*A paper prepared by the IEA as background information for the CCUS Action Group work on CCS in Industrial Applications as a contribution to the 4th Clean Energy Ministerial 2013. It is not a publication of the IEA and as such its conclusions do not constitute a position of the IEA.*

# Interviews and questionnaires

The following sections summarise the responses given by respondents from sectors that were studied in preparing the paper '***Global Actions to advance Carbon Capture and Storage in Industrial Applications:*** *International Energy Agency report to the fourth Clean Energy Ministerial on behalf of the Carbon Capture Utilisation and Storage (CCUS) Action Group*'. The responses have been used, in combination with the views expressed at the stakeholder workshop on 30 January 2013, to provide an overview of the perceptions of informed industrial actors in the sectors considered.

A representative selection of organisations from a number of key sectors that are anticipated to require the use of CCS in the coming few decades were contacted for responses. Firms based in CCUS Action Group countries were of particular interest. Responses were collected via a mixture of face-to-face interviews, telephone interviews and written submissions. The Annex lists the questions that were used as the basis for the interviews and written responses. The contributions reported in the sections below are intended to provide a faithful and unedited account of the perceptions of key industrial stakeholders.

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## 1. Aluminium sector

### 1.1. Technical readiness

The sector is relying on other parties to advance CCS and make it commercially available. Capture from dedicated power plants at aluminium smelters will be ready as soon as it is developed for the power industry. Capture of process emissions from the reduction process in the smelter is commercially practiced to separate CO2 for waste treatment today. The concentrated CO2 stream is easy to capture.

### 1.2. Technology needs

### 1.3. Financial and economic issues

The industry has a very short-term time horizon for investments.

### 1.4. Policy needs

The industry is currently in survival mode in many regions, and so any policy that incentivised CCS would need to do so by funding 100%, and that may not keep plants alive if they cannot compete with competition from, e.g., China.

Policy needs to make low emission power generation competitive.

To motivate CCS via a carbon price, the price will need to cover a critical mass of competitor countries.

### 1.5. Regional variations and trends

China saw 80% of smelting growth between 2000 and 2010.

Old, smaller smelters are closing, and newer smelters are larger.

## 2. Cement sector

### 2.1. Technical readiness

Lab scale tests look promising for oxy-firing, but pilot scale tests are needed. Going straight to demonstration scale today would encounter too many hurdles.

To convert cement production to oxy-firing would be the most fundamental redesign in the sector for almost a century. The changes to dry kilns, pre-calciners and alternative fuels in the 1960s were less fundamental.

Flue gas scrubbing techniques for CO2 capture are available today, but look more expensive than oxy-firing and need optimising. If the industry had to apply CCS today, and a pipeline was available to take away the CO2, capture could be applied now by retrofitting. It would make the cement very uncompetitive.

### 2.2. Technology needs

There are technology needs for storage of CO2 but the cement has only focused on capture to date. Someone else will need to develop and provide the solutions for storage, or, even better, utilisation. Because cement sites produce less CO2 than other industrial sites, it would not appear to make sense to build a dedicated pipeline and storage solution for a cement site. A grid of pipelines will need to be constructed and brought to the boundary fence.

Oxy-firing technologies have been identified as the most promising method of CO2 capture. But, how do you seal the kiln? How do you understand the clinker chemistry, the flame design and the refractories?

A demonstration plant is needed sometime after 2020. By 2030 there should be several large-scale CCS projects on cement.

### 2.3. Financial and economic issues

### 2.4. Policy needs

Public subsidies will be needed to finance the pilot tests as the industry's willingness to pay is insufficient.

Funds for R&D are necessary.

A support mechanism to accelerate CCS is needed, along with public acceptance of CO2 storage and pipelines. It is public authorities who should find a solution for CO2 storage and make it available to industries such as cement.

Equal treatment with the rest of the world and a global CO2 regime are needed. Border tax adjustments are a correct approach but face the same problems as the inclusion of aviation in the EU ETS.

Not every plant can fit CCS due to geographic availability of storage, so CCS cannot be mandated.

### 2.5. Regional variations and trends

China is building the total cement production capacity of Germany every year. New plants can be constructed each year on the basis of widely available technical know-how.

There are only 3-4 major suppliers of equipment in the world.

The average kiln size is growing, but not by much. By 2030 it may be 15kt/day.

Europe is not as accepting of pipelines as the United States.

There is less strategic interest in keeping cement production in Europe, compared to steel or refining. Importing cement is likely to be the future.

There are unlikely to be new cement plants in Europe in the next twenty years. Any new production would be likely to be placed at existing sites.

## 3. Chemical sector

### 3.1. Technical readiness

The petrochemical sector uses efficient carbon capture technologies in the normal course of business. For large scale capture at chemical sites, the technology for CO2 capture is developed, tested in pilot scale and needs now demonstration scale references. Upscaling has risks in costs, reliability and operation.

The solutions for power sector to capture CO2 can be adjusted for the hydrogen production facilities.

For coal-to-chemicals, CCS is at the starting stage but this relates mostly to the utilization and storage aspects. The CO2 that is produced from coal gasification and conversion has high concentration, pressure and low enrichment cost, which makes it good for CCS. Some coal-to-chemicals CO2 capture technologies would have crossover applications in the iron and steel industry. In the application of CCS, emission levels of other contaminants would be reduced.

### 3.2. Technology needs

Other gas separation technologies like membranes need efforts for implementation from laboratory to industry.

There are deficits in knowledge in transporting and operating large CO2 pipelines and in storage technologies for onshore and offshore. The long term behaviour of CO2 in the storage area is not sufficient known. Cost reductions for CO2 compression and storage should be targeted. It takes a long time to prove a storage site so more long-term, storage only projects need to come online to demonstrate the technology is safe and effective over at least five years.

Utilisation and storage of CO2 present the biggest technical challenges to CCS in the coal-to-chemicals area. Research and demonstration are necessary. Development of additional value added uses for the CO2, such as algae to biofuels, could reduce over costs or add positively to the cash flow to the business.

CO2 capture from hydrogen production is well known and of moderate cost (compared to the power sector) and is normally an initial part of the design.

### 3.3. Financial and economic issues

CCS could increase the cost of production by 5-50%, depending on the application, but there is a strong exposure to markets that are serving global customers. Extra costs for CCS will result in product price increases and customers have serious difficulties to remain competitive in their markets.

The political uncertainty associated with CO2 storage technology is an investment risk. The investment can be rendered worthless by a change in political stance.

### 3.4. Policy needs

Find a value for CO2 to support any investment decision to create a robust business case for demonstration projects. Investors need long term security that framework conditions are solid and trustable and that the technology is sufficiently demonstrated.

Governments should accept the liability risk for long term storage.

Global agreement for reducing CO2 emissions with clear program how to price CO2 emissions long term and robust.

Gain public acceptance for CO2 transport and storage.

Financial and policy support to promote technology research, development and demonstration of CCS in coal-to-chemicals.#

Government support will be needed for scaling up the full chain of CCS technologies.

There is a lack of coordination between different parts of the CCS chain.

Because CO2 capture and storage is just an added cost on production, governments need to invest, with industry, in value-adding CO2 sequestration technology that can generate profits.

Policies that support EOR near the Gulf Coast today make CO2 capture from methanol an interesting prospect as demand for methanol is high and the cost of capture is low.

### 3.5. Regional variations and trends

Sizes of plants will increase in the coming decades.

The total CO2 emissions of coal-to-chemicals plants in China will be increased as the scale of each plant expands. Investments will be in new-build plants.

New fertiliser plants will be larger but there will not be many in regions such as Australia.

## 4. Gas processing

### 4.1. Technical readiness

For natural gas processing, CO2 capture process is a very mature technology and is routinely installed to meet CO2 specification of the products (pipeline gas/LNG). The sector is technically ready, at commercial-scale. CO2 separation is included as part of the gas processing design.

Storage sites, could be more easily identified that by other sectors because the subsurface information is well investigated prior to/during oil and gas production.

There are four commercial CCS installations in this sector.

Technical barriers for CCS are lower than other sectors.

### 4.2. Technology needs

Agreeing and meeting CO2 specifications – i.e. meeting specific requirements for pipelines, injection, use

Improving knowledge of CO2 geosequestratio (storage volume, permeability and porosity)

### 4.3. Financial and economic issues

Cost barriers for CCS are lower than other sectors. A cost increase of around 1% compared to a facility without CCS. The economics of what is traditionally the highest cost component of the CCS chain (CO2 capture) is inbuilt.

Key investment risks stem from policy uncertainty with respect to incentives or penalties to catalyse investment in the full CCS chain. Many of these projects are experiencing significant development cost blow outs that challenge the economics of the project’s core business and places more pressure on “add ons” such as CCS without support.

The costs in the compression of CO2 for injection and the well infrastructure are additional to normal gas sweetening practices and just add cost to the operation.

### 4.4. Policy needs

There are no co-benefits to CCS in this sector, but penalties for CO2 emissions or incentives for CO2 reductions would be a motivation to apply CCS in this sector. Sufficiently high price signal on CO2 as a market mechanism is needed to drive investment in the capture, transport and storage/use of CO2 from the natural gas processing sector. A CO2 trading market at present and in the foreseeable future will not assign a sufficiently high enough price on CO2 to catalyse investment. Direct subsidies or a tax could also be applied. Once there is a commercial market then normal industry forces will lead to technological improvements.

Establish regulations and the methodology for CCS-CDM scheme.

Requirements for CCS on all new gas processing projects, or emissions caps on the sector that force reductions

Broadly agreed criteria/CO2 specifications for transport and storage of CO2.

The cost of transporting and storing CO2 should be subsidized. These components are relatively low cost compared to capture costs.

### 4.5. Regional variations and trends

There are no typical plants sizes but 1 million tons of CO2 emission per plant is a representative size.

The sector is expected to expand and this will include gas that has high CO2 content. According to the industrial journal of oil& gas engineering, there are over 20 projects at FS/FEED/EPC bidding stage for gas processing.

Oil and gas is a conservative industry. Unless there are strong commercial incentives then current practices will remain unchanged.

## 5. Iron and steel sector

### 5.1. Technical readiness

In general there is no specific need for further demonstrations of CO2 capture technologies per se. What is needed is a number of pilot plants to prove how the CO2 capture can be applied to the steel sector. Some pilot tests for integrating CO2 capture are ongoing.

There is no previous experience on treating large volume of CO2 in the sector.

The steel industry is more technically advanced compared to power generation and there is substantial technical capacity. The challenge is how to implement CCS as the steel mills are highly integrated.

### 5.2. Technology needs

Industry-specific technology should be developed and applied for blast furnaces, since the process CO2 and combustion CO2 have different characteristics (gas composition, pressure, impurity, water content, etc.) compared to power generation. On the other hand, flue gas scrubbing techniques as proposed for the power sector could be applied to the power generation plants at steel sites, which could be a ‘quick win’ since much of the furnace gas ends up at the power plant. But, this would require a whole-of-plant redesign.

A demonstration project at a blast furnace site needs to be times so that it coincides with blast furnace refurbishment.

CO2 capture from blast furnace gases and other by-product gases can be an effective tool to increase the heating values of blast furnace gases, since they are used for fuels in an integrated iron and steel mill. If other acid gas such as H2S can be removed using absorption, a CO2 capture option, it would be also effective for emissions control.

The big question is: how do you capture CO2 from a steel plant without undoing all the prior work on integration and efficiency improvements? Top gas recycling looks prospective but is a major technical challenge. Pilot project are needed.

Similar challenges as those for refineries present themselves when you look at the many smaller emissions around the site. Work needs to be done to identify how these can be captured in a cost-effective and practical manned.

Current development focuses mainly on capture technology but more understanding is needed of the transportation of captured CO2 from large points sources to the storage sites, as well as CO2 injection/monitoring issues at the storage site. A key challenge for moving forward in the steel industry is to demonstrate a storage site, and look at source/sink matching issues.

Possible milestones:

- Development and application of waste heat recovery and heat integration technology by 2017.
- Development of large-scale CO2 capture technology by 2020.
- Full integration and demonstration of CO2 capture and storage technology by 2020.

A more detailed picture of costs is needed due to the uncertainties relating to price forecasts for CO2, coke, natural gas and electricity.

Steel production by electrolysis is important but is still 20-30 years away.

### 5.3. Financial and economic issues

The estimated cost of CO2 capture is $100-200/t hot metal excluding the storage cost. The incremental cost is less than for power generation but the issue is how to maintain competitiveness within an international market.

The risk and impact for other dependent industrial sectors is important.

Most of the steel industry has been careful about investing. They don’t have a lot of viability for long term investments and the industry is looking for short term guaranteed returns on investment. For CCS, not knowing the long terms stability of various economies (and carbon systems) of the world makes it hard to make these long term decisions

### 5.4. Policy needs

A global market value of carbon emissions.

Policies to ensure that the international competiveness of the industry be ensured to allow the industry to compete with other international producers that are not subject to the same emissions penalties.

A CCS chain needs to be established to allow iron and steel companies to access the infrastructure.

### 5.5. Regional variations and trends

There are few spaces to store CO2 in the territory of the Republic of Korea, so it needs to set up the policy regarding storage method (geological, industrial use, etc.), infrastructure, and so on.

Not much work has been undertaken in Australia due to the relatively small size of the sector. Iron and steel emissions in Australia are small compared to power generation and there are only two steel companies that produce significant emissions. Even without costs anywhere near the level of CCS, it is unclear whether policy provisions to protect internationally exposed emissions intensive industries under the carbon price are sufficient to maintain the competitiveness of the industry In Australia. There are currently no requirements for deSOx and deNOx on power plants. So the introduction of capture may require lower SOx and NOx.

Specific emissions from blast furnaces won’t significantly change unless CCS is implemented. Industry will continue to make some smaller emissions improvements. The business model for redesigning the steel plant for CO2 capture is unclear when you consider that many companies are moving towards using higher levels of recycled steel and electric furnaces. Consequently, looking ahead, it may be better for the industry to look at opportunities to implement capture on their on-site power plants.

## 6. Refining sector

### 6.1. Technical readiness

Coal- and gas-to-liquids technology users already produce concentrated CO2 streams suitable for sequestration, but the technology for storage and the suitable geological sites are a long way off being commercially available.

Most demonstrations are however associated with power projects but using technologies developed for power plant flue gas stripping may be prohibitively expensive for some refineries depending on the number of stacks that they need to capture from.

Overall, technical readiness in the sector is low because the complexity of an oil refinery means that there are a number of different flue gas sources and boilers to which CO2 capture would need to be applied.

CCS would also reduce particulate and SO2 emissions.

The technical challenges in refineries would most likely be possible to solve if a sufficient economic driving force is in place.

### 6.2. Technology needs

For coal- and gas-to-liquids, there are no technology risks, only commercial risks. The availability of suitable storage sites and infrastructure to export CO2 are the major technical hurdles.

More efficient post-combustion technologies, especially targeting the cost effective concentration and capture of CO2 from low pressure applications.

Solutions to handle a high number of CO2 sources/stacks with minimal interaction with production units to prevent loss of availability.

Adapt the capture technology to utilise available waste heat at low temperature (100 C) for CO2 desorption.

Third generation algae technology may be appropriate for capturing and using CO2 from fuels production, but it is not comparable with CCS technology with regards to the amount of CO2 which can be removed.

Methods of incorporating additional DeSOx and DeNOx kit will be necessary for operation of flue gas scrubbing equipment at a refinery.

### 6.3. Financial and economic issues

Projects are likely to be in the order of $1billion, which would have a high impact on the costs of producing one unit of output. There is currently no economic driver or compelling incentive for businesses to implement CCS. The most important action is to establish an economic incentive that could make projects bankable.

Infrastructure will have to be in place with dedicated vessels, storage areas etc.

The impact could be some USD 0.5 per barrel of oil refined at a complex refinery. At an EU refinery, a cost of EUR 30/tCO2 would raise production costs by 13%.

The biggest issue for the sector would be the distorting effect on competition and the high cost/low incentive nature of CCS today.

Insurance companies need to better understand the risks associated with projects, especially the subsurface parts of the project.

### 6.4. Policy needs

Incentive to implement CCS would be needed.

One respondent said that a CO2 tax or emission restriction would be effective in terms of incentivising energy efficiency improvements and water consumption and air emissions as a result, but such a tax would not be able to increase to the point where CCS becomes economically viable in the near term.

One respondent said that governments do not recognise the whole CCS chain and how to minimise the risk between partners that need to come together for a single project. For example, some policy instruments only pay on a basis of tonnes stored. If there is a breakdown in part of the project (e.g. at capture or transport stage), then none of the project partners will be paid

Government will need to underwrite the CCS value chain, especially for early projects, and will need to have a coordinated view across the CO2 chain between the different operators. This includes managing the biggest risk, which is the storage sink. This is important for early projects because once this is demonstrated, industry can come in and manage those risks

Development of suitable storage sites and delivery infrastructure.

Financing mechanisms in the absence of Enhanced Oil Recovery opportunities in the region via large direct grants.

Development of legislative framework for CO2 storage.

Simple rules based on “cost of emission of CO2” are normally efficient and the market will then find the most cost-efficient way to reduce emissions.

### 6.5. Regional variations and trends

The forecast is pessimistic for the European refinery industry. A recovery is expected after 2020 due to a number of closures in combination with growing demand outside Europe. But new bunker specifications are expected to influence profitability after 2020.

South Africa does not have EOR opportunities and does not have highly suitable geological formations. A significant implementation of clean fuels in 2017 is foreseen, and will drive plant investments in the region. CCS will need to feature in the energy policy discussion in terms of energy pricing and not only environment discussion.

$CO_2$ emissions reduction in the sector will accelerate with the introduction of $CO_2$ taxes / emission controls / energy efficiency improvements due to increasing input costs.

The size of new plants will increase to take advantage of improved efficiency.

In Europe and Australia most of the government focus has been on coal-fired power generation. This is largely a reflection of different government organisations looking after energy and industrial processes with the drive for CCS coming from energy departments that often have very limited exposure of industrial processes.

## Annex – questions from the questionnaire

Below are summarised what we believe to be the key questions to be answered in studies that seek to understand the potential impact of and constructive actions towards the implementation of CCS in industrial (non-power) sectors. These questions reflect the fact that the industrial sectors under consideration are diverse (both inter- and intra-sectors) and that their characters are highly regionally specific.

Answers will therefore relate to one of the following sectors and one or more /countries.

| Sectors |
|---|
| • Manufacture of Cement<br>• Manufacture of Iron and Steel<br>• Refining of Petroleum Products<br>(including manufacture of liquid fuels from other fossil fuels)<br>• Manufacture of Chemicals and Petrochemicals<br>• Manufacture of Pulp and Paper<br>• Manufacture of Non-Ferrous Metals<br>• Processing of Natural Gas<br>• Manufacture of Biofuels<br>• Manufacture of Food Products and Beverages |

### Name

Click here to enter text.

### Organisation

Click here to enter text.

### Sector(s) of expertise

Click here to enter text.

### Country/countries/regions of expertise

Click here to enter text.

1. Sector specific questions related to technologies

**a. How would you describe the technical readiness of CCS in your sector?**

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**b. Is this sector able to apply CCS technologies developed for other sectors (e.g. power)? If not, why is this?**

Click here to enter text.

**c. Are alternative, sector-specific technologies being researched and / or developed for the sector?**

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**d. What are the key technical challenges to applying CCS in the sector today (up to five)?**

1. Click here to enter text.
2. Click here to enter text.
3. Click here to enter text.
4. Click here to enter text.
5. Click here to enter text.

**e. What are the key *technical* knowledge gaps that prevent CCS from being applied in the sector today (up to five)?**

1. Click here to enter text.
2. Click here to enter text.
3. Click here to enter text.
4. Click here to enter text.
5. Click here to enter text.

**f. What are the key actions needed over the next 10 years to advance CCS in the sector (up to five, please try to include specific timelines for each of the actions)?**

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**g. What impact is CCS likely to exert on the costs of producing one unit of output from the sector? (and, if known, what is the error in this figure?)**

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**h. Could CCS confer any non-$CO_2$-related advantages on the sector (efficiency, lower emissions of other pollutants etc.)?**

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2. Sector specific questions related to policies

**a. What are the main differences between this industrial sector and the power sector that should be taken into account when designing policies to advance CCS in this sector?**

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**b. What are the key investment risks facing CCS in this sector?**

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**c. What recommended policies and actions do you think should be applied to advance CCS in the sector?**

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**d. What are the key market failures to address in the near term for this sector in order to advance the application of CCS? (e.g. market value of carbon emissions; insufficient promotion of learning; capital and financial market risks due to imperfect information; lack of coordination between different part of the CCS chain; imperfect competition between market players)**

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3. Regional/country specific questions related to the sector

**a. What are the expected trends in the sector in the region?**

**i. $CO_2$ emissions per unit of production**

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**ii. $CO_2$ emissions per plant**

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**iii. Size of plants**

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**iv. Investment in plant expansions, new-build or refurbishments**

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### v. Profitability

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### vi. Market structure (e.g. number of companies, market share, domestic production vs imports, etc)

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### b. What policies and actions currently exist in the sector in the region that act to advance CCS?

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### c. What are the key policy relevant policy issues to be addressed in this region for the advancement of CCS in this sector?

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4. Other

### a. Any other comments

Click here to enter text.