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Global Technology Roadmap for CCS in Industry

Sectoral Workshops Report

30 June – 1 July 2010
Abu Dhabi, United Arab Emirates

UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION

SECTORAL WORKSHOPS REPORT

Global Technology Roadmap for CCS in Industry

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Sectoral Workshops

30 June – 1 July 2010
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Project Funders:

The Global Carbon Capture and Storage Institute is a bold new initiative aimed at accelerating the worldwide commercial deployment of at-scale CCS.

The principal responsibility of the Ministry of Petroleum and Energy is to achieve a coordinated and integrated energy policy for Norway. The Ministry is responsible for CCS matters.

Partners:

The IEA is an intergovernmental organization which acts as energy policy advisor to 28 member countries in their effort to ensure reliable, affordable and clean energy for their citizens.

The IEA GHG is an international collaborative research programme focusing its efforts on studying technologies to reduce greenhouse gas emissions.

Masdar is a multi-faceted company advancing the development, commercialization and deployment of renewable energy solutions and clean technologies.

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Vienna, 2010

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1. The Global Technology Roadmap on CCS in Industry

In February 2010, a project was launched to develop a global technology roadmap on carbon capture and storage applications in various industries. CCS is generally associated with applications in the power sector, however there are potential opportunities to deploy the same basic fundamental technologies in many of the world's largest industrial sectors. Critically, there still remain significant knowledge gaps in moving towards commercial implementation of carbon capture and storage, especially in industry. The roadmap will explore the technical details, deployment potential and specific policy and regulatory aspects of CCS deployment in high-purity industrial sources of CO_2, cement, iron and steel, refineries and biomass-based industrial sources of CO_2. Simultaneously, the roadmap aims to raise the awareness of the subject.

Initiated by the United Nations Industrial Development Organization (UNIDO), the EUR 500,000 project is supported by the Norwegian Ministry of Petroleum and Energy and the Global Carbon Capture and Storage (CCS) Institute. The partners of the project include the International Energy Agency, the IEA Greenhouse Gas R&D Programme, and Masdar - Abu Dhabi Future Energy Company. The project will draw from existing methodologies and experience in technology foresight and road-mapping, and provide relevant stakeholders with a vision of industrial carbon capture and storage up to 2050. It will have a focus on developing countries with energy intensive industries, and aim to inform policymakers and investors about the potential of such technologies. The roadmap is due for completion by the end of 2010.

As part of the project, two workshops will be organized. This document serves as the report of the first workshop held on 30 June and 1 July 2010 in Abu Dhabi, which congregated an international group of industry representatives and experts.

2. Objective of the meeting

The workshop has served several purposes. First, it was intended to provide the Global Technology Roadmap on CCS in Industry with information about the sectors by bringing together experts and discussing the work done so far. Second, it was intended as an opportunity for stakeholders from a wide range of countries, including developing countries, to gain insights on potential opportunities for CCS.

The workshop was structured in a plenary session setting the scene, and four parallel breakout sessions with a sectoral focus. In addition, there were crosscutting issues in which representatives of the different sectoral workshops could discuss alignment, similarities, differences and overlap on four different topics: long-term vision, data and projections; costs and financing, incentives and regulation, and technical issues for transport and storage. The crosscutting groups report back into the sectoral workshops, and the sectoral workshops presented the outcomes in the plenary.

Annex 1 provides an overview of the meeting agenda, and the list of participants is in Annex 2.

3. Introductory sessions

3.1. Opening

During the opening session, the speakers highlighted importance of advancing CCS in industry. The objectives of the Global Carbon Capture and Storage Institute (GCCSI) are to remove barriers that prohibit the deployment of CCS, to provide advice and knowledge, and to influence governments, industry and CCS stakeholders. The GCCSI aims to encourage CCS demonstration projects, of which a 'balanced portfolio' of CCS demonstrations between developing and developed countries, and between the power sector and industry are needed.

MASDAR, a partner in the Roadmap and host of the meeting highlighted that although the Emirate of Abu Dhabi is a fossil-fuel dependent economy, the governing bodies are aware that such resources are finite, and that it is important to look into renewable sources of energy, and to explore CCS in attempts to mitigate climate change.

3.2. Scene Setting

Industry accounts for approximately 40% of total energy-related CO_2 emissions. The majority of industrial energy use takes place in developing countries, and the involvement of such countries in technological development is important. In certain industrial sectors, such as the cement sector, CCS is the only way to significantly reduce CO_2 emissions. So far, the majority of attention has been given to CCS deployment within the power sector.

According to the IEA, not considering CCS as a mitigation option will increase the costs of achieving a 50% reduction on 2000 CO_2 levels by 2050, by approximately 70%. Within the IEA Technology Roadmap for Carbon Capture and Storage (2009), almost half of the emission reduction potential using CCS needs to occur in industry, if this target will be reached at the lowest possible cost.

A roadmap is actionable, and should provide an agenda to act for government, industry and the financial sector. The progress through a roadmap can be measured by defining milestones to be reached, for example, a certain number of CCS demonstrations in industry by a specific point in time. This Roadmap starts with an assessment of the current situation, and then uses data, methods and assumptions to derive a vision of the future. Actions and milestones, gaps and barriers and relevant actors and stakeholders will then be identified.

The presentations of the introductory sessions are available in Annex 3.

4. Sectoral workshops

The sectoral workshops had three sessions to address specific issues, namely scene-setting on the background, data and broad characteristics of the sector; gaps and barriers to a future, low-carbon vision for the sector, and potential actions and milestones to be included in the roadmap. The sectors discussed were:

1) High-purity CO_2 sources
2) Cement
3) Iron and steel
4) Refineries
5) Biomass-based sources

The presentations of the introduction to each sector can be found in Annex 4, and the main messages (including gaps, barriers and potential actions and milestones) stemming from the sectoral workshops discussions can be found in Annex 5.

4.1. High-purity CO_2 sources

This sectoral workshop brought together a range of expertise from the natural gas production industry (e.g. OMV, BP, PTTEP), equipment and service providers (e.g. Schlumberger, Linde) and secondary manufacturers (e.g. the Indian Fertiliser Association), as well as respected academics in the field of CCS.

The sectors to be included in the high-purity section are gas processing/refining; hydrogen production/ammonia production (and fertiliser production from NH3); synthetic fuel production (synthetic gas production/coal-to-liquids/gas-to-liquids); and ethylene oxide production. The unifying feature between the sectors is the production of high CO_2 concentration process offgas streams, which are readily available for CCS without the need to "capture" CO_2 (i.e. without the need to concentrate a dilute stream of CO_2 to make it economically viable to transport and store).

Most current CCS demonstration projects are taking place in the high purity sector (e.g. Sleipner, In Salah), and the skills and technologies for CCS have been used in this sector for many years (e.g. gasification technology). The fertilizer industry is also capturing CO_2 from flue gas to provide additional CO_2 for urea production. High purity sources offer the lowest capture costs – as little as $[1]8/t$CO_2$ – compared to the "typical" costs cited for CCS deployment (e.g. in the range $50-$100/tCO_2 for the power sector).

Enhanced oil recovery using CO_2 should also act as a major pull factor to potentially develop early opportunity CCS projects using CO_2 from high purity sources. The evidence that this can be achieved is demonstrated through the network of CO_2 infrastructure in the United States. Here low cost and mined CO_2 is supplied at a price of about $35/t$CO_2$ at the wellhead to oil field operators for tertiary oil recovery in mature fields; the economic benefits are clear as 1tCO_2 can deliver 2-3 incremental barrels of oil (this adds around $11-17 to the marginal production cost per barrel in

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[1] USD

these regions, which is still economically attractive). This discussion set the tone for many subsequent sessions of the workshop, where a focus was maintained on the role of CO_2-EOR in pulling in high-purity CO_2 sources as a form of early demonstration for CCS technology (in the absence of CO_2 price incentives).

Gaps were highlighted in a range of areas including the lack of CO_2 transportation networks in which to place high purity CO_2 (to deliver it to oilfields); the need for better source-sink matching to understand potential; improved understanding of offshore EOR potential (and challenges); a lack of data on future emissions from natural gas production; clearer understanding of future fertilizer production pathways; and understanding of possible perverse outcomes through incentivizing CCS for process offgas streams. Identified barriers to deployment included: the lack of a CO_2 price incentive; oilfield economics (for EOR); whether high purity sources are sufficient for EOR; and operator perception of CO_2 injection into oilfields.

Near-term actions were highlighted as: identification of candidate regions with early CCS opportunities linked to high purity CO_2, raising of awareness amongst policy makers and other stakeholders of the role of early opportunities linked to high purity CO_2, cooperation and sharing of data; and the development of coherent policies and industrial strategies for CCS demonstration and deployment. A range of milestones were highlighted including the need to recognize CCS as a mitigation activity under UN mechanisms; recognition of CO_2-EOR as a mitigation activity; the establishment of standardized monitoring, reporting and verification requirements for CCS; and better information sharing through development such as a CO_2 storage map for key regions such as the Middle East.

4.2. Cement

The attendees of this sectoral workshop agreed that deep reductions in CO_2 emissions within the cement sector would only be possible with CCS. Also from the discussion it was noted that most of the gaps and barriers were shared with other sectors. A financing mechanism to cover both high capital and high operational costs, the typical location of cement plants to limestone quarries rather than CO_2 sinks, the reliance of the industry on technology providers to undertake the necessary R&D, the lack of direct availability of steam, and the reluctance of cement producers to undertake non-core business operations (such as CO_2 capture, transport and storage) and the lack of sufficient cooperation with other industries were some of key barriers identified by the group. More specific barriers included the gas and product quality consequences of oxy-combustion, the consumption of water in some regions, disposal of waste and land requirements. The development of human resources to take care of operations and safety were also flagged as attention points.

Although within the group it was generally felt the projections by the IEA regarding uptake of CCS were optimistic, the importance and need for engagement with India and China was identified. Further, the actions and milestones identified relate primarily to the gaps and barriers (see annex 5). Regulatory clarity, overcoming the gap between R&D and deployment, funding of demonstration projects (particularly oxyfuel cement plants) and structural financial incentives emerged as key actions.

4.3. Iron and steel

The iron and steel sector is rather proactive in terms of CO_2-lean steelmaking, with programs aimed at developing breakthrough technologies that have been launched across the world for almost 10 years. The most comprehensive and ambitious program in the sector is the EU ULCOS program, which has presently reached the point where a demonstrator of one of its 4 flagship projects is proceeding towards a full CCS implementation on a blast furnace in France (ULCOS-BF), with storage in a deep saline aquifer. Other programs are active and exchange news on their progress in a Forum of Worldsteel, the sectoral business association, called "CO_2 Breakthrough Program Committee". The project of MASDAR and Emirates Steel to capture and use the CO_2 for EOR is also quite exemplary. Both the ULCOS-BF and the UAE projects should go on stream around 2015.

CCS has a large role to play in the steel sector, because carbon is used in the sector as a metallurgical reducing agent, not as a fuel for combustion. This, however, raises issues as technologies tailored for the sector have to be developed. Favored are so-called "in-process" capture, which does not match any of the categories familiar in the case of combustion, which offer the promise of reducing energy needs and increasing productivity in parallel to their effect on GHG mitigation. There are however, longer term options, also under development in ULCOS, which are post-carbon society solutions, based on the use of electricity, hydrogen and biomass and thus different from CCS.

Currently, there are many hurdles to overcome until this vision is turned into practical, commercial implementation, with hoards of risks. None of the steel CCS solutions are no-regret as they imply extra OPEX and CAPEX, the financing of which remains very uncertain today - which is not helpful in a business context. To ensure that the new technologies are actually developed calls for large subsidies from governments and regional organizations to let the process gear up to speed; some more political solutions will be needed to ensure deployment of the technology, foremost of which is a world level playing field to avoid carbon leakage to carbon-heaven countries. A worst case scenario, where all the risks would materialize, would mean that the implementation of CCS might not take place at all, beyond an initial demonstration stage. The issue of the social acceptance of CCS was also discussed, with the uncertainties that it carries.

It was also pointed out that the temporalities for developing new technologies and deploying them might not be in line with the target of, for example, 100 CCS plants (both industry and power) by 2020, posted in the IEA CCS roadmap. The time needed to deploy projects might be underestimated. The point of developing many demonstrators, like what is preferred in the coal-based electricity sector, does not apply in the steel sector, at least in the short term (until 2020, when technologies like HIsarna or ULCORED will become ripe). A single demonstrator or very few of them seems to be sufficient.

The barriers to CCS deployment in the sector were also discussed. The issue of the quality of the data on present emissions and energy consumptions was also debated, with a strong focus on their uncertainties and fuzziness. There is a lack of knowledge regarding the geology of the underground, worldwide, especially regarding the deep saline aquifer geological layers of interest. This data gathering is needed and it is probably the responsibility of the states to take care of it. There is also a lack of experience, competence and knowledge on CCS in the iron and steel sector. Efforts in capacity building will be needed. A strong communication program, oriented towards a general public, is also important.

The concept of "CCS ready" can make sense in the steel sector, for the ULCOS-BF, for example, where it would mean operating the furnace with pure oxygen and recycling the top gas after de-carbonizing it. This is a major technology shift, which does not simply mean that provisions have been made for later storage, like what is often meant in the power sector. The concept may be a bit fuzzy and needs clarification.

4.4. Refineries

Participants who took part in this sector workshop agreed that the technical challenge with refineries is the complexity and the variation in the unit operations at each facility and hence the vastly different emissions sources at each. Because of this a simplification is considered the best approach and the methodology used was acceptable, but when defining capture options it is important to make distinction between Greenfield and Brownfield installations. A point may be to investigate the proportion of IOCs, NOCs, and JVs in the refining industry and the relative willingness of each category to undertake CCS. There is also a need to comment on the impact non-conventional fuels are likely to have on the refining industry, e.g. NGLs, GTLs, CTLs & bio-fuels. The participants could not offer any recommendations of data sources for emissions projections or for the role of CCS in the refining sector, but did offer some good technical references.

Gaps and barriers were categorized as specific to the sector or applicable to all CCS deployment. Issues specific to refining industry are: low refining margins, lack of real estate to retrofit CCS technology, multiple relatively small sources of different CO_2 specifications. Issues which are more broadly related to all sectors are: finance, storage, water and electricity supplies, CO_2 specification, and legislation. A weakness for this discussion was the technical background of the participants, which lead to a focus on issues at a more detailed level than policy.

The conversation on sector specific actions and milestones concentrated on lack of actual data and experience with CCS. It was felt in order to put any sort of legislation in place there was a need to introduce standard methodologies for emissions measurement and develop a comprehensive emissions inventory. There is also a need to increase awareness of CCS in the refining industry, particularly amongst the engineers and professionals, both through course and design guidelines/standards. Outside of Europe and North America, CCS is a relatively unknown technology. Knowledge transfer and sharing with developing nations is considered very important to the quick deployment of CCS. Under all scenarios, there is a need to demonstrate CCS technology and the high purity CO_2 sources in the refining industry offer the opportunity for low cost demonstration, to prove to the developing regions that technology is viable. Local “champions” for CCS technology will increase the opportunities to demonstrate and disseminate the technology.

4.5. *Biomass-based sources*

Biomass-based industrial CO_2 sources form an indispensable solution in pursuit of low GHG concentration stabilization levels in the atmosphere. A wide array of biomass-based industrial CO_2 sources is expected to be available in both short- and long-term future, and as a result the CO_2 capture costs for biomass-based CO_2 sources will probably vary significantly. CO_2 capture during ethanol production offers a large-scale near-term opportunity at relatively low CO_2 capture costs. CO_2 capture during production of synfuels and H2 from biomass is projected to capture 2.1 Gt CO_2 by 2050, according to the BLUE map scenario presented in the IEA technology roadmap for CCS (2009). However, less than a handful of pilot and demonstration plants are planned or under construction to date.

Bio Energy with Carbon Capture and Storage (BECCS) is a forgotten technology at present; it is overlooked by both biomass and CCS communities. The technology lacks industrial champions to pursue broad implementation, while there is a lack of awareness amongst policy makers. Consequently, BECCS is excluded from any incentive or demonstration programme that is currently in place.

One of the first actions to be undertaken is the formation of a BECCS stakeholder network. This requires mobilization of all relevant communities: policy makers, NGO's, scientific community and industry champions. The involvement of bodies such as the IEA, UNIDO and GCCSI is considered to be essential in the formation of such a network. Other early movers are nations that could have a short-term interest in application, being Brazil, Sweden, the USA and Indonesia. The UNFCCC could play key role in recognizing negative emission accounting for BECCS. More detailed scientific studies are needed on costs, long-term contribution on GHG reduction and early opportunities. Dedicated BECCS pilot and demonstration projects should be facilitated.

5. Crosscutting issues

In addition to the specific sectoral sessions, the participants were also invited to take part in one of the cross-cutting sessions, 5 of which ran in parallel on the second day of the workshop. The topics covered in these cross-cutting sessions (see 5.1 – 5.5) were considered important for all industrial sectors.

5.1. *Long-term vision, data and uncertainties*

The IEA is to release new data in its Energy Technology Perspectives (ETP) 2010 report on 1 July 2010. Insights were provided into how the data and information in the new report may have altered since the previous Energy Technology Perspectives 2008 report. A key difference is the use of the updated World Energy Outlook 2009 emission baseline data, which accounts for the global economic crisis in 2008, It was highlighted that the due, in part, to the economic crisis, the baseline scenario for CO_2 emissions up until 2050 has been reduced by approximately 5 Gt. The projections for CCS deployment were also understood to have decreased, although no exact figure could be presented.

The projections for CCS deployment in industry presented in the IEA Technology Roadmap Carbon Capture and Storage (2009) were reviewed. The representatives of the sectors were asked to give their expert opinion on the plausibility of the data presented in the document, specifically in terms of the levels of emissions that were projected to be abated in each sector by 2020. Within the session, experts in the field of biomass, steel and cement production were present. There was a general consensus that the level of CCS deployment by 2020 presented in the IEA roadmap was challenging given the current status of the technology, this was particularly so for the biomass sector due to the relative immaturity and low scale of biomass-to-liquid (BTL) and hydrogen production (via biomass).

The model used by the IEA to generate such projections identifies the lowest cost combination of technologies to achieve a 50% reduction in CO_2 emissions from 2000 levels, by 2050 (The IEA Blue MAP scenario). The model is intrinsically optimistic, which explains the high projections of CCS deployment in industry. The use of alternative, complementary scenarios and data sources for the development of the roadmap was discussed.

5.2. Costs, financing and business models

It is generally accepted that taxation and emissions trading schemes are going to adversely affect industry, unless a truly global deal is found. Until there are better incentives and prices on carbon then it is unlikely that CCS will be widely deployed commercially. Until such a time there are still niche markets for financing some projects through sale of carbon credits to either high priced carbon countries such as Norway and Sweden or by the Chicago carbon exchange, through EOR and also biomass CCS. Carbon credit mechanisms are limited in size, given the Chicago exchange only deals in about 10 Mt of credits per year. Biomass has the potential to get double credit for CO_2 sequestered and EOR because of the oil value.

It is felt that the public sector will probably have to make some of the initial investments to demonstrate technology and to build infrastructure. Private-public partnerships are seen as one method for governments to raise capital. Parallels were drawn with the initial deployment of natural gas and electricity infrastructure and the large public investments that were made in the initial deployments of these technologies. One of the big fears with adding CCS, is increasing the price to consumers and hence inducing fuel and energy poverty on them.

In terms of funding technology, US$40 billion has been pledged by nations at the Copenhagen Summit and UK, US and Australia all have funds for developing CCS in China. In order to reduce the risk to investors to raise finance, fundamental issues such as the security of utilities, carbon accounting mechanisms all need to be agreed at the highest levels. In summary until a global deal is agreed, there is limited financial opportunity available for a few small projects, enough to prove the technology, but not enough to deploy it as widely as required to meet international targets.

5.3. Incentives, policy and regulation

One of the key issues during this workshop was the general lack of sufficient financial incentives to deploy CCS. There are incentives to reduce CO_2 emissions within the European Union through the Emission Trading Scheme (ETS), and Norway has introduced a carbon tax, however the prices are currently too low to stimulate investment in CCS. Also, in developing countries, there are no strong incentives to deploy CCS as emission reductions through CCS will not be assigned emission reduction credits under the UNFCCC Clean Development Mechanism (CDM). One of the complexities of a global price on carbon, is how you distribute the burden of cost across various economies in different stages of development across the globe.

It was recognized that in the EU, CCS demonstrations are also encouraged through direct government support, however these have tended to focus on the power sector. There is also no regulatory framework that exists that could incentivize negative CO_2 emissions through the combination of CCS and biomass, and there is little funding or attention for such technologies.

The use of CO_2 collected from high-purity CO_2 sources and used for enhanced oil recovery (EOR) could lead to very low abatement costs, however EOR maybe more attractive and realistic in some regions than others. The lack of clear policy and regulatory guidelines linking EOR with a global climate framework is certainly a barrier to further deployment.

A main talking point in the session concerned 'carbon leakage'. Carbon leakage can occur when businesses shift production from nations with stringent regulatory regimes including high emission taxes or permit schemes, to nations with little or no regulatory enforcement in order to avoid losing profits. This could mean that instead of an overall reduction in carbon emissions, merely the distribution of emissions would be shifted across the globe. Due to issues such as proximity to markets, the mobility of industries and corporate strategy, it is unknown how serious the problem of carbon leakage may be, however it is a potential problem which may have to be addressed through policy.

A regulatory framework to cover issues such as public awareness and environmental impact statements were called for, and it was stated that policy and regulatory development must receive the same attention of technology development. In certain countries, existing legislation may block the deployment of CCS, for example in South Africa, anybody wanting to store CO_2 geologically would need to pay for a mineral right, in France a demonstration plant took 4 years to obtain an environmental permit, and in Indonesia it was thought that the current legislative framework could not 'handle' CCS.

The requirement for monitoring, measurement and verification (MMV) of CCS projects was also discussed. A globally unified approach to MMV of CCS projects was called for, and it was agreed that capacity building is required to be able to ensure that MMV is completed correctly. MMV is particularly important under the scenario that geologically stored CO_2 would receive credits under the CDM, and the liability issues of CO_2 leakage over longer timeframes was also discussed.

5.4. *Technical issues for CO_2 compression, transport and storage*

The crosscutting group on technical issues related to transport and storage of CO_2 from industrial sources discussed two broad issues: 1) likelihood that industrial sources are close to storage reservoirs; 2) impurities requirements for transport and storage.

With regard to the first issue, for biomass, cement and iron/steel there does not seem to be a relation between CO_2 source locations and geological storage reservoirs. Cement plants are generally built near limestone reservoirs, but there is no relationship between limestone and underground sedimentary basins. For gas processing plants, there is a relatively high likelihood that sources and reservoirs are close together, as the gas is recovered from a sedimentary basin. This explains the short transport distances in the Sleipner and In Salah projects. For refineries, there is not necessarily a proximity to oil or gas fields or to other sedimentary basins, but refineries are often built near the coast to allow for marine transport of oil, where prospective storage is also regularly located. This suggests a weak bias towards proximity of refineries to storage reservoirs.

Requirements for impurities in the CO_2 stream depend on the application of the CO_2 and on the mode, organization and distance of the CO_2 transport. If the CO_2 is used for EOR, its requirements for low oxygen levels are very strict. This might be an issue if the CO_2 originates from an oxy-fired cement kiln. If the transport is long-distance or in a network with various sources, dehydration is important to prevent leaking of pipelines, but if the CO_2 is intended for EOR and the source is close by, it might be more cost-effective to build a short stainless steel pipeline, and leave the water in the CO_2, as it is no problem to inject water with CO_2 for EOR. There may also be a requirement to have phase purity to ease compression. In general, however, if a transport network is designed in which a variety of industrial and electricity sources of CO_2 feed the CO_2, and various storage applications. What was also flagged was a lack of awareness with the CO_2-emitting industries about underground storage issues, such as impurities.

It is recommended that guidelines and standards for impurities are drafted with ranges in mind. Guidelines should recommend to start basing impurity requirements with requirements for storage or EOR and work via the transport phase to what the source of CO_2 should do to meet the requirements. This could be done in a flow diagram or a table.

6. Early opportunities in the Middle East

Most countries in the Middle East can be characterized as energy-intensive economies because of a large oil and gas industry and associated industrial activities. It is projected that demand for electricity and gas will increase rapidly in the region. Another characteristic, relevant to CCS that is inherent in the region is the opportunity to implement CO_2-EOR. Contrary to other places in the world, EOR can be seen as a main driver for CCS – it can provide the demand pull factor for separation and use of CO_2, instead of its emission to the atmosphere.

The crosscutting group resulted in a distribution of Middle Eastern countries over three main categories:

1) Countries in which CCS (with EOR) will take 10 to 15 years to materialize. The oil and gas demand is there and EOR opportunities are there. Knowledge build-up is taking place and there are some government activities, but it will not be until 2020 or after that CCS is a broad possibility. Examples could be Saudi Arabia and Kuwait.
2) Countries that are a step further: There is political will to act on climate change, there are sources of CO_2, but the possibilities for EOR are limited in the short term. With an incentive and more capacity development, these countries could start relatively soon with implementation, possibly within 10 years. Examples could be Qatar and Oman.
3) Countries for which all ingredients are in place: EOR capacity, sources of CO_2, political will, human capacity and companies to implement (such as Masdar). These countries lack the level of organization and the interaction between sources and reservoirs of CO_2. Examples: UAE and Iran (although the technological availability in Iran is an issue)

The different categories of countries would require different action plans. In some countries, international organizations could play a role to see whether political will can be built. On the other hand, however, the limitations will need to be understood; in particular the lack of a global climate change agreement with clear incentives for emission reductions, which means that an EOR demand pull is essential for short-term rollout of CCS.

7. Next steps

The next steps towards the preparation of the Global Technology Roadmap on CCS in Industry are:

- Finalization of the sectoral assessments based on the sectoral workshop inputs and further information.
- Initiation of the drafting of the Roadmap itself.
- Organization of a second workshop to review the Roadmap around GHGT10 in Amsterdam.
- Finalization of the full Roadmap, publication of sectoral assessment and launch.

8. Acknowledgements

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Annexes

Annex 1: Annotated agenda

Annex 2: Participants list

Annex 3: Scene setting presentations

Annex 4: Introduction to each industrial sector

Annex 5: Sectoral workshop results

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