to the pipeline infrastructure and the storage site during periods when power generation fluctuates to reflect intermittent renewable generation on the power grid.

Costs for CCS in industrial applications are currently being reviewed by Element Energy for the UK Government. With the exception of CO_2 captured from hydrogen production processes it is considered that cost papers are still at the conceptual stage. There is little or no cost data from FEED[6] studies to give more accurate results and the few papers that exist tend to draw on the same few data sources, which are becoming outdated. The site specific variance – such as the source of heat for the capture process – makes it hard to extract generalisable conclusions. The range of possible CO_2 capture costs are presented in Figure 1 and include all applications. It can

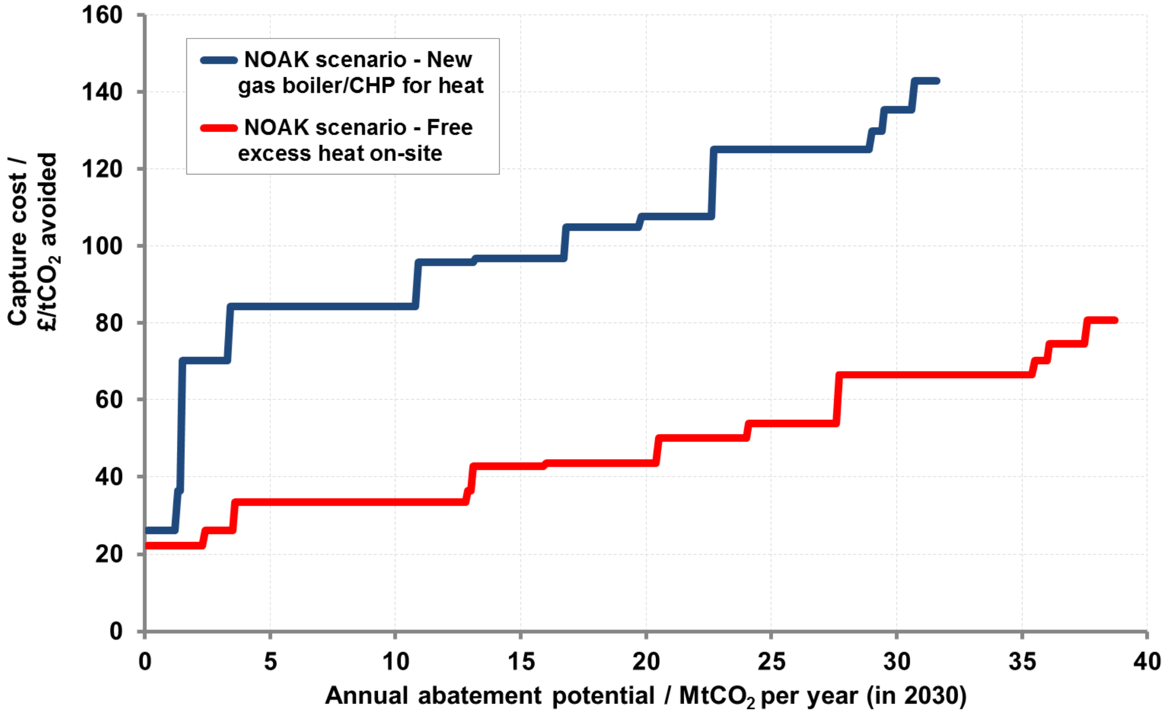
[5] For more information: www.ukccsrc.ac.uk/meetings-events/ccs-industry-workshops

[6] Front End Engineering and Design

be seen that the source of heat to be used for operating the CO_2 capture process makes a large difference to the costs.

The low-cost options (bottom left) are generally in hydrogen production production, whilst the higher costs relate to capture of CO_2 from relatively small boilers providing heat and power to large industrial users. Cement kilns and steel blast furnaces fall somewhere in the middle. Analysis suggests that First Of A Kind (FOAK) could be around 50% more expensive than the Nth Of A Kind (NOAK) plants presented in Figure 1. This has relevance to the timing of introduction of CCS in different sectors, as it is unlikely that all sectors would adopt CCS in 2030; some may do so earlier, some later.

Figure 1 • Marginal Abatement cost curve for CO_2 capture from UK industrial sources in 2030 (Element Energy)



The next steps for the UK government will include assessing whether more R&D will be needed, how to incorporate competitiveness concerns into an appropriate timetable for CCS in industrial applications and encouraging more cooperation on suitable solutions.

3.2 A European perspective on the opportunities

Mr. Jonas Helseth, Director of Bellona Europa, presented the work undertaken to date by the Working Group on Other Industries that has been established within the European Technology Platform for Zero Emission Power Plants (ZEP). ZEP is a technology platform established to provide advice to the European Commission on CCS technologies. The Working Group on Other Industries comprises members from various industrial producers, research institutions, oil and gas companies, equipment suppliers and environmental organisations. In a forthcoming report they plan to:

- look at technology options and potential per industry
- consider the situation and outlook for those industries in the EU

- pointing to major EU-specific (and some general) administrative and economic hurdles to CCS deployment
- discussing some potential options for facilitating EU CCS deployment in non-power industries light of ongoing and future EU policy processes.

Mr. Helseth highlighted the recent mentions of the importance of CCS in industrial applications by the European Commission's Directorate-General for Energy and the European Parliament's Industry Research and Energy Committee. He also stressed that the only CCS project to receive governmental support in the first round of the European Commission's NER300 funding competition was for an industrial application. This project was the proposed ULCOS project at a French steel mill, but was ultimately withdrawn from the competition.

In Europe, the iron and steel sector operates a relatively small number of sites that are very large point sources of CO_2. The European cement industry, on the other hand, is much more spread out between more, smaller sites.

The main policy instrument for addressing CO_2 emissions in the EU is the Emissions Trading System (ETS). Although prices of CO_2 allowances are currently too low to simulate any technological change, the ETS provides significant investment uncertainty regarding future costs. Furthermore, policy makers have sought to shield energy intensive industries from the full impacts of the ETS as the prospects for an effective global climate agreement in the near-term have diminished. Thus, there is strong resistance among industries that are internationally competitive to CO_2 pricing in Europe without additional compensatory measures such as the provision of free allowances. Without free allowances it is considered that EU competiveness would be significantly affected. Of the sectors under discussion, trade intensity in iron and steel is the highest, according to the European Commission, followed by fertilisers, refined petroleum products and cement.

The Working Group on Other Industries is looking at the possible compensatory measures that might stimulate CCS in these sectors.

- Level costs downwards through free allocation of allowances in line with benchmarks (but would such an incremental measure stimulate CCS?), through investment subsidies or by changing the cost structure of production (e.g. reducing the tax burden on low carbon inputs)
- Adjust costs upwards through border carbon adjustments (which has been proposed at EU level by Member States such as France and Italy) or sectoral agreements.

Among the challenges to be considered will be the resources for the remaining technical scale-up needs for the technologies (which will be vital to reducing uncertainties) and the ability to influence investment decisions in the coming years that will affect emissions intensities for decades to come. In addition, the inability for small industrial producers to become involved in the transport and storage aspects of CCS should not be underestimated.

3.3 Supporting non-power CCS in Shaanxi, China

Dr. Lin Gao of the Chinese Academy of Science (CAS)' Institute of Engineering Thermophysics, presented a study completed in 2012 that looked at supporting early CCUS development in non-power industrial sectors in Shaanxi Province, China. The work was undertaken by CAS, Azure International, the University of Leeds and the Energy Research Centre of the Netherlands (ECN) and funded by the British Embassy Beijing.

A guiding motivation for the work was the consideration that while CCS will be necessary in China, it currently comes with an additional coal demand that makes it unacceptable for application in the power sector. Consequently, other major emitters were surveyed in Shaanxi province to assess their suitability for the low cost capture of CO_2 for use in Enhanced Oil Recovery (EOR). EOR is considered as a way to lower the costs of early CCS projects through provision of a revenue stream associated with the increased production of oil. The intention was to gain a greater understanding of which might be the most suitable CCS demonstration projects to promote in China.

The CO_2 sources that were considered to be appropriate were those that require little separation from flue gases or impurities. Ammonia and methanol plants were found to be the most suitable. Alongside the survey of low-cost CO_2 capture opportunities, a survey of EOR opportunities was undertaken. An additional consideration was the ownership structure that might facilitate a demonstration project. For example, the reluctance of a major oil company to partner with another player in the value chain could be a possible hindrance. Therefore, companies that are integrated in local hydrocarbons and methanol production could be ideal candidates. One consideration is that for a demonstration project it could be most straightforward to work with companies that fall under the responsibility of the province, which is supportive of CCS and EOR and is under pressure to reduce emissions.

The final conclusion was that Shaanxi offers a number of good opportunities and that EOR would be the most cost-effective way to initiate a demonstration project. From the four case studies analysed the most attractive option against a range of scoring criteria was considered to be CO_2 capture from the Yanchang oil field methanol plant combined with EOR at the Yanchang oil field 160 km away. Cost of the project could be between 22.5 and 27.5 per tCO_2, leading to net revenue of USD 5.5 to 55.5 per tCO_2 after additional sales related to oil produced using EOR.

Development work to assess the feasibility of such a project is now being considered with funding from the Ministry of Science and Technology, the National Development and Reform Commission and the Global CCS Institute.

3.4 CCUS AG Working Group analysis to date

A background paper on the technologies and sectoral dynamics in CCUS Action Group countries was prepared by the IEA in advance of the workshop and can be read online[7]. Dr. Simon Bennett presented the main findings, which confirmed the conclusions of the other existing recent work in the area.

Some sectors have mature technologies for CO_2 capture - refining (hydrogen production), chemicals (ammonia, methanol production), gas processing, biofuels (ethanol) – while other sectors have not yet passed the pilot stage - cement, iron and steel, chemicals (crackers). Because of the differences in technological readiness, the costs and options are not well understood for each of the sectors. However, commercial interest in industrial capture sources for EOR purposes provides a reliable indicator of the hierarchy of capture costs. Importantly, some industrial applications are the cheapest options for demonstrating the integrated CCS value chain today.

The hierarchy of capture costs needs to be understood as a continuum of sources with varying CO_2 concentrations, partial pressures and stream pressures. These variables, coupled with the size of the individual sources, are the key influences on cost. If the range of flue gases and off-gases from industrial processes is considered as a continuum then we can see that there are opportunities for collaboration between sectors in the development of capture technologies. Flue gas scrubbing with chemical solvents can, for example, be applied to a range of processes,

[7] www.iea.org/newsroomandevents/workshops/workshop/name,34219,en.html

but needs to be tailored. Optimising costs may mean redesigning plants, which can have a high perceived risk and this will need to be thoroughly understood by policymakers.

The technical aspects of CO_2 capture provide a good indication of cost and opportunity for the sectors, but it is also vitally important to understand the industrial dynamics. Some sectors in some countries are expanding and consolidating, whilst other regions see contraction or stability, which implies that retrofit solutions will be most appropriate. Downstream uses of CO_2 can be important when understanding mitigation opportunities in, for example, ammonia production. Most ammonia plants in Asia, the Middle East and the United States are integrated with urea fertiliser production that consumes a proportion of the produced CO_2 as high as 90%, depending on feedstock. The amount of CO_2 vented may not be attractive for EOR or CO_2 storage.

Many CCUS Action Group countries have no CCS activities ongoing in the key sectors, although some significant demonstration projects are under development, notably in the United States, Canada, and China, but also developments in Japan, Korea and France. Among these activities are some good examples of collaboration between firms in the same sector, such as the European Cement Research Academy (ECRA), the European Ultra-Low CO_2 Steelmaking project and the Japanese COURSE50 exercise in the steel sector.

In terms of policy measures that set a long-term pathway for CCS deployment, these are mostly absent in CCUS Action Group countries. Most industries are protected from the full impacts of carbon pricing where it exists for both competitiveness and carbon leakage reasons. In recognition of the fact that different CCUS Action Group countries will have different priority sectors, depending on trade exposure, fuel sources and national importance countries will need to develop nuanced CCS and climate policies in this area. In the near-term, collaboration between countries may have high value if countries do not have the capacity or intention to each develop CO_2 capture technologies across a range of sectors.

3.5 Discussion and conclusions

In the discussion that followed these presentations it was recognised that the paucity of studies and real-world examples of CO_2 capture in some sectors means that even existing data on costs is often non-comparable. Costs vary considerably with varying assumptions on fuel prices, availability of excess heat and extent of onsite CO_2 captured. This lack of standardisation of cost calculation methodologies is one explanation for the wide ranges of CO_2 avoidance costs seen in the literature.

It was proposed that CCS terminology applied to the power generation sector (post-combustion, pre-combustion, oxyfuel) are not appropriate for industrial applications, where the technology choices are no so clear-cut and where process emissions can account for a large percentage of overall emissions. Industrial applications introduce greater variety into the spectrum of CO_2 capture techniques and the descriptions of CCS need to account for this. The IEA was encouraged to avoid talking about CCS in industrial applications as one collective mitigation measure, but to consider CCS as applying to a range of sectors, including power generation, that each have specific challenges and some common features.

There is a distinction between competitiveness and carbon leakage that means that the protection of industrial production in a region can be pursued by governments for different reasons. The replacement of industrial production in a region that regulates greenhouse gas emissions by industrial production in a region where regulation is less strong, does not always lead to an overall increase in emissions. The closure of an ageing plant in a mature economy and the construction of a new, more efficient plant in a developing country can lower overall emissions. However, in this situation a country may choose to maintain production in the mature economy for reasons of national competitiveness, employment and security. Furthermore, it should be recalled that in regions operating under a fixed CO_2 emissions cap, such as the EU, any closure of production capacity in the region will not reduce emission. Emissions will be allowed to grow in other sectors to meet the cap, whilst relocated production outside the region will create additional overall emissions at a global level.

The main messages to come from the session were summarised by the Chair as:

- Costs for CO_2 capture in the iron and steel, cement sectors, as well as flue gas scrubbing from boilers and crackers at refining and chemical sites, remain uncertain, but will be improved by further studies and, as soon as possible, engineering design work.
- Different sectors in different countries have different degrees of trade exposure.
- The low-cost opportunities for CCS today lie in industrial applications, such as the example of methanol production in China, and not in the power sector. However, policy priorities may lead to power sector projects leading the way in some countries.
- There are clear advantages to minimising the number of contracting parties in the CCS value chain, for example by identifying firms that have expertise in the processing and extraction of hydrocarbons.
- Experiences in both the policy and technology aspects of CCS in industrial applications are varied today, both between sectors and between regions. Given that the firms in these sectors often have multinational operations, and given that public and private resources for technology development may be limited, there are strong arguments for making sure that experiences are shared so that policy can be as well-informed as possible.

4. Challenges associated with the development of the necessary technologies and policies

Mr Luke Warren of CCSA chaired the second session of the workshop, which was conducted as an open discussion of the challenges for policy in this area. The main topics and the related positions have been summarised below as a list and not as a chronological report of interventions.

4.1 What do policymakers want to know?

- A governmental participant expressed their opinion that they need to know whether CCS in the sectors are comparable and how to tailor policies accordingly.
- A governmental participant expressed their opinion that it would be very useful to know the extent of the opportunity for CO_2 utilisation as this would enable policymakers to either focus on this, or move on to a focus on geological storage. There was a request that the CEM process be honest about the extent of this opportunity.
- The Korean Government is funding the development of CCS pilot and demonstration projects. USD 1.7 billion of public and private money has been identified for demonstration projects that will inform the government about the role CCS could play in meeting emission targets. A further USD 300 million is available for smaller scale projects. Most of the work so far – and the expected demonstration projects – are in the power sector, but USD 27 million is being spent in the steel sector on pilot projects to capture CO_2 using liquid ammonia. Microalgae capture systems are also being tested for CO_2 capture from heating systems. Among its members, the Korean CCS Association has two steel producers. The motivation of the government is to meet internal emissions targets and also to take advantage of technology export opportunities.
- A governmental participant asked if there was good knowledge of what pilot and demonstration projects might cost in these sectors. In answering, participants said that for projects in sectors where technologies are available and mature the costs could be found but there would be variation regionally if CO_2 storage were incorporated, depending on regulations and geology. For sectors where further technology development is required, there are some existing estimates that need to be further refined but these are not published. No ballpark figures were given.

4.2 What do policymakers need to know?

- In most industrial applications, especially in iron and steel and cement, we are not yet at the stage of implementing CCS to cut emissions. This can begin once the technology is demonstrated and is succeeded by enabling climate policies. In these sectors the near-term imperative is to ensure that the appropriate pilot and demonstration projects are funded.
- It was agreed that CCS in industrial applications offers some of the 'lowest hanging fruit' in terms of cost and technical requirements for avoiding CO_2 emissions. But, all investments in these sectors will have to be commercially feasible, in the early stages due to government support and in later stages due to a supportive policy environment that corrects climate-related market failures.
- According to the financial community, there are currently no incentives present in the steel or cement sectors that would support any investment in CCS. It is unusual to have a

new technology that could increase costs, and to such a high degree, in these sectors. Unlike in the power sector, these sectors cannot pass additional costs to customers without losing competitive advantage and, probably, market share.

- At the current rate level of progress and impact, leaving the development of CCS in industrial applications to the UNFCCC[8] process will deliver neither the technical development nor, consequently, the commercial deployment of CCS to the necessary timetable or scale. Nevertheless, without a global agreement on mitigating climate change, the role of CCS in industrial applications could remain limited and this adds uncertainty.
- Industrial and academic participants indicated that CO_2 pricing is not an appropriate instrument for stimulating innovation in longer-term technologies such as CCS. Some level of public support will be needed to help develop technologies that are not mature today until they are available as investment propositions.
- Efficient cement production today generates 750 kgCO_2 per tonne of cement. This can be reduced to 600 kgCO_2 using efficiency improvements, biomass and clinker substation. Achieving further reductions would require CCS, but the impact of CCS could be a doubling of the cement production cost.

4.3 Competitiveness

- A steel sector representative expressed the opinion that pricing CO_2 will not create momentum for CCS for several decades due to the unwillingness of governments to negatively impact the competitiveness of their industries. Therefore, spending of government revenues on early projects will have the largest near-term impact.
- A metric that could be introduced to the discussion, alongside the trade exposure of the sectors, is the CO_2 intensity of the value of industrial production (i.e. tonnes of CO_2 emitted per dollar of revenue from product sales). This would help to indicate which sectors would be hit hardest by the application of CCS. However, it does not take into account the variation in CO_2 capture costs in different sectors. An alternative measure could be the cost of CO_2 capture per dollar of revenue from product sales.
- In Europe, the European Commission has proposed that the proportion of European GDP that should be targeted for the process industries be set at 20% (it is 16% today). This provides a strong rationale for the role of CCS in delivering this inline with the EU objective of reducing CO_2 emissions in the economy by 80% by 2050.
- A cement sector representative commented that the UK should be commended for its ambitious CO_2 budgets, but that without additional supportive policy, the easiest way to meet the budget will be for industry to leave the UK.

4.4 Current industrial situation and trends

- The European steel sector is under intense financial pressure at the moment and is only capable of taking very short-term decisions about investment or maintaining operational plants. In addition, there is often too little understanding of the complexities of the steel supply chain, which is highly sophisticated and integrated (compared to, for example, aluminium) and any impacts on upstream production have job and competitiveness implications further downstream in sectors such as automobile production.

[8] United Nations Framework Convention on Climate Change

- Cement production is growing globally and is expected to be higher in 2050 than it is today, due to a lack of substitutes for cement, a low recycling potential and a rapid development of infrastructure in the developing world.
- Today, cement is rarely imported from overseas, but this could foreseeably make commercial sense if the alternative was to take on cost increases at the level of CCS costs.
- The European steel industry is currently elaborating a roadmap in line with a long-term emissions reduction pathway. In the context of the European Commission's forthcoming consultation on 2030 emission reduction targets, the steel sector recognises a need to begin deploying CCS relatively quickly. However, in the absence of a viable investment proposition due to the lack of commercially adapted capture technology or CO_2 storage infrastructure, and given the apparent costs of CCS, this does not appear to be a near-term pathway that the industry can support.
- Ammonia demand is growing worldwide, and with it the supply of ammonia based on coal as a feedstock. This is the most CO_2-intensive ammonia production route and is mostly based in China. 25% of global production is based on coal, and is responsible for 42% of CO_2. In regions that rely on urea fertilisers (mostly Asia, but urea is produced in the Middle East and United States for this market), much of the generated CO_2 is converted to urea. In regions that rely on ammonium nitrate fertiliser, the urea is vented. In ammonia production there is a significant risk of carbon leakage if the marginal production capacity outside a carbon-regulated region (e.g. Europe) is based on coal.

4.5 The additional benefits of CCS in industrial applications?

- The participants from environmental organisations stressed that the promotion of CCS as the only technology that can retain industrial capacity and jobs while reducing CO_2 emissions could be a vital approach for gaining public approval for CCS more generally. In European countries, such as Germany, there has been some success in explaining that if we are to combat climate change, CCS will be necessary to enabling industrial production to compete and its development will provide a competitive advantage. The cement industry, for example, was urged to promote potential projects as being important and positive for European industry.
- Having CCS available and demonstrated for industrial applications could actually assist the process of reaching a global climate agreement by showing how it is possible to reach deep CO_2 emissions reductions at a cost that is affordable if the technology is supported via international – rather than regional – mechanisms.
- In fact, while sectoral discussions have not made much progress in the UNFCCC mechanisms, CCS has the potential to bring together a relatively small number of countries who might agree to collaborate on projects that will help to make the technologies available in the next decade.
- In steel production, the top gas recycling approach to CCS could confer efficiency benefits on the process, but will raise capital costs.

4.6 What needs to be done to fill the technology gaps?

- Demonstration projects are needed, but not in all sectors or processes. The CO_2 capture processes that have lower costs than the power sector are largely demonstrated. Others, such as processes in iron and steel, cement, process heaters, fluid catalytic crackers, steam crackers and pulp and paper, need a stepwise approach to reaching demonstration stage this decade.

- The cement sector does not foresee more than one demonstration CCS project by 2020, and such a project may only be realistic in China. ECRA is targeting a European pilot project by 2018 but it is unclear who could pay for this and cement manufacturers and equipment manufacturers are reluctant to pool much of their own money. ECRA has identified oxyfuel as the most promising route to CCS in the cement sector and this is the technology it wishes to pursue to pilot and demonstration scale.
- Several studies that have looked at applying CCS to steel production have found it possible to reduce CO_2 emissions by just over 50%, but more work needs to be done to increase this figure.
- CCS in the refining sector is considered technically feasible and a representative from the refining sector stated that CCS is a must for a low carbon future for the sector, and that demonstration needs to be achieved as soon as possible.
- One common perspective was that by seeing the demonstration of a range of CO_2 capture technologies and storage options as a global portfolio approach, it could be possible to limit the total cost of technology demonstration and deliver value for money through collaboration. Collaboration between governments and between companies would be required for the optimal outcome for industrial and power applications.

4.7 - What can we learn from programmes to support CCS demonstration to date?

- There was broad consensus that where EOR opportunities are present, the additional revenue stream could enable demonstration projects to proceed more quickly. The United States and Albertan governments were commended for financing all of the additional costs of CCS demonstration projects.
- There was some discussion of the NER300 scheme in the EU, which has promised to enable the first demonstration project of CCS in industrial applications in Europe. Some participants expressed the opinion that the split of funding that allowed the European Commission to cover 50% of additional costs while the remaining 50% could be shared between the Member State, and the project promoters as appropriate, was too flexible in giving the opportunity for industry to contribute funds. The ULCOS project had support from the French government but was ultimately withdrawn, partly because the government and the project promoter (primarily ArcelorMittal) were unprepared to take on the full risk associated with the European Commission rules, but also largely due to the difficulty that the company had in committing to keeping open a steel mill for a decade-long demonstration project within the current financial environment.
- A participant from the refining sector reminded the workshop that the Barendrecht project in the Netherlands was in the refining sector and its failure to gain public support has had negative repercussions on the ability of projects in other sectors to move forward onshore in the Netherlands. One lesson from this experience was considered to be the importance of a press that is well-educated in the scale and needs of the climate challenge.

4.8 The importance of CO_2 transport and storage

- Several speakers pointed to the facilitative impact of EOR in the United States, where the demand for CO_2 has driven the development of low-cost CO_2 capture projects and has led to the construction of an extensive pipeline network for CO_2. Other regions are highly envious of this situation, and EOR has the potential to provide a revenue stream for projects in other countries, including Canada and China, and potentially also the British and Norwegian North Sea. However, most regions do not have a highly promising EOR opportunity and offshore operations can significantly raise costs and commercial risks.
- A cement sector representative was very clear about the need for public acceptance before committing to deployment of CCS. At present, in some European countries, the sector has concerns that an existing plant could receive unwelcome negative attention if it publicly discloses intent to consider CO_2 storage locally. Thus, the companies would not promote CCS for fear that the profitability of existing plants could be affected.
- There was general agreement that industrial producers in sectors such as steel and cement will not become integrated into CO_2 transport and storage. The consequence is that they may be unlikely to adopt CCS until it is evident that a third party transport and storage operator will be available to take the CO_2 and store it under favourable contractual conditions. A business model for commercial providers to enter the CO_2 transport and storage business is therefore urgently needed. This is of particular importance because until CCS is a value proposition throughout the value chain, there will not be an incentive to develop storage capacity (or CO_2 capture technologies). Consequently, either a business model is required or public funding for capacity development.
- A representative from the chemical sector expressed his opinion that the scale of CO_2 emissions from individual ammonia plants based on natural gas feedstock is insufficient for producers to also become involved in any other parts of the CCS value chain. Ammonia producers already separate and vent the CO_2, and would welcome the opportunity to pass the CO_2 on to a provider of CO_2 transport and storage services.

4.9 Policy measures that could be available

- Global measures should be a major focus of efforts, either through the UNFCCC mechanism or otherwise. These have the potential to unite the efforts of multinational companies that are active in several regions and level up the competitive playing field. This could be through CO_2 pricing or another measure, but to incentivise CCS it is likely that it will need to set a long-term vision and provide support to first-movers rather than simply improve emissions incrementally.
- The possibility of emissions performance standards for units of industrial production was raised. It would be a first step towards being able to consider such a measure would be better reporting of current emissions levels globally.
- Because we are a long way from a CO_2 price that could drive CCS, Can either reward investment, or penalise dirty production.
- The Shell Quest project is moving ahead because it has an NPV of 0, due to government support. No European government has yet confirmed such a level of support, and certainly not for CCS in an industrial application. There was much sympathy from the industrial and financial sectors at the workshop for the inference that in the current climate, in trade-exposed sectors, public funding will have to cover the full costs of CO_2

demonstration. This was also evidenced by experience in Korea where the major steel companies have made investments up to pilot scale but are waiting to see how global climate negotiations evolve and are requesting that the government cover demonstration costs in the meantime.

- An additional aspect to the discussion of whether demonstration projects should be fully public funded was a feeling around the table that industry could contribute to the costs of CCS in the near term, up to the extent that they would have otherwise have had to pay in CO_2 allowances or taxes.

- It was mentioned that ideally policy should focus on rewarding the production of clean products, rather than subsidising particular technologies per se, or penalising CO_2 alone. In doing so, a careful balance between market mechanisms must be achieved. One consequence of an emissions performance standard in a region with an emissions trading scheme (overall CO_2 emissions cap) is that it can lower CO_2 prices, thus reducing one of the stimuli for CCS.
- Border tax adjustments – or border carbon adjustments – could be recast as a measure that removes an existing subsidy for dirty production rather than being seen as a green protectionist measure. The consequence of these types of measures could be that exporting countries choose to apply a similar tax before the product leaves their shores. If the measures were aligned, the rents from the tax would stay with the exporting countries and the product would not be doubly taxed by the exporting and importing jurisdiction. Ideally, the effect would be to gradually draw more countries into a global regime and not to trigger protectionist measures.
- It was noted that whilst border carbon adjustments can appear attractive for correcting a market failure that does not internalise CO_2 costs, the outcome is not necessarily going to be the preservation of industrial production in the regulated region. Cleaner production outside the region, or production that benefits from lower labour, capital or material costs, would be more competitive. Regions may either find this to be an unattractive result, or may apply additional measures to protect jobs thus moving away from the environmentally optimal outcome.
- The issue of compatibility of come measures with World Trade Organisation (WTO) rules was raised by several people who suggested that all potential policies should be reviewed in this context. In relation to the specific case of border carbon adjustments, WTO issues can often be regarded at toxic by governments and, crucially, may need the political support of countries such as China in order to be accepted and successful.
- There was some discussion of whether high levels of support for demonstration projects, and early deployment, would be against state aid. It was clarified that there is precedent at the European Commission for allowing state aid to projects that are non-commercial and where the aid only covers the additional (non-commercial) costs of CCS for environmental reasons and does not confer a competitive advantage. The Mongstad project in Norway, for instance, received state aid clearance.
- The support for renewable energy in Europe is instructive for CCS in industrial applications. The policies have been implemented at national level, not EU level, and have been outside the ETS system, but have passed costs on to consumers without providing ways in which energy-intense sectors can absorb these extra costs. Close attention needs to be given to policy design and how costs can be passed on.

5. Recommendations and messages for policy-makers

The draft recommendations proposed to the workshop were presented for discussion (Box 1). Participants were asked to consider the following:

- Have the key challenges & messages been identified?
- Is the focus and level of detail of the recommendations appropriate?
- Do you have suggestions for any other improvements?

Comments were received that gave general guidance for the revision of the recommendations. Firstly, they need to be recommendations for *energy* ministers, who are often not responsible for climate policy or decision-making in CEM countries. One thought that was raised by an academic expert was that the ability to cluster CCS projects in industrial applications around first-mover power sector projects, and thus reduce overall mitigation costs, could be attractive to energy ministers.

It was mentioned that the paper and its recommendations currently create a tension between stressing the need for collaboration between nations and stating that economies that make provisions for CCS will have a competitive advantage in a climate-constrained world.

The recommendations were considered by some to be too focused on the ideal market-based policy environment that climate action advocates would like to see in place. There was a suggestion that the recommendations relating to funding of technology demonstrations be highlighted as the main near term action for governments, to be undertaken before CCS in these sectors can 'pass Go' and begin to have an impact in reducing emissions. There was a concern that market mechanisms will not be implemented with the strength to be motivate any significant action in the near term.

In general the feedback was that the draft policy paper and the recommendations had been thoroughly and correctly formulated. However, the draft text was widely considered to lack the necessary punchiness.

A representative from the cement sector suggested that Recommendation 4 should be more explicit in recommending that governments formulate industrial strategies that aim to retain manufacturing within their borders.

It was suggested that Recommendation 2 be more precise. One suggestion was to highlight the role of global knowledge sharing between the power sector and the various industry sectors as they develop CCS technologies.

In summing up, Mr Lipponen in the Chair requested any additional written comments to be sent to the IEA by Wednesday 6 February 2013, and for participants to pay special attention to Table 1 in the draft policy paper, which contained potential incentive policy measures on which the authors would appreciate feedback.

Box 1 • The seven draft recommendations as presented to the workshop for discussion

1. **Support regional and international consortiums to demonstrate CO_2 capture across industry sectors**. Consortiums of relevant firms should be encouraged to jointly lead promising technologies through sequential phases from pilot to demonstration, in such a way that competiveness concerns are minimised; for example, by pooling any intellectual property and focusing on areas that do not currently impact competitive advantage.
2. **Target cross-sectoral research and development towards generic technologies** that can be adjusted or combined to tackle the specific circumstances in a given sector or site. Open-access pilot facilities for testing the various CO_2 capture technologies on different flue gases, thus advancing CCS for power generation and industrial applications together. To achieve a rapid roll-out of CCS will require the availability of off-the-shelf solutions wherever possible.
3. **Funds that are consistent with a stepwise technology pathway are needed**. Differentiation between sectors will be necessary to target private investment, national funds and international finance (e.g. UNFCCC mechanisms) to where they will be most effective. Gas processing and hydrogen production are ready for large-scale integrated demonstration, whereas steel, cement and some chemical and refining processes require pilot-scale projects before moving to demonstration by 2020. Public funds (or CO_2 certificate revenues, production levies etc.) are most needed for projects larger than pilot scale where they can leverage investment from consortium partners. Furthermore, sectors with different CCS costs should not compete against one another for public funds on the basis of a uniform metric but should be targeted according to their maturity and CO_2 avoidance needs.
4. **Expand national policy plans to address CO_2 emissions from industrial applications** and introduce CCS as a necessary solution. Depending on which sectors are of national relevance, the policy measures will vary between R&D support and technology-neutral fiscal measures. Attention should be given to policy architectures that will effectively reduce emissions whilst being sensitive to technology investment challenges and competitiveness concerns. It will be important to be aware of the ways in which technologies and sectoral dynamics could change in the next twenty years.
5. **Address competiveness concerns with national climate policy instruments** and give investors security to plan for a low-carbon future in the absence of a global CO_2 price. Instruments for further study include sectoral quantity measures and output- or lifecycle-based emissions standards, at a sectoral level or linked to national/regional financial support, as well as border adjustment measures.
6. **Involve all relevant stakeholders in actions that are being undertaken to progress CCS**, and include relevant industrial sectors on an equal footing. This will raise the level of knowledge among all firms that will need to use CCS and will recognise that the local endorsement of CCS will be crucial to the future of the sectors regionally. It will include national and regional actions related to: public engagement, knowledge sharing, CO_2 storage capacity mapping, exploration and operation and R&D across the CCS value chain.
7. **Plan the stepwise deployment of CCS in major industrial clusters**. This includes investigating accessible CO_2 storage sites and options that would make the local sectors more 'CCS ready', potentially lowering future costs of CCS deployment and enabling sectors that have commercial CO_2 capture technologies to start deploying CCS as soon as the policy drivers are in place. In addition, the establishment of commercial CO_2 transport and storage operators will require a solid business case and infrastructure development plans; it is unlikely that many heavy-emitting firms will evolve to become integrated into CO_2 storage themselves and will wish to have any remaining liability concerns resolved before undertaking CCS.

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