Joint IEA-OPEC workshop on CO_2-enhanced oil recovery with CCS

Kuwait City, 7-8 February 2012

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This workshop report was prepared for the Joint IEA-OPEC workshop on CO_2-Enhanced Oil Recovery with CCS held in February 2012 in Kuwait City, Kuwait. It was drafted by the IEA CCS Unit. This paper reflects the views of the International Energy Agency (IEA) Secretariat, but does not necessarily reflect those of individual IEA Member countries. For further information, please contact the CCS Unit at: ccsinfo@iea.org.

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Foreword

Both oil-consuming and oil-exporting countries share the challenge of ensuring adequate supplies of energy for their economies while at the same time mitigating greenhouse gas (GHG) emissions and diversifying their energy sectors. Analytical collaboration on a range of topics including energy markets, energy policy and energy technology can help facilitate the search for constructive solutions.

In recent years, the International Energy Agency (IEA) and the Organization of the Petroleum Exporting Countries (OPEC) have worked together on a number of studies centred on international energy markets. We welcome the opportunity to extend our collaboration into a technical area such as carbon dioxide enhanced oil recovery (CO_2-EOR). This technology can help sustain the longevity of national hydrocarbon assets by increasing the amount of oil recovered from mature fields, while locking large volumes of CO_2 away from the atmosphere for geological scales of time.

The present joint IEA-OPEC report represents a new and important phase of our collaboration, focusing on a technology combination that is widely seen as having the potential to address simultaneously some shared energy security and climate change concerns. While CO_2-based enhanced oil recovery in combination with geological storage may not be the preferred option in all cases, it could be the technology of choice in some regions and under certain circumstances. Our work so far has certainly identified a number of issues worth exploring in greater depth.

We hope that this report promotes discussion among stakeholders on the policy, economic and technical issues related to the use of CO_2-EOR for the reduction of GHG emissions, therefore providing a basis for future work.

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Acknowledgements

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Executive Summary

The IEA and OPEC jointly organised a workshop to discuss CO_2-EOR and its role in supporting the early demonstration of CCS. The workshop was hosted by Kuwait Petroleum Corporation, and held in Kuwait City on 7-8 February 2012. It brought together OPEC Member country (MC) experts and international CO_2-EOR experts to discuss commercial, economic, technical, regulatory and political aspects associated with the technology. Issues discussed include factors that can promote CO_2-EOR ahead of "pure" CCS, barriers preventing uptake of the technology, and the range of policy interventions that could be employed to promote its use in OPEC MCs and other parts of the world. This report presents a synthesis of the discussions that took place.

1. Workshop Scope

CCS entails the geological storage of anthropogenic CO_2 for the purpose of its long-term isolation from the atmosphere. In this report we will refer to the use of CO_2-EOR combined with CO_2 storage for the purpose of climate change mitigation as "CO_2-EOR with CCS". CO_2-EOR with CCS is widely regarded as an "early opportunity" to demonstrate the viability of CCS as a climate change mitigation option[1]. The use of captured CO_2 from large point sources in CO_2-EOR operations is often argued as having the potential to offset some or all of the additional costs associated with capturing, transporting and storing CO_2 because of the additional revenue available from incremental oil production. As a result, CO_2-EOR is often referred to as a "win-win" technology both in terms of improving recovery factors from oil fields, with the associated economic benefits, and mitigating climate change.[2]

In analysis carried out ten years ago, the International Energy Agency Implementing Agreement on Greenhouse Gas Research and Development Programme (IEAGHG) identified 488 CO_2-EOR candidate projects as "early opportunities", with many located in the Middle East (IEAGHG, 2002). Today, however, the main concentration of CO_2-EOR projects in the world remains in the mid-west of the United States of America (USA), the majority of which were established during the 1970s. Despite increasing interest worldwide in the potential for CCS as a climate change mitigation technology and the support role that CO_2-EOR could play in its deployment, few, if any, of the more recently identified opportunities have been developed outside the USA.

In view of this lack of development, the IEA Secretariat has set out to gain a better understanding of the factors affecting uptake of the technology in different parts of the world. To achieve this objective it has established a work programme which aims specifically to investigate the following aspects of CO_2-EOR with CCS:

- barriers to uptake, including economic, technical and cultural factors;
- regional perspectives, covering key global oil-producing regions; and
- ways forward, including the political, economic and technical factors that could deliver the perceived "win-win" scenario for CO_2-EOR.

As a starting point for the work, the IEA and OPEC secretariats organised a joint workshop with OPEC MCs and international CO_2-EOR experts to explore factors affecting the uptake of CO_2-EOR with CCS in OPEC MCs. Specific objectives included:

- gaining an insight into the commercial and economic aspects of CO_2-EOR with CCS;
- reviewing CO_2-EOR technology, its potential benefits and the technical considerations, challenges and risks associated with converting CO_2-EOR into CCS;
- sharing lessons learnt from former and current CO_2-EOR projects; and
- identifying areas of mutual interest for a possible follow-up workshop.

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[1] The Intergovernmental Panel on Climate Change (IPCC) (2005) report *Carbon Dioxide Capture and Storage* defines early opportunities as projects that [are likely to] "involve CO_2 captured from a high-purity, low-cost source, the transport of CO_2 over distances of less than 50 km, coupled with CO_2 storage in a value-added application such as EOR." For information on CCS application at high-purity sources, refer to Zakkour and Cook (2010).

[2] Each incremental barrel of oil produced in a miscible CO_2 flood typically requires the net injection of between 0.25 and 0.40 tCO_2. Net injection takes account of the CO_2 that is reproduced with the oil and recycled.

The workshop was co-chaired by Ambassador Richard H. Jones, Deputy Executive Director of the IEA, and Dr. Hasan M. Qabazard, Director of Research, OPEC. This report presents a synthesised summary of the discussions and is built around the following themes:

- characterising the differences between a "pure" CO_2-EOR project, and one with the joint objective of CCS;
- identifying factors affecting uptake of CO_2-EOR with CCS;
- identifying issues affecting uptake of CO_2-EOR with CCS in OPEC MCs; and
- reviewing potential policy interventions needed to support CO_2-EOR with CCS.

The following sections reflect views expressed by participants at the workshop, and do not necessarily represent those of either the IEA or OPEC.

2. Differentiating CO_2-EOR from CO_2-EOR with CCS

A primary consideration that emerged on a number of occasions during the workshop was how a "pure" CO_2-EOR project differs from one involving CO_2-EOR with CCS. In the case of the former, the primary objective of the operation is oil recovery, and any storage of CO_2 is an incidental benefit. In such cases, there is limited need to provide assurance over effectiveness of the technology in mitigating climate change. For the latter, the long-term storage of CO_2 is also a primary goal of the CO_2-EOR operation, and as a consequence, assurances should be provided regarding the capacity of the project to isolate CO_2 from the atmosphere over the long term. This was a major consideration for the workshop, with the objective of understanding whether CO_2-EOR can act as a catalyst for long-term deployment of CCS and potentially deliver the desirable "win-win" outcome. This section provides a summary of the discussions that took place at the workshop within this context.

2.1 Benefits of CO_2-EOR with CCS

In the first instance, discussions highlighted that even where CO_2 floods are operated purely for the purpose of EOR, typically 50% of the CO_2 is not recovered at the production wellhead during the operational phase of the project. This implies that around 40-50% of the injected CO_2 is trapped in the oil reservoir. This occurs even where reservoir management strategies are employed to recover as much of the injected CO_2 as possible.[3] Such results suggest that geological processes act to promote containment of CO_2 in geological formations following CO_2-EOR whether intended or not. Whilst it is not possible to prove definitively that this is the case in the absence of dedicated monitoring, the broad evidence seemingly support a commonly held view that a "win-win" outcome might be achieved with even the most basic of CO_2-EOR operations.

Furthermore, workshop participants considered certain specific factors that justify the deployment of CO_2-EOR with CCS ahead of just "pure" CCS in isolation:

- The trapping mechanisms within the reservoir have been proven since the trap has been shown to retain hydrocarbons for millions of years.
- Oil-producing regions have a historic framework in place for permitting and regulating injection of fluids into the subsurface, including those with active CO_2-EOR, which could be more easily adapted to storage than developing an entirely new framework for "pure" CCS.
- Communities living in close proximity to the site of oil fields generally accept the role of oil production and oil field practice, meaning public objection to CCS is likely to be diminished in these areas.

The workshop also considered options for optimising a CO_2-EOR project to achieve the best outcomes for both oil production and climate change mitigation (*i.e.* maximising volumes of CO_2 stored). One presenter highlighted several potential technical means by which this could be achieved, including:

- injecting CO_2 earlier in the life of a field, perhaps during or for the purpose of secondary depletion;

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[3] In the USA, as operators are paying around USD 40/tCO_2, they tend to try and recover and recycle as much CO_2 as possible.

- operating the field in a continuous CO_2 flood mode, as opposed to the more typical water-alternating-gas (WAG) presently widely used for CO_2-EOR in the US;
- injecting CO_2 into the flanks of producing fields below the conventional oil zone/oil water contact in order to mobilise oil in residual oil zones (ROZs); and
- producing residual water to make additional pore space available for CO_2 storage.

It was noted that most of the latter approaches have yet to be fully demonstrated in practice.

2.2 Challenges for CO_2-EOR with CCS

In contrast to the potential benefits highlighted, some participants were more circumspect in their view on the role of CO_2-EOR in supporting CCS. They suggested that there could be challenges in managing fields when trying to enhance storage and reduce CO_2 breakthrough. Several issues were raised by participants in this context, including the following:

- Increasing the volumes of CO_2 stored compared to a standard CO_2-EOR flood creates more risk due to increases in reservoir pressure. This could lead more readily to fracturing of the cap rock and greater displacement of *in situ* reservoir fluids. It was suggested that, typically, conventional CO_2-EOR techniques leave CO_2 in a fairly stable state in the reservoir and usually below the initial reservoir pressure. Increasing the pressure in an oil reservoir could therefore create problems that operators may not need or want (see below).
- It was suggested that increasing the amount of CO_2 stored during an EOR flood could be difficult due to the presence of legacy wells that may not be plugged using CO_2 resistant cements. Increasing reservoir pressure could lead to well failure.
- Typically during a CO_2-EOR operation, the whole field is not flooded, but rather flooding takes place in phases across different zones of the field. The exact length of operations and phases will be determined by oil price. Once a zone has been flooded and extraction operations completed, wells within the zone will be shut in and abandoned. Once a well has been abandoned, it is difficult to re-enter flooded zones, making incremental storage difficult.
- On an economic basis, an operator might decide to run a CO_2-EOR flood sub-optimally, *i.e.* in "CO_2 storage mode". Under circumstances where storing CO_2 provides a greater return than oil production, sub-optimal CO_2-EOR operations may result in oil production being foregone.

It was noted that the Weyburn-Midale CO_2-EOR operations located in Saskatchewan, Canada, involve a combination of both WAG and pure CO_2 flooding across different zones. Part of the reason for this is to access different pay zones in the reservoir, with water being effective in the lower horizons, but CO_2, due to buoyancy, being more effective at overriding and sweeping pay zones in the upper horizons of the reservoir.

2.3 The Importance of measurement, reporting and verification

Although long-term isolation from the atmosphere of CO_2 injected in conjunction with CO_2-EOR appears to be technically feasible, a key challenge discussed during the workshop was how climate mitigation achieved through CO_2-EOR can be recognised by operators, policy makers and regulators. To achieve this aim, participants broadly agreed that operators will need to apply appropriate measurement, reporting and verification (MRV) procedures and programmes to provide assurance that the injected CO_2 continues to be effectively isolated from the atmosphere. For this same reason, MRV programmes will also be vital when carbon finance is used to support such projects. To date, the lack of dedicated MRV programmes in most CO_2-EOR floods around the world means that climate change mitigation benefits have generally not been recognised. The one possible exception to this is the Weyburn project in Canada.[4]

For this reason, MRV was identified by workshop participants as a key consideration affecting the viability of and interest in CO_2-EOR with CCS. Many participants noted that running a CO_2-EOR project as a CCS project means the MRV requirements pose additional burdens for operators, especially where extending operations into CO_2 storage could lead to risk of CO_2 leakages (see Section 2.2). The length of monitoring required after the cessation of CO_2 injection was also noted as an issue. Participants suggested, however, that if it was in principle desirable for CO_2-EOR to be recognised in the same way as a "pure" CCS activity, then good policy would dictate that the same rules for MRV be applied to both.

2.4 Other greenhouse gas accounting issues

The workshop also considered the type of project-level GHG emission accounting frameworks that may be applicable to CO_2-EOR. This relates to the types of emission that occur during CO_2 capture and transport, and emissions generated when the incrementally produced oil is combusted. The topic is relevant because of concerns in some quarters, particularly among policy makers in the field of climate change, about whether the technology actually delivers a "win" for the climate, with some holding the view that CO_2-EOR produces additional fossil fuels and thus limited or no net environmental benefits.

There is also limited agreement on how benefits may be quantified in GHG accounting frameworks. The range of benefits calculated for some of the projects discussed in the workshop are summarised below (Table 1). As can be seen in the summary data presented, it is not straightforward to quantify the net benefits to the climate that might accrue from these projects, even where data is available. This highlights the dilemma that many policy makers face in this arena.

The discussions at the workshop suggested that many factors are involved in assessing the GHG emissions reductions from CO_2-EOR, including:

- where the boundaries of the GHG emissions accounting framework should be set for a particular project (*e.g.* whether to include emissions from oil production or not). It was suggested that if energy-related emissions from an equivalent system are displaced, CO_2-EOR leads to emissions reductions. On the other hand, other workshop participants questioned this view;
- whether CO_2-EOR can be optimised for storage so as to increase the amount of CO_2 injected per barrel of oil produced (see above);
- the "baseline" used in the emissions accounting framework, such as what the relevant emission factor should be in the case of CO_2 that is captured from power plants (*e.g.* the grid emission factor, the build margin or the operating margin). Similar issues can also arise when considering industrial applications of CO_2 capture;

[4] The USA reports the CO_2 captured from the Dakota Gasification Plant and exported to Weyburn for CO_2-EOR as not emitted (US EPA, 2012), although the Canadian national GHG inventory report (Environment Canada, 2012) is unclear on whether the amounts of CO_2 injected at Weyburn are considered emitted or not.

- whether a barrel of oil produced using CO_2-EOR displaces marginal production elsewhere (*i.e.* whether there is no net increase in overall production), whether new demand is created (or suppressed demand met), and in the case of the former, what the emissions would be for the displaced production (*e.g.* light crude or oil sands); and

- the effects on oil price of increasing the amounts of CO_2-EOR worldwide, and what effects this would have on oil economics and marginal production. To date, this topic has not been researched in any detail and may warrant further investigation.

Table 1 • Summary of projects discussed at workshop

Project	Location	Status	CO_2 supply/injection	Incremental oil produced
Weyburn-Midale	Saskatchewan, Canada	Operational, predominantly WAG (2000)	2.5 $MtCO_2$ /yr supplied from Dakota Gasification syngas plant via 320 km, 14" pipeline Weyburn: 17 $MtCO_2$ stored (Dec 2010) Midale: 2.1 $MtCO_2$ stored (0.4 Mt/yr)	220 Mbbl (estimated) 35% RF (of OOIP)
DUC project	Danish North Sea	Planned (2015)	1.1 $MtCO_2$/yr from ROAD project 0.5 $MtCO_2$/yr from $GreenH_2$ (both in the Netherlands)	-
Gulfaks & Ecofisk	Norwegian North Sea	Under consideration	Around 5 $MtCO_2$/yr from unidentified sources	28 Msm^3 Additional 6.4% RF
Halden/ Draugen	Norwegian North Sea	Under consideration	Around 2.5 $MtCO_2$/yr from Mongstad to Halden and Draugen fields	-
-	Norwegian North Sea	Whole of continental shelf	Total storage potential of 24 $GtCO_2$	
ADCO	Abu Dhabi	Pilot (2009)	60 t/day	-
In Salah	Algeria	Operational (2004) CCS only	0.7 $MtCO_2$/yr from Krechba Gas Processing Plant 3.8 $MtCO_2$ injected to date	n/a
Saudi Aramco	Saudi Arabia	Planned (2014)	40 MMscfd of CO_2 into mature oil reservoir	-

Source: Unless otherwise indicated, material in all figures, tables and boxes derives from IEA data and analysis.

It was broadly agreed that there is a lack of clarity on all of these aspects, and very few operators had considered the appropriateness of accounting frameworks in any detail, at least in the public domain.

One participant outlined how some of these issues had been taken into account when developing a Clean Development Mechanism (CDM) project involving CO_2-EOR, and how similar principles had been applied to a planned CO_2-EOR project in the North Sea.

Other participants questioned why such issues are of importance, suggesting that all oil will be produced with or without the use of CO_2, and therefore, if CO_2-EOR is employed and CO_2 sequestered, there is inherently a net environmental benefit.

One participant highlighted that we can see differential implementation of GHG accounting frameworks and MRV approaches today, outlining the point that some countries like Norway are reporting CO_2 injected as "not emitted" in their national GHG inventory, whilst in the USA, CO_2 injected for EOR in some cases is reported as emitted even if it is apparently sequestered in the ground. Primarily this variation is a consequence of use of the different MRV approaches to the stored CO_2 in the two jurisdictions. This occurs even though a standardised approach for CO_2 storage accounting has been proposed in the Intergovernmental Panel on Climate Change (IPCC)

Guidelines for National Greenhouse Gas Inventories. This particular example highlights the challenge of demonstrating (and gaining acceptance of) the "win-win" claims for CO_2-EOR.

The need for public policy to support both objectives was an ongoing theme of the workshop, and is discussed further in subsequent sections of this report.

Box 1 • Key discussion points

In the context of the "win-win" concept, participants highlighted that:

- CO_2-EOR inherently leads to CO_2 storage even if it is not intended because approximately 50% of the CO_2 injected during a CO_2-EOR flood is retained in the reservoir, apparently due to geological trapping. Thus, where anthropogenic sources of CO_2 are used, CO_2-EOR could offer a "win-win" solution if it ultimately leads to a net reduction in GHG emissions;
- there is uncertainty about whether CO_2-EOR operations can technically be designed to offer an optimised "win-win" solution, as many of the suggested means of enhancing storage are either untested and/or pose greater risk to operators of seepage of CO_2 from the reservoir;
- proving that CO_2 is being retained in the reservoir requires dedicated MRV programmes to definitively demonstrate what is happening to the injected CO_2; and
- as a consequence, operating a CO_2-EOR project as a CO_2 storage project creates additional requirements for operators, in particular MRV. MRV is, however, critical to demonstrate the effectiveness of the technology as a climate change mitigation approach.

The issues discussed suggest a gap in the current understanding of the role of CO_2-EOR as a climate change mitigation technology. Further work may be warranted to develop standardised approaches to GHG accounting for CO_2-EOR.

3. Factors affecting uptake of CO_2-EOR with CCS

As described above, CO_2-EOR using CO_2 captured from anthropogenic sources is widely regarded as an "early opportunity" to demonstrate the viability of CCS as a climate change mitigation option. However, it was also noted that whilst the technology is proven – with over 30 years experience and more than 100 active CO_2 floods in operation in the USA and Canada alone, and various smaller floods taking place in locations as diverse as Brazil, Trinidad and Tobago, and Turkey – widespread uptake of the technology has yet to be achieved despite increasing interest and support for CCS.

Worldwide, the most extensive network of CO_2-EOR projects is in the US, focused around Texas, New Mexico and Colorado. In this region and surrounding states, over 3 000 miles of CO_2 pipelines exist, transporting CO_2 from a variety of sources to a large number of oil fields for injection. In the region, CO_2-EOR is producing more than 250 000 barrels per day of incremental oil, of which over 240 000 barrels are produced by miscible CO_2 floods (the remainder being immiscible CO_2 floods).

3.1 Preconditions supporting uptake

The establishment of extensive CO_2-EOR infrastructure in the USA is well documented in a wide body of literature, and a variety of reasons have been outlined for its particular emergence. These include the following:[5]

- **Presence of oil fields with reservoir characteristics amenable to miscible CO_2 flooding.** Oil fields that have been depleted by primary and secondary means are typically a precondition for starting tertiary techniques such as CO_2-EOR; there is little recorded experience of flooding reservoirs with CO_2 before undertaking water flood. Nor is there experience worldwide in undertaking CO_2-EOR in offshore environments. Other specific characteristics that make a reservoir suitable for miscible CO_2 floods include appropriate depth, pressure, temperature, oil gravity and oil saturation.
- **Availability of affordable and reliable sources of CO_2.** Most of the CO_2 used in CO_2-EOR operations in the USA is from natural sources such as the McElmo and Jackson Dome where pure CO_2 production costs are very low. The balance is captured from low-cost anthropogenic sources such as gas processing plants (see Figure 1). CO_2-EOR operators in the region are currently paying around USD 40 per tonne of CO_2 delivered to the wellhead.[6]
- **Favourable economics, including government support.** As well as requiring favourable oil prices, US government incentives played a key role in the emergence of CO_2-EOR in the 1970s. This included the elimination of quotas and price regulation for oil produced using tertiary recovery methods such as CO_2-EOR. Further incentives were provided in the 1990s by way of a federal tax credit, alongside other state-level incentive programmes aimed specifically at supporting CO_2-EOR.
- **Appropriate risk appetite and technical know-how**. At the time of early CO_2-EOR development in the USA, the technology was untested, meaning operators took on significant investment risk. Still today, test injections are usually required to determine suitability of an oil field to CO_2-miscible flooding with a good degree of certainty. As such, a corporate culture that understands

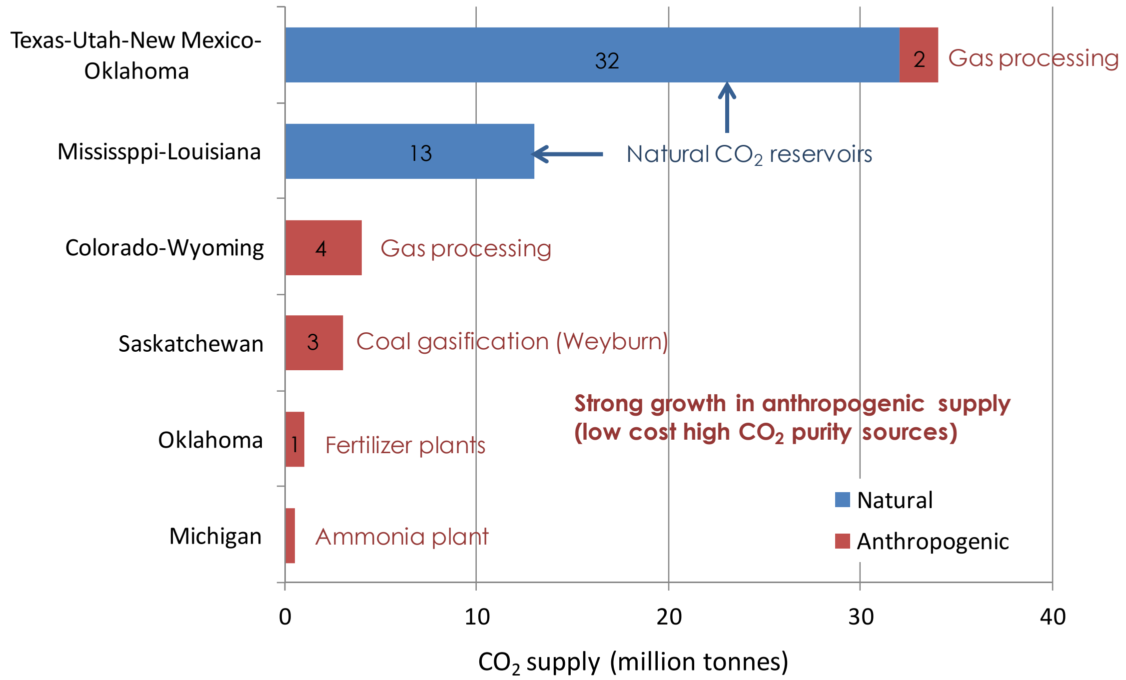
[5] Based on analysis presented in UNIDO (2011).

[6] Supply contracts are generally indexed to oil prices. The cost of CO_2 means that most CO_2-EOR floods in North America are optimised to recover as much breakthrough CO_2 as possible in order to avoid the cost of purchasing additional make-up CO_2.

the balance of risk and reward, and an appetite to learn from previous experience, have been critical in the growth of the CO_2-EOR industry in the USA.

Experience would suggest that these preconditions have led to the successful deployment of CO_2-EOR in the USA for the purpose of enhancing oil production.

Figure 1 • Sources of CO_2 used for CO_2-EOR in North America



Source: UNIDO, 2011

3.2 Factors deterring uptake

Taking into account the potential for a "win-win" outcome, and the lack of development of such projects worldwide despite this potential, workshop participants considered reasons why CO_2-EOR, against most expectations, had not emerged significantly over the last ten years. Reasons suggested by participants included:

- a lack of financial incentives in place to run CO_2-EOR operations as CCS projects. Specifically it has been unclear whether CO_2-EOR, CCS or a combination of the two could be recognised under carbon-pricing mechanisms such as emission trading, the Kyoto Protocol's CDM, or other climate change policy instruments;
- difficulty in managing the commercial interface required to establish CO_2-EOR with CCS projects given the need to balance supply and demand of CO_2. On this note, the suggestion was made that the dynamics between suppliers and receivers would likely change if clearer obligations were placed on large point source-emitters of CO_2 (*e.g.* power plant operators) to reduce CO_2 emissions or employ CCS;
- increased complexity and costs for project development, operation, closure and stewardship brought about by treating CO_2-EOR as a climate change mitigation technology through CCS (see also Section 2);
- high costs and complexity of the technology. For some regions, such as in the North Sea, various pre-feasibility studies and front-end engineering designs have suggested that the

technology is presently too expensive relative to the potential income streams, and too complex to develop at the current time;

- opportunity costs. In the US, recent oil company investment capital has flowed into shale gas as a near-term realisable opportunity, rather than into CO_2-EOR;
- a lack of local expertise to facilitate deployment of CO_2-EOR. This could be a challenge for its future development in some OPEC MCs; and
- the increased business risk associated with the complexity of CO_2-EOR with CCS operations. This can deter investment.

Conversely, it was pointed out that in some areas of the world, such as the central and southern states of the USA, CO_2-EOR could need CCS in order to provide a cheap, reliable source of CO_2 and push down the cost of delivering CO_2 to the wellhead. On this basis, CCS also has the potential to reduce the overall cost of CO_2-EOR operations.

The range of challenges and uncertainties discussed at the workshop highlighted the commercial deterrent to investing in CO_2-EOR in many regions of the world. As mentioned by several participants, generally speaking businesses prefer certainty when considering investment, and in its absence capital will tend to flow into other areas.

Box 2 • Key discussion points

The discussions highlighted the kind of issues presented by CO_2-EOR project development and the potential frameworks needed to support deployment of CO_2-EOR with CCS. The following were the main issues identified:

- While the preconditions for CO_2-EOR uptake in the USA are well understood and documented, the circumstances for similar preconditions do not exist in any other jurisdiction.
- The revenue streams available for CO_2-EOR (other than oil sales), such as carbon finance, have historically been unclear. This has deterred investment, with other emerging opportunities being more attractive in some regions (*e.g.* shale gas). Gaining greater clarity on the commercial business case is essential for widespread uptake of the technology.
- Claiming climate change mitigation benefits for CO_2-EOR operations is likely to create additional complexity and regulatory burdens for operators, in particular the need for MRV. This is a major disincentive to investment. Greater consideration of the appropriate regulatory approach and MRV frameworks for CO_2-EOR with CCS may be warranted to assess whether they can be streamlined to encourage investment.
- Challenges exist in building synchronised value chains (*i.e.* matched CO_2 supply and demand), and proving the suitability of reservoirs for CO_2-EOR in many jurisdictions.

Several technical challenges for CO_2-EOR were also discussed during the workshop, including:

- the need to understand the cap rock/seal properties after repressurisation, to gain assurances that CO_2 would be physically trapped in the reservoir;
- reservoir thickness (>400 feet), in some countries in the Gulf region. This poses problems for gravity override, segregation, fingering and baffles; and
- the potential need for mobility agents to control flow and movement of CO_2 in large reservoirs typical of the Gulf region.

Most participants agreed that specific technical requirements and injection strategies could only be determined following pilot injections.

4. Drivers for CO_2-EOR uptake in OPEC Member countries

During the workshop, the OPEC Secretariat suggested that in OPEC internal meetings on the matter, the concept of CO_2-EOR as a "win-win" for both oil production and GHG emissions reductions has been widely discussed and acknowledged. Several presentations highlighted the potential role that CO_2-EOR could play within the OPEC MCs. In identifying the drivers, participants highlighted a growing urgency to increase output from OPEC MCs, even from the largest fields, given that these countries account for around 30% of global oil production, with their exports forming a vital component of global economic stability. In addition, for most OPEC MCs, petroleum exports typically form over 75% of export earnings, and are therefore critical to domestic economic stability.

As such, participants broadly agreed it appropriate to consider the role that CO_2-EOR could play in the future, both to maintain and increase OPEC MC output and also to enhance recovery factors to ensure the longevity of national hydrocarbon assets. In the context of the latter, it was noted that the general perception 20 years ago was that 30% recovery factors were acceptable, while these days up to 50% is becoming the standard. The role of OPEC MCs in contributing to global climate change mitigation efforts was also highlighted as a key driver.

It was also noted that OPEC MCs acknowledge that tailored approaches are needed in each country, based on specific national circumstances and needs. Mindful of this consideration, a range of views from different OPEC MCs on the drivers promoting CO_2-EOR with CCS within their own jurisdictions were presented, as follows.

4.1 Abu Dhabi

The range of drivers identified included:

- environmental commitments under the United Nations Framework Convention on Climate Change (UNFCCC) and Kyoto Protocol;
- an interest in finding alternative ways to enhance oil production;
- good availability of CO_2 for use in CO_2-EOR within the region. Costs of CO_2 however need to be brought down;
- an interest in increasing the reserves base providing it can be shown to be viable for the reservoirs in the region[7]; and
- a need to find a substitute for natural gas in oil field operations to offset an increasing demand for natural gas in power plants in the region.

Notwithstanding the positive outlooks for CO_2-EOR with CCS in Abu Dhabi in the near-term, the speaker suggested that the failure of projects to materialise in developed countries, namely Norway and Denmark, both countries which are covered by the European Union's emissions trading scheme, highlights the challenges faced in realising these types of projects.

[7] Most remaining oil-producing reservoirs in the region are characterised by difficult and/or tight oil, oil in transitional zones, and volumes of oil in residual oil zones.

4.2 Ecuador

Petroamazonas is considering using CO_2-EOR as part of a suite of measures to raise reserves by around 200 million barrels by 2015. The national oil company has already screened several reservoirs to assess their suitability for CO_2-EOR, and initial findings are considered promising.

4.3 Kuwait

Kuwait Petroleum Company has determined that miscible gas injection could be a suitable technique for around 80% of Kuwait's light crude fields, and in the northern fields preliminary analysis has suggested that CO_2 flooding could bring recovery factors up to 41% and store up to 3.3 $MtCO_2$/year. Challenges mentioned were the availability of low cost CO_2 and determining the best location to start such activities. The speaker suggested that initial estimates indicate that Kuwait could have CO_2-EOR in place by 2025 at the earliest.

4.4 Kingdom of Saudi Arabia (KSA)

The King Abdullah Petroleum Studies and Research Centre (KAPSARC) has undertaken extensive studies of the role of CO_2-EOR with CCS in the country. It identified the main sources of CO_2 to be located in clusters around Dhahran and on the west coast near Jeddah, with most of the storage capacity located in the eastern half of the country. The total area available for storage is thought to cover around 1 million km² of the country's surface area, and storage capacity estimates have been made in the range of 200-2 000 $GtCO_2$. The benefits and challenges relating to CO_2-EOR with CCS deployment are summarised in Table 2 below.

Table 2 • Benefits and challenges of CO_2-EOR with CCS in KSA

Benefits	Challenges
• Only technology suitable to achieving large scale emissions reductions • Existing infrastructure can be reused • EOR has a good fit with industrial uses (*e.g.* use to grow algae for third generation biofuels)	• High cost of the technology • Environmental concerns regarding safety of stored CO_2 • Liability arrangements • Issues relating to international negotiations on climate change • The energy penalty associated with CO_2 capture, transport and storage • Water requirements for CO_2 capture

Source: KAPSARC, 2012

Notwithstanding the challenges highlighted, it was also outlined that Saudi Aramco is considering a CO_2-EOR demonstration project by 2014 using CO_2 captured from a natural gas processing plant. The objective of the pilot is to learn more about the potential of the technology in the KSA, and also to test the range of potential monitoring technologies. To finance the project, Saudi Aramco is considering the role of government support and international climate finance mechanisms such as the CDM. It was noted that the KSA has no need to use CO_2-EOR for many years, with limited urgency to develop the technology.

A range of technical challenges for CO_2-EOR in the Gulf region were also discussed (see Section 3.2), and several other CO_2-EOR with CCS studies were reviewed during workshop discussions, as summarised previously (Table 1).

Box 3 • Key discussion points

- The range of drivers for CO_2-EOR in OPEC MCs varies across the group; for some it is primarily about boosting the reserves base, while for others the drivers are more unique, such as substituting natural gas for pressure maintenance.
- For most OPEC MCs, the commercial business case for CO_2-EOR is generally unclear because of the high cost of capturing and transporting CO_2 to wellheads, low find and discovery and marginal production costs in most cases.
- In the Gulf region, the large oil reservoirs present some specific technical challenges, and the lack of large amounts of low cost CO_2 in close proximity to oil fields is a deterrent to developers.
- Greater understanding of the fate and behaviour of CO_2 in large oil reservoirs is needed to prove the viability of the technique in OPEC MCs.

5. Possible policy interventions to support CO_2-EOR with CCS

In an attempt to address the gaps and barriers relating to CO_2-EOR with CCS, the workshop considered the range of policy interventions that may be required to support evolution of the technology as a "win-win" in coming years. These covered a range of interventions: technical, energy policy, research and development (R&D), and climate policy, all detailed as follows.

- Technical interventions:
  - Promote the increase in net CO_2 stored during CO_2-EOR operations.
  - Establish a standardised suite of MRV and GHG accounting standards for CO_2-EOR projects. In principle, these should apply the same approaches as those that would be applied to a "pure" storage project (*e.g.* in a saline aquifer) in order to ensure a level playing field for the two options.
  - Establish rules that govern site abandonment and long-term stewardship of CO_2 injected and stored as a result of CO_2-EOR operations. It is a moot point whether differential treatment should be applied to CO_2-EOR compared to that of "pure" storage. Given the claims about the lower risks for CO_2-EOR projects compared to "pure" storage, this may warrant further consideration (see Section 2).
  - Establish appropriate health, safety and environmental protection regulations governing CO_2-EOR operations.

- Energy policy interventions:
  - Implement laws and regulations that promote the uptake of CO_2-EOR, perhaps ahead of other competing types of tertiary recovery/EOR technologies.
  - Ensure that energy policies encourage CO_2-EOR as a measure to prolong the economic life of oil reservoirs and to displace more carbon-intensive forms of productions at the margin, rather than just increasing global oil output.

- R&D interventions:
  - Develop R&D programmes to address specific information gaps in the technical understanding of CO_2-EOR. In the context of this workshop, these may be focused on OPEC MCs, for example, relating to thick and segmented reservoirs, and issues of gravity override.
  - Prepare better quantitative estimates of the global benefits that could be achieved through widespread uptake of CO_2-EOR with CCS.

- Climate policy interventions:
  - Establish appropriate and measurable performance goals for CO_2-EOR when integrated with CCS.
  - Ensure that CO_2-EOR is recognised in the portfolio of options for CCS as a climate change mitigation technology.

- Establish appropriate GHG accounting rules that accurately award net emissions reductions that are achieved, or CO_2 emissions that are avoided, through CO_2-EOR with CCS.
- Establish appropriate MRV requirements for CO_2-EOR with and without CCS as an identified co-benefit.

In addition, for many OPEC MCs it is important to consider whether future frameworks for climate change mitigation under the UNFCCC and/or Kyoto Protocol will specifically recognise or promote CO_2-EOR. Considerations include:

- whether CO_2-EOR can and should be eligible under the CDM;
- whether CO_2-EOR could feature in new emerging forms of United Nations-related climate finance (*e.g.* Nationally Appropriate Mitigation Actions, NAMAs); and
- how technology-specific efforts, such as Technology Mechanism, Green Climate Fund or World Bank Climate Technology Funds, will treat CO_2-EOR with CCS.

During the ensuing discussions, the issue of NAMAs was considered further. NAMAs could include unilateral pledges made by non-Annex I countries that would receive international climate finance support from various sources such as those listed above. As such, NAMAs could provide a potential means to incentivise developing countries to develop CO_2-EOR with CCS using co-finance from donors.

On this topic, one participant suggested that for the KSA a more important systemic issue to address is fuel subsidies for industry. The participant highlighted that the KSA is presently considering how the country can manage fuel demand more effectively through better pricing. It was emphasised that whilst climate finance is interesting, the KSA is not only looking at these sources of finance to support climate change mitigation actions, but also more widely at systemic factors such as fuel prices as means to reduce national emissions.

The workshop discussions did not consider in any detail the range of policy options that could support CO_2-EOR with CCS in different jurisdictions and regions.

6. Conclusions

The workshop put into focus the challenges that need to be met for CO_2-EOR to serve as an option to mitigate CO_2 emissions and catalyse CCS deployment. These relate mainly to technology, policy and commercial/economic issues as summarised below.

In terms of the technical challenges in making a CO_2-EOR project a CCS project, different views were heard on the potential to operate CO_2-EOR with CCS. Positive aspects were highlighted (*e.g.* proven geological trap in which to retain fluids), as were negative aspects compared to standard CO_2-EOR operations (*e.g.* increased risk of containment failure, greater MRV requirements). Other technical challenges were identified specifically for the Gulf region relating to the type of reservoirs present (*e.g.* thickness and segregation issues).

Discussions also highlighted commercial and economic issues, such as uncertainty over project economics and the value proposition of pursuing CCS in conjunction with CO_2-EOR, the challenge of building complex CO_2 value chains, and the increased regulatory burden associated with operating the project as a CCS project, especially for MRV and over the long term. On the other hand, suggestions were made that, at least in some areas, CO_2-EOR needs CCS in order to reduce the costs of CO_2 supply. It was also highlighted that permitting of CO_2-EOR with CCS was likely to be more straightforward than for “pure” CCS projects. Suitable legal regimes requiring less modification are established in oil-producing provinces, as compared to regions with no history or experience of oil production contemplating “pure” CCS.

Overarching policy issues were also brought into focus, covering a range of potential interventions that could support the uptake of CO_2-EOR with CCS, including technical (*e.g.* MRV considerations), energy-related (*e.g.* promotion of the use of CO_2 for tertiary recovery), climate-related (*e.g.* the role of carbon finance in support CO_2-EOR) and R&D (*e.g.* enhanced research on reservoir engineering for CO_2 in large reservoirs).

In summing up, the co-chairs made salient points about the future for CO_2-EOR. In their view, the following conclusions could be drawn:

- It is possible to see the potential for a “win-win” outcome, but it is not as straightforward as perhaps previously believed.
- There are many technical challenges, and while many lessons have been learned from the USA, it is difficult to apply without infrastructure.
- The *Master Gas Gathering System* of the KSA provides an interesting analogue to this problem. Without its evolution, the petrochemical industry in Saudi Arabia would never have been able to evolve, and similar parallels can be drawn for CO_2-EOR in the region. A common carriage system could potentially create a market for CO_2.
- The costs of CO_2-EOR are a challenge for investment, particularly in comparison with tried and tested alternatives. If the focus continues to be on short-term gains, the longer-term opportunity and potential for CO_2-EOR in the regions such as the Gulf may be lost.
- Government intervention seems essential. As elements such as a common carriage network constitute a public good, the role of policy will be critical for success.

Further analysis of the issues raised is suggested as means to develop appropriate policy to address the various issues hampering CO_2-EOR deployment around the world.

Acronyms and abbreviations

CCS	carbon capture and storage
CDM	clean development mechanism
CO_2	carbon dioxide
CO_2-EOR	carbon dioxide-enhanced oil recovery
GHG	greenhouse gas
IEA	International Energy Agency
IEAGHG	International Energy Agency Implementing Agreement on Greenhouse Gas Research and Development Programme
IPCC	Intergovernmental Panel on Climate Change
IR Iran	Islamic Republic of Iran
KAPSARC	King Abdullah Petroleum Studies and Research Centre
KSA	Kingdom of Saudi Arabia
MC	Member country
MRV	measurement, reporting and verification
NAMA	nationally appropriate mitigation action
OOIP	original oil in place
OPEC	Organization of the Petroleum Exporting Countries
KPC	Kuwait Petroleum Corporation
RF	recovery factor
ROZ	residual oil zones
R&D	research and development
UAE	United Arab Emirates
UNFCCC	United Nations Framework Convention on Climate Change
UNIDO	United Nations Industrial Development Organization
USA	United States of America
US EPA	United States Environmental Protection Agency
WAG	water-alternating-gas

Units of measure

$GtCO_2$	gigatonnes of CO_2
Mbbl	million barrels
MMscfd	million standard cubic feet per day
Msm^3	million standard cubic metres
$MtCO_2$	million tonnes of CO_2

References

Barghouty, M. (2012), *Framework for Carbon Capture and Storage Program in the Kingdom of Saudi Arabia*, presentation at IEA-OPEC workshop on CO_2-enhanced oil recovery with CCS, Kuwait City, February.

Environment Canada (2012), *National Inventory Report: Greenhouse Gas Sources and Sinks in Canada 1990-2010, The Canadian Government's Submission to the UN Framework Convention on Climate Change,* Part 1, http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/6598.php

IEAGHG (International Energy Agency Implementing Agreement on Greenhouse Gas Research and Development Programme) (2002), *Opportunities for Early Application of CO_2 Sequestration Technology*, Report PH4/10, IEAGHG, Cheltenham, Gloucestershire, United Kingdom.

IPCC (Intergovernmental Panel on Climate Change) (2005), *Carbon Dioxide Capture and Storage*, Cambridge University Press, Cambridge, UK.

UNIDO (United Nations Industrial Development Organization) and Advanced Resources International (2011), *Global Technology Roadmap for CCS in Industry: Sectoral Assessment CO_2 Enhanced Oil Recovery*, www.unido.org/fileadmin/user_media/Services/Energy_and_Climate_Change/Energy_Efficiency/CCS/EOR.pdf

US EPA (United States Environmental Protection Agency) (2012), *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2010*, US EPA, Washington D.C., USA, http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/6598.php

Zakkour, P. and G. Cook (2010), *CCS Roadmap for Industry: High-purity CO_2 sources,* Sectoral Assessment-Final Draft Report, www.unido.org/fileadmin/user_media/Services/Energy_and_Climate_Change/Energy_Efficiency/CCS/High%20Purity_FINAL%20DRAFT.pdf

Annex I Workshop programme

Programme
IEA – OPEC CO_2-EOR Workshop
Kuwait City, 7 – 8 February 2012

DAY 1	
08:30-09:30	**Session I: Opening and keynote addresses** **Welcoming and safety moment** **Opening speeches** -Kuwait: Bader Naser Al-Khashti, Managing Director, Research & Development and HSE, Kuwait Petroleum Corporation -IEA: Ambassador Richard H. Jones, Deputy Executive Director, IEA -OPEC : Dr. Hasan M. Qabazard, Director, Research Division, OPEC **Introductory video: The history of oil and gas in Kuwait** **Co-chairs introduction, workshop programme:** Fahad Nouri, Manager, R&T Group, Kuwait Oil Company **Workshop theme, objectives and expected outcome:** Ambassador Richard H. Jones, Deputy Executive Director, IEA
10:00-12:00	**Session II: EOR techniques and why CO_2-EOR** **Why CO_2-EOR?** Malcolm Wilson, Chief Executive Officer, PTRC, Canada: “Why CO_2-EOR?” **From CO_2-EOR to CCS** Mike Godec, Vice President, Advanced Resources International, USA: “Prospects and challenges of combining CO_2-EOR with storage” **The economics of combining CO_2-EOR with storage** Klaas van’t Veld, Associate Professor in Economics, Center for Energy Economics and Public Policy, University of Wyoming, USA: “The economics of combining CO_2-EOR with storage” **Discussion and Q/A**
13:30-15:00	**Session III: CO_2-EOR storage projects worldwide** **Lessons learned from existing, cancelled and planned projects** -Arafat Al Yafei, CO_2/N2 Development Manager, ADNOC, UAE, “ADNOC: Towards CO_2” -Malcolm Wilson, Chief Executive Officer, PTRC, Canada, on behalf of Cenovus (Weyburn) -Richard John Earl, Senior Project Engineer, Maersk Oil -Eva Halland, Project Director, Norwegian Petroleum Directorate: "Perspectives and experiences in the application of CO_2 for Enhanced Oil Recovery on the Norwegian Continental Shelf"

15:30-16:30	**Session III: CO_2-EOR storage projects worldwide (continued)** **Lessons learned from existing, cancelled and planned projects** -Xavier Maasarani, New Business Development Manager, Middle East and North Africa, Shell -Fayçal Selama, Sonatrach, Algeria: "Algerian Experience on CO_2 Storage in In Salah" -Huda Al Enezi, Senior Reservoir Engineer, Kuwait, "Current technical activities on EOR-CO_2" **Discussion and Q/A**
16:30-17:30	**Session IV: The role of CO_2-EOR in IEA analysis** **Review of CO_2-EOR in IEA analysis** Paul Zakkour, Director, Carbon Counts **CO_2-EOR in ongoing and future IEA analysis** -Sean McCoy, Analyst, IEA -Wolf Heidug, Senior Analyst, IEA **Discussion and Q/A**
DAY 2	
09:00-09:15	**Co-chairs recap on day 1 and overview of day 2**
09:15-10:45	**Session V: Opportunities for CO_2-EOR and storage** **Overview of CO_2-EOR regional potential** Paul Zakkour, Director, Carbon Counts **Case studies: exploring opportunities for CO_2-EOR in OPEC Member Countries** -Francisco Paz, Operations Manager, PETROAMAZONAS EP, Ecuador: "EOR's strategy at Petroamazonas EP" -Maryam Khosravi, EOR Researcher, R&D, National Iranian Oil Company, Iran: "EOR techniques in Iran"
11:00-12:30	**Session V: Opportunities for CO_2-EOR and storage (continued)** **Case studies: exploring opportunities for CO_2-EOR in OPEC Member Countries** -Abduljaleel Mohammad Hamad Alrobaiei, Senior Chief Engineer, Ministry of Oil, Iraq: "EOR in the Iraqi oil industry" -Misfera Al Qahtani, Petroleum Engineer, Kuwait, "Carbon management strategy for CO_2 emission and potential use for EOR or CCS -Murad Barghouty, Project Leader, KAPSARC, Saudi Arabia: "KAPSARC's effort in developing CCS implementation strategies for KSA"
14:00-16:00	**Session VI: Closing session** Co-chairs: -Fahad Nouri, Manager, R&T Group, Kuwait Oil Company -Richard H. Jones, Deputy Executive Director, IEA -Hasan M. Qabazard, Director, Research Division, OPEC **Summaries from previous sessions** **General discussion** **Concluding remarks**

Annex II Workshop participants list

IEA – OPEC CO_2-EOR Kuwait Workshop

JW Marriott Hotel, Kuwait City

7th – 8th February, 2012

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