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Government promotion of large scale coal fired CCS demonstration projects and a case for anthropogenic CO_2 application for EOR within the United States

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Abstract

Due to issues concerning global warming, Mitsubishi Heavy Industries Ltd. (MHI) and Kansai Electric Power Co., Inc. (KEPCO) have jointly developed a post combustion flue gas CO_2 capture system (called the KM-CDR Process), using a proprietary solvent, which can be applied to fossil fuel fired power stations. The main advantage of this system is the solvent efficiency, enhanced by an easily maintained equipment process. Data collected from pilot and demonstration plants using both natural gas and coal as primary fuels has further enhanced our understanding of the effects of these flue gas streams for CO2 capture. Combined with an expanding international delivery record, significant larger scale (3000 tpd CO_2 capture plant) engineering design activities, and ongoing R&D projects, the coal fired power utility sector will, in the very near future, be offered a workable solution to address CO_2 emissions. The use of captured high purity CO_2 becomes financially attractive if executed in enhanced oil recovery (EOR). EOR through means of CO_2 injection is seen, by many energy analysts, as a major technology that will contribute to maximizing oil recovery in the near future. Given recent government policy trends, in many industrialized nations, combined with the emergence and expansion of global carbon markets, the possibility of future wide scale implementation of CO_2 capture for the power utility sector is realistic. However governments must play a more active role by encouraging economic incentives for CCS technologies and promotion of medium to large scale CO_2 capture demonstration projects. These types of demonstration projects will further increase our confidence in the larger scale impacts and efficiencies, leading to cost reduction and when the CO_2 product is utilized for application in EOR it will further offset costs associated with CO_2 capture. Ultimately this will lead to the implementation of large commercial scale projects generating significant side stream profit revenue, securing important domestic energy reserves and reducing CO_2 emissions, thus alleviating the potentially harmful impacts of global warming.

Keywords;

CO_2 capture technology; flue gases; fossil fuels; KM-CDR Process; energy security; enhanced oil recovery; global warming.

Introduction

The recent highly publicized debate concerning global warming augmented by popular mass media releases such as Al Gore's 'An Inconvenient Truth', the UK Governments' 'Stern Review on the Economics of Climate Change' and the Intergovernmental Panel on Climate Change (IPCC) fourth assessment report titled "Climate Change 2007", have raised awareness of this important issue to unprecedented levels. Furthermore these forums have brought the issue of climate change into the homes and businesses of the global community where it is being enthusiastically discussed and debated. The escalation of this discussion has coincided with the warmest El-Niño year (2006/07) on record in the United States (NOAA, 2007) and, for many, this has ingrained the future reality of a world subject to climate change. Combined with this environmental element has come an economic realization that the days of cheap energy supplies are over. Record high prices for natural gas and oil in the past year have forced many governments to scrutinize and adjust their energy policies.

The rapid economic and industrial expansion of several, large, developing countries is leading to increasingly higher demand for several hydrocarbon fuel resources. A dilemma resulting from this phenomenon is this; many energy analysts believe that the world's demand for energy is still 'young' whilst they also concede that many of the world's energy resources are becoming depleted and more expensive. The beginning of the 21st century has witnessed significant GDP growth in many developing nations and the emergence of an 'energy-hungry' middle class. The undeniable truth is that increased economic growth is equal to increased energy consumption which ultimately leads to increased emissions of CO_2 – the principal greenhouse gas (GHG) responsible for global warming. According to the '*Stern review*', the former World Bank Chief Economist Nicholas Stern, said climate change could result in an economic upheaval on scale with the Great Depression of the 1930s and that a failure to tackle climate change will be "the greatest market failure we have ever seen" (Stern 2006). The scientific evidence supporting climate change as a serious and urgent issue is now compelling. Stern remarked that strong action to reduce GHG emissions throughout the world is needed. This will help to reduce the risk of very damaging and potentially irreversible impacts on ecosystems, societies and economies.

However the authors believe there are a number of solutions which can allow us to continue using critically important fossil fuels in an economical and environmentally friendly way. For this to happen we must move past pre-conceived ideas in which we consider CO_2 to be a waste gas of no value. On the contrary, highly purified CO_2 is a valuable product and can be utilized in a number of existing and developing industries. If we consider CO_2 as a commodity item and part of a distinct value chain, several industries may rapidly develop creating drivers for the expansion and advancement of a CO_2 based market place, as indicated in Fig. 1.

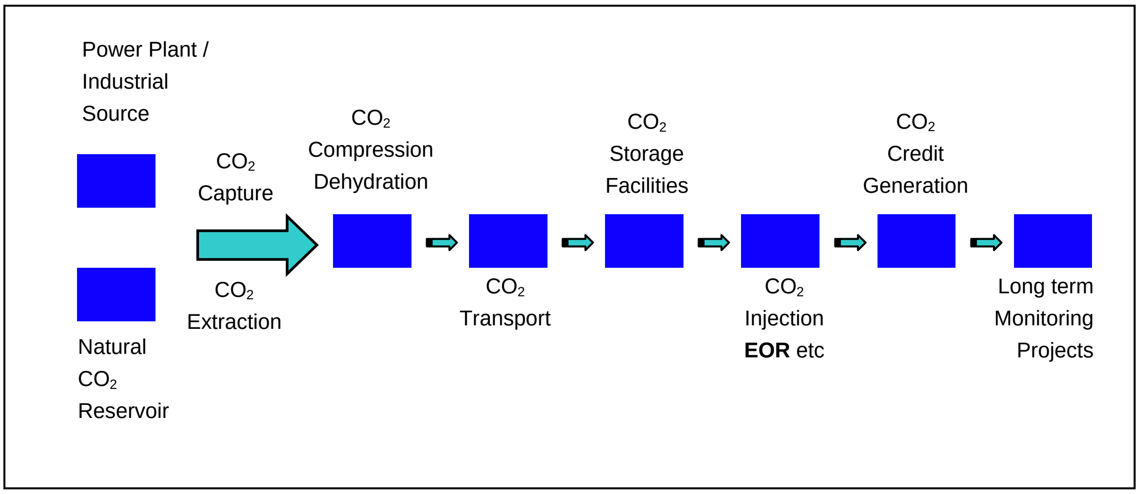

Fig. 1 CO_2 as a future commodity, value chain and future investment opportunities.

For their part, the European Union Emission Trading Scheme (EU ETS), Kyoto Protocol and associated flexible mechanisms such as the Clean Development Mechanism (CDM), Joint Implementation (JI) and international carbon trading are providing the necessary drivers and framework leading to the establishment of a demand-supply orientated market arrangement. However, if we are to continue using low cost, abundant and stable fuels such as coal for energy generation, governments must further facilitate this process by providing economic incentives to companies supportive of carbon capture and sequestration (CCS) technologies. A blueprint published by the Massachusetts Institute of Technology (MIT) in 2007 states that CCS is the critical enabling technology allowing significant reduction in CO_2 emissions while allowing fuels such as coal to meet future energy needs. The MIT authors comment further that the US Government should provide assistance only to coal projects with CO_2 capture in order to demonstrate technical, economic and environmental performance. The authors of this paper agree and wish to see the rapid deployment of medium-large scale CCS demonstration projects to assist in our further understanding of the larger scale efficiencies and impacts of these technologies.

MHI understands that in its current form, CO_2 capture and sequestration is not economically viable and it necessitates the induction of economic incentives in order to drive these projects into commercial development and implementation. Since the UNFCCC has not yet ruled in favor of CCS methodologies as a CDM project type (although it is expected some time in the near future), this leaves only one economically viable option; enhanced fossil fuel recovery such as oil and natural gas (respectively known as EOR and ECBMR).

Oil accounts for approximately 35% of global energy production (ECOAL 2006) and, due primarily to rapid growth in vehicle ownership in developing nations and industrial energy production processes, demand for oil and oil based products is expected to grow. The price of oil in 2007 has lingered around the US $60 per barrel mark and is not widely predicted to drop below US $50 in the near future. For these reasons, and others, MHI has identified EOR as a developing market capable of utilizing anthropogenic CO_2 sources.

In the US, oil is recovered from reservoirs utilizing several extraction methods and the most advanced of these is termed ‘tertiary recovery’ or gas injection. This method can increase oil recovery in two ways; (1) gases such as natural gas, nitrogen, or carbon dioxide expand in a reservoir to push additional oil to a production well bore, or (2) gases dissolve in the oil, thus creating miscible conditions whereby the oil and the gas assume a single phase, leading to a decrease in the oil viscosity and an improved flow rate to the well bore. The EOR technique attracting most market interest is CO_2 gas injection which has been used on a commercial scale mostly in North America. A report issued to the US Department of Energy in February 2006 estimated that CO_2 EOR could result in the additional recovery of up to 83.7 billion barrels of oil within the continental US (U.S.D.O.E 2006).

Until recently, most of the CO_2 used for EOR projects has come from naturally-occurring reservoirs. But new technologies are being developed to capture CO_2 from industrial sources in locations where naturally occurring reservoirs are not present. The post combustion CO_2 flue gas capture process developed by MHI is one of the most technologically advanced and efficient methods currently available in the commercial market place.

The key to large scale implementation of CO_2 EOR is the advancement of governmental support for CCS technologies and of those companies which promote them. MHI has participated in global warming mitigation R&D, relating to CO_2 capture from flue gas streams of fossil fuel fired power stations, over the past 17 years. Combined with these extensive R&D programs, MHI has also pursued, with success, commercial application of CO_2 capture using natural gas fired boilers and steam reformers. The next step is to apply this proven and trusted technology process to a medium-large scale CO_2 capture demonstration plant utilizing a coal fired boiler, where by the captured CO_2 (around 500-1000 tpd) can be applied in EOR thereby offsetting the costs associated with CO_2 capture and generating a potential profit stream. This will lead to increased confidence in the larger scale impacts and efficiencies of CCS, risk mitigation, cost reduction through experience and, most importantly, will provide incentive for larger scale investment by financial institutions who are showing strong interest in carbon based markets.

This manuscript firstly outlines MHI's proprietary, CO_2 capture process. We then provide an overview of EOR with special reference, via a case study, to its potential wide scale implementation in the US. Lastly we comment on the governments' role in supporting CCS technologies to incentivize widespread commercial scale investment by industry.

MHI's CO_2 Capture Technology: The KM-CDR Process

General Description

The evolution of MHI's CO_2 capture experience incorporates a comprehensive combination of (a) small scale (10 tpd) demonstration testing of CO_2 capture from coal fired flue gas streams at a plant located in Matsushima, Japan (>4000 hours operational experience). This has been critical in progressing our understanding concerning the effects of coal fired flue gas stream impurities on the KM-CDR Process and in helping to develop countermeasures for each of these; (b) long term pilot scale (2 tpd) testing of MHI's CO_2 capture process from natural gas fired flue gas streams (>16 years experience) which has refined the KM-CDR Process and; (c) an expanding international commercial delivery record summarized below;

① Malaysia: 200 tpd CO_2 capture from a natural gas steam reformer to produce urea. On stream since 1999 (8 years experience).

② Japan: 330 tpd CO_2 capture from a natural gas and oil fired boiler for 'general use' products. On stream since 2005 (2 years experience).

③ India: 2 separate 450 tpd CO_2 capture plants utilizing natural gas to produce urea. On stream since December 2006.

④ United Arab Emirates: 400 tpd CO_2 capture plant utilizing natural gas to produce urea. FEED completed and due for start-up in 2008.

⑤ China: 800 tpd CO_2 capture from a natural gas steam reformer to produce methanol. FEED completed.

MHI's flue gas CO_2 recovery plant utilizes the KS-1 solvent as the CO_2 absorbent. Application of the KS-1 solvent and KM-CDR Process will lead to mean low energy consumption, extended solvent life with near infinitive degradation in comparison to other amine-based type processes.

The CO_2 recovery plant consists of three main sections (Fig. 2);

① Flue gas cooling
② CO_2 recovery
③ Solvent regeneration

Following the CO_2 recovery process outlined above, the gaseous, CO_2 rich stream is directed to a compression and dehydration unit prior to pipeline transport and client delivery.

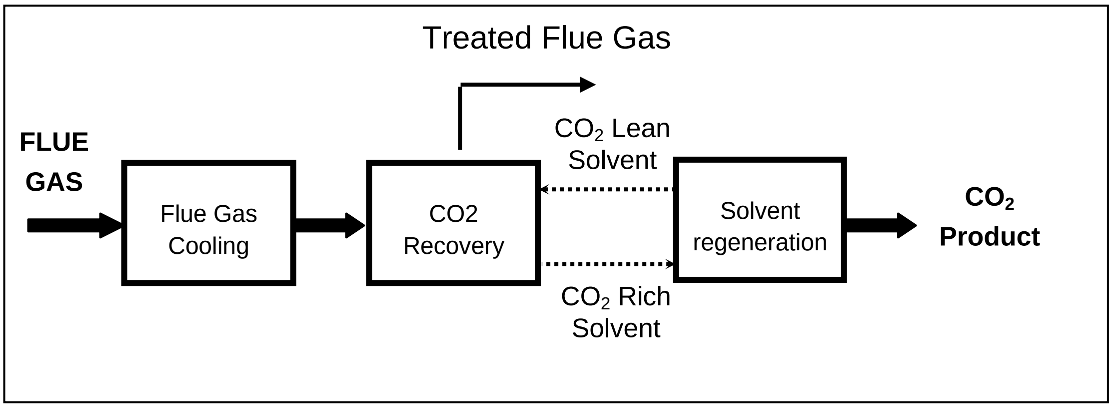

Fig. 2 Typical process configuration showing the three processes of a CO_2 recovery plant.

The CO_2 rich solvent is collected from the CO_2 Recovery unit and is then directed to the Solvent Regeneration unit where it is subject to steam-stripping which separates the CO_2 resulting in regeneration of the solvent. The lean solvent is then is reintroduced into the CO_2 Recovery unit for CO_2 absorption and the process continues within a closed cycle.

Flue Gas Cooling unit (Quencher)

The flue gas temperature is generally too high to feed directly into the CO_2 Absorber. Therefore, the hot flue gas is cooled by the Flue Gas Water Cooler (FGWC) prior to entering the CO_2 Absorber. Lower flue gas temperatures are preferred to increase the efficiency of the exothermic CO_2 absorption reaction and to minimize KS-1 solvent loss due to gas phase equilibrium increases. The optimum temperature range for CO_2 recovery is between 35-45°C however is flexible in consideration of other factors such as water utility requirements and availability.

The FGWC serves two purposes. It is designed and constructed to (a) sufficiently cool the flue gas via direct contact with water and (b) further remove various impurities such as vaporised limestone slurry, dust and halogens. The FGWC is a tower packed with a dimensionally structured packing matrix to minimize pressure loss and reduce load on the Flue Gas Blower. The flue gas is introduced into the bottom section of the tower, and it rises upwards through the structured packing. The cooling water will be evenly distributed from the top of the packing material, where the flue gas and the cooling water come into direct contact thus facilitating the cooling process.

CO_2 Recovery unit (Absorber)

The CO_2 Absorber has two main sections, the CO_2 absorption section (bottom section), and the treated flue gas washing section (top section). The conditioned flue gas from the Flue Gas Water Cooler is introduced into the bottom section of the CO_2 Absorber. The flue gas progresses upward through structured, stainless steel packing material while the CO_2 lean KS-1 solvent (lean solvent) is distributed evenly from the top of the absorption section onto the packing material. The flue gas comes into direct contact with the KS-1 solvent at the surface of the packing material, where CO_2 in the flue gas is absorbed into the solvent. The flue gas then moves upward into the treated flue gas washing section, located in the top section of the CO_2 Absorber tower. This section is similar to the Flue Gas Water Cooler, where the flue gas comes into direct contact with water to remove vaporized KS-1 solvent and further cool the flue gas in order to maintain water balance within the system. The treated flue gas then exits the top section of the CO_2 Absorber to the Stack. Meanwhile, the CO_2 rich KS-1 solvent (rich solvent) is collected from the bottom of the Absorber and is directed to the CO_2 Regeneration unit for steam stripping.

Solvent Regeneration unit (Regenerator or Stripper)

The Rich Solution Pump transfers rich solvent from the bottom of the CO_2 Absorber to the Lean/Rich Solution Exchanger so that the rich solvent can be heated using the lean solvent from the bottom of the CO_2 Stripper. The heated rich solvent is then introduced into the upper section of the CO_2 Stripper, where it will come into contact with stripping steam of around 120°C. The rich solvent is then steam-stripped of its CO_2 content through the packing material of the CO_2 Stripper, and is converted back into lean solvent. Steam is produced by the Stripper Reboiler, which uses LP steam to boil the lean solvent. The lean solvent at the bottom is then directed to the Lean Solution Pump through a Lean/Rich Solution Exchanger. The Lean Solution Pump forces this lean solvent to the Lean Solution Cooler, where it is cooled to the optimum reaction temperature of approximately 40°C before being reintroduced to the top of the absorption section of the CO_2 Absorber unit.

Solvent reclaiming (intermittent operation)

A reclaimer unit is required in order to eliminate heat-stable salts (HSS) from the solvent. When the HSS content of the solvent has reached preset limits, the reclaimer must be operated to boil down the solvent and concentrate the HSS so that it forms a residue that can be discharged. The expected reclaimer operation frequency will be extremely low compared with other types of amine-based solvents. This is due to the low degradation properties of the KS-1 solvent.

Effects of SO_2 – additional flue gas scrubbing may be required

Significant amounts of sulphur may exist in flue gas, especially from coal-fired boilers that utilize high sulphur content coal. Impurities such as SOx and NOx can react with the absorption solvent upon contact. Generally, SOx is more potent in terms of acidity, and the concentration of SO_2 within the flue gas must be substantially lowered prior to induction into the CO_2 recovery plant. This can be achieved through use of an additional deep flue gas desulphurization (FGD) process which can be retrofitted as a separate flue gas pre-treatment component or it can be constructed within the quencher unit of the CO_2 recovery plant and will depend on the SO_2 concentration at the stack.

The high temperature of the flue gas must be reduced to approximately 35 to 45°C, depending upon the desired utility requirements due to the exothermic CO_2 absorption reaction. Low temperature flue gas will positively affect the reaction equilibrium, while high temperatures will shift the equilibrium so as to lessen the amount of CO_2 bonding per unit of KS-1 solvent. Primary impurities of concern are SOx, NOx, dust and suspended particulate matter (SPM). The respective impurity concentrations and the flue gas temperature depend upon the source of the flue gas. Clean-burning, natural gas typically has low concentrations of CO_2 and impurities, while coal-fired boiler flue gas usually contains higher respective concentrations. Mono ethanol amine (MEA) based solvents are adversely more affected during the CO_2 capture process, degrading rapidly and leading to high consumption whereas KS-1 is significantly more resilient. However the aforementioned compounds can still react with the KS-1 to form HSS and other reaction by-products that reduce the concentration of available solvent for CO_2 recovery. Therefore, the flue gas impurity composition should be minimized, thus reducing solvent loss and lessening the frequency of reclaiming operations. Furthermore the flue gas temperature should be reduced to facilitate and further promote the CO_2 absorption reaction mechanism.

MHI has a long standing commercial history and has developed an extensive suite of FGD technologies, utilizing the limestone-gypsum process which can accommodate the individual requirements of each power plant. Accordingly MHI has a widespread presence in both domestic and international markets where it offers high efficiency (>98%), SOx removal, FGD equipment.

Requirement for a medium-large scale demonstration plant

In recognition that MHI has completed extensive R&D programs and to address flexibility issues, which will offer further robust incentives for post combustion CO_2 capture using absorption technologies, we believe it is critically important to progress into the medium-large scale (500-1000 tpd) demonstration phase for coal fired flue gas streams. This will further advance our understanding of the larger scale impacts and efficiencies regarding the interface between the power plant and the CO_2 capture plant, thus providing an established foundation for future wide-scale commercial implementation.

Furthermore coal fired CO_2 capture on a medium scale and application for the EOR market will help offset associated costs and provide an additional profit stream. MHI's comprehensive experiences and proven delivery record for both CO_2 capture and large capacity FGD plants means that we are well positioned to remain at the forefront of post combustion CO_2 capture technology and to pioneer the way for its application in large, commercial-scale, coal fired power stations.

Why the need for CO_2 EOR?

Recent developments around the world including; (a) increased global energy demand, (b) the economic and industrial expansion of nations such as China and India, (c) the evolution of carbon markets, (d) increased R&D in carbon sequestration, geological storage site selection and reservoir modeling, combined with record-high crude oil prices is rapidly creating attractive market conditions for CO_2 EOR implementation. It is also apparent that commercial application of alternative energies is still a long way off in the future and that we will continue to rely on the use of hydrocarbon fuels, such as oil, for the foreseeable future. Accordingly a question asked by many people is this; 'When will the oil run out?' This simple yet disturbingly complex question has stimulated broad debate within the petroleum industry and upon examination of production data for the majority of the world's large oil fields (with the exception of Saudi Arabia) it certainly appears that production has peaked and is now in decline. This is a theory supported by the Association for the Study of Peak Oil and Gas (ASPO) and if such a phenomenon is true, then ultimately the future supply of crude oil can only diminish which in turn will stimulate price increases. For countries like the US, where production declines are categorical and undisputed, the necessitation of EOR is expected to be paramount. This will prolong the life of existing oil fields and corresponding capital equipment and ultimately secure important, long term energy reserves upon which US industry is most dependent.

The EOR process

There are typically three stages which lead to the recovery of oil from a reservoir. The first is termed ‘primary recovery’ where oil is retrieved under natural flow or by using a pump or gas lift. ‘Secondary recovery’ uses an external agent (usually water or gas) to increase the pressure of the reservoir and force the oil to the well head. ‘Enhanced or tertiary recovery’ is the last of these processes and is usually undertaken in the latter years of an oil reservoirs’ production life after primary and secondary recovery has ceased. One of the most advanced and commercially applicable forms of tertiary oil recovery utilizes CO_2 gas injection and this technique constitutes a significant portion of current market interest.

The most cost effective form of capturing CO_2 in sufficient volumes for application in EOR is from a fixed point source such as a power station. Following removal from the flue gases using a proven and commercially demonstrated method such as the KM-CDR Process, the high purity (>99.9%) CO_2 is then compressed, dehydrated and transported under pressure via a pipeline to an oil reservoir injection site. The US is well positioned for application of anthropogenic CO_2 EOR given the number of highly suitable oil reservoirs (DOE estimates CO_2 EOR potential in 23 States) in advanced stages of production, the large number of CO_2 emission sources and the existing CO_2 transport infrastructure, technology and expertise. Once the CO_2 is injected into an oil reservoir, a miscible condition occurs where the gas and the oil is freely mixed under pressure, thus lowering the viscosity of the oil and allowing it to flow to the well head, resulting in enhanced recovery (Fig. 3). Typically CO_2 EOR involves injecting CO_2 and water alternately. EOR requires the use of high purity CO_2 and since MHI’s flue gas CO_2 recovery process typically produces CO_2 with a composition base greater than 99.9%, it is highly applicable for this activity.

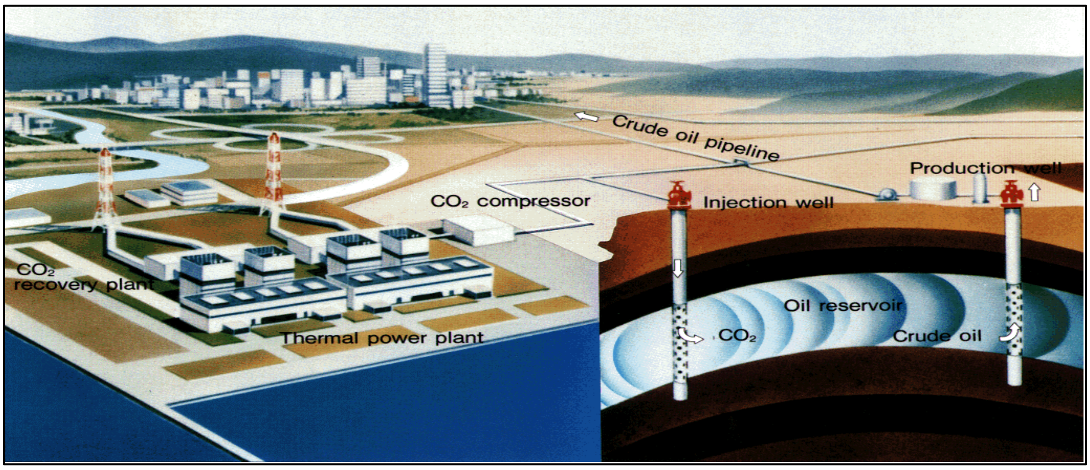

Fig. 3 Concept diagram showing the application of CO_2 EOR following capture at a fossil fuel fired power plant.

EOR case study – the United States

The US has been at the forefront of EOR activities for several decades and accordingly provides a useful case study for the future application of anthropogenic sources of CO_2 in this industry. Additionally, given recent trends in government policy regarding the possible inception of formal CO_2 regulation, it is plausible to assume that CO_2 can be supplied from the power utility sector to the oil companies for use in this activity. The US has just 5% of the world's population but consumes about 25% of the world's oil and gas (Simmons 2006). The US domestic oil production is in decline with statistics showing that oil production peaked in 1970, at 10.3 million bbl/d, and that the US is now the world's largest energy importer, with crude oil imports of 10.1 million bbl/d. Furthermore the US has the most number of EOR projects and correspondingly the largest EOR based production which was estimated at 14 700 bbl/d in 2004 (De Reus 2005). This has led to the establishment of businesses, infrastructure and technical know how specific to this field. However all of the current CO_2 EOR projects in the US utilize naturally occurring CO_2 which is transported via pipeline from reservoirs and no industrial CO_2 capture processes have yet to be implemented. The authors believe that the continental US is a developing and potentially lucrative market for wide scale CO_2 EOR for the following reasons;

- Large Number of oil fields (OOIP: 582 B bbl) in advanced production stages
- Declining production from existing recovery methods
- Highly suitable regional CO_2 storage sites
- EOR prolongs the life of oil fields and capital equipment
- Investment opportunities – CO_2 value chain – other stakeholders will enter the market
- CO_2 transport and injection technology is mature and available
- Regional reliance on 'cheap', local fossil fuels (coal) for power generation
- Corporate/Social responsibility – decreased environmental opposition
- Recent government shift regarding climate change policy
- Government support through tax incentives for efficient coal use
- Highest number of CO_2 emission sources in the world >2,000 (100+ kt CO_2/year)
- Emission sources located close to suitable oil reservoirs
- Expected future inception of wide scale CO_2 regulation
- Government endorsement of zero CO_2 emission technology
- CO_2 capture costs will decrease with experience
- Global carbon trading markets will continue to develop - further incentive
- Future increase in energy demand leading to greater CO_2 emissions

The role of governments in promoting CCS technologies

Issues surrounding CCS projects, such as CO_2 EOR, are complex and it is important to convince policy makers and the wider community that through proper planning and due diligence, large scale CO_2 EOR can help to reduce CO_2 emissions, whilst also securing important energy reserves by enhancing the recovery of specific fuels such as oil and natural gas. Site selectivity is critically important in this process and the CDM Executive Board has identified a range of issues which need to be addressed in order to gain suitable confidence in this activity as a proposed CDM methodology type. However many authors agree (Stott and Hatano 2005; MIT 2007) that CCS will become an important tool in the fight against climate change and that support for a wide range of CCS projects types, such as CO_2 EOR, is required to realize this aim. This is where the role of the government is significantly important. Government policy plays a defining role in the strategic direction of private organizations and influences the way they invest their money. However recently there has been policy shifts in several industrialized nations in relation to energy use and the environment. A poignant example which underpins this shift was observed in the US mid-term election (2006) in which previously conservative Senators, who continually blocked efforts to address GHG emissions in the US, were overwhelmingly defeated by their more environmentally–friendly Democratic counterparts. A report released in March 2007 by MIT specifically discusses the issues of coal use and the necessity for larger scale demonstration plants to test a variety of CCS technologies. The US Congress responded to this release by stating that the report could influence national policy. The Senate’s Energy Committee Chairman (Jeff Bingaman) went on to say that “this landmark report comes at a very opportune time. Its recommendations will carry a lot of weight here in Congress, as we deal with the important issues surrounding the future use of coal” (Point Carbon 2007). The release of the “National Carbon Dioxide Storage Capacity Assessment Act of 2007” is another positive step toward providing the necessary framework to facilitate CCS project implementation and several major US power companies have openly expressed their support for regulation leading to caps on CO_2 emissions whereby commercial scale CCS will allow them to continue using cheap fossil fuels such as coal into the future.

For its part, the US Department of Energy has contributed by creating an exclusive road map for energy and a comprehensive proposal to include CCS projects as part of the mainstream energy use model by stating that “we must consider that the current energy system could be modified significantly to make an economical capture and sequestration system possible” (U.S.D.O.E 2005). The Carbon Sequestration Regional Partnerships supported by DOE is engaged in R&D programs focusing on CCS technologies. The partnerships consist of 3 distinct phases outlined in the Carbon Sequestration Atlas of the United States and Canada produced by DOE and the

National Energy Technology Laboratory (U.S.D.O.E 2007). The final deployment phase (phase 3) consists of several, large volume sequestration tests designed to demonstrate injectivity sensitivity and to show that sequestration sites are capable of storing CO_2 safely, for a long period which additionally seeks to strengthen community acceptance of CCS. However to achieve these aims, a number of larger scale CO_2 capture demonstration plants (500-1000 tpd [70-100 MW]) must be built utilizing current commercial technology. It is our opinion that currently there is too much emphasis being given to developing technologies which are still well in their infancy in terms of R&D and not enough support is being extended to existing CO_2 capture technologies. As the authors of the MIT report concluded "Key changes must be made to the current Department of Energy research development and demonstration program to successfully promote CCS technologies. The program must provide for demonstration of CCS at scale and a wider range of technologies should be explored" (MIT 2007). The authors of this paper believe MHI is well qualified and positioned to be part of this suite of larger scale demonstration projects. The completion of long term R&D activities and the commercial application of the KM-CDR process using other fuel sources, suggests MHI is strategically positioned to employ this experience to larger coal fired flue gas streams. MHI has completed small scale (10 tpd) demonstration testing using coal as the primary fuel, from which unrivaled experience and expertise concerning the impacts of the corresponding impurities on the CO_2 capture process has been gained. Accordingly MHI is now eager to dramatically scale up this experience to larger volumes of coal fired flue gas and believe this will serve to demonstrate that post combustion CO_2 capture from coal fired power stations and application in EOR is realistic in the short term, leading to an economically viable method of securing energy, reducing CO_2 emissions and helping to prevent global warming.

Conclusions

The climate change debate is continuing to gain wide exposure through the media and other sources around the globe. This is leading to greater awareness of the related issues and is facilitating advanced discussion both in domestic and international communities. Conjecture and uncertainty surrounds the exact impacts of conducting 'business as usual' with regards to global CO_2 emissions and the long term effects of climate change but can we afford to take a blasé approach with regards to such an important issue? Especially considering many of the world's most respected scientists agree with the underlying assumption; human activity has and will continue to facilitate a global warming trend fueled by increased anthropogenic emissions of CO_2 which trap heat within the earth's atmosphere. This was confirmed (with 90% confidence) by the IPCC at their latest round table meeting in Paris (February 2007). What makes the IPCC so important in our further understanding of climate change is that the panel does not conduct its own scientific inquiries, but reviews worldwide research, issues regular assessment reports, and compiles special reports and technical papers. The IPCC's findings form a useful counterbalance to the often highly charged political debate over how to address climate change because they reflect global scientific consensus and are apolitical, objective and nonbiased in character.

Combined with the potentially disturbing environmental dilemma is the related issue of continued energy use which maintains the progression of the global economy and results in an increase in the standard of living for humans throughout the world. As with any naturally occurring, finite resource there will come a time (if not already) when the world's hydrocarbon resources will 'peak', following which an inevitable decline will occur. It is widely agreed that global demand for these collective resources is still young, as a suite of factors including the propensity of humans to live longer, the economic and industrial emergence of developing states and the full scale impacts of highly competitive, globalized markets has led to an insatiable appetite for energy. McKillop (2006) went on to say that world oil demand is too strong to permit any return to cheap oil, growing at around 2.25-2.75 % per year but world oil supply is increasing, at best, at less than 1.5% on a net-of-depletion basis.

Given the fact that coal provides countries throughout the world with a cheap, stable, abundant and reliable form of energy and, noting that CO_2 capture and storage technology exists, it is completely plausible to assume that we can 'have our cake and eat it too' by continuing to use coal in an environmentally friendly way. MHI's CO_2 flue gas recovery process is commercially proven and is underlined by several excellent features including lower energy consumption, low degradation of the KS-1 solvent, minimal corrosion and simple, easily maintained equipment.

Furthermore, the development and expansion of global carbon markets and the increasingly progressive interest from the financial and investment banking sectors highlights the potential for a lucrative commodity based industry. Application of CO_2 EOR is seen as a key developing industry and the US is well placed to pioneer the way for its wide scale implementation. However, for this to occur, several current barriers must be overcome and this will necessitate governments to take the lead role in supporting the emerging CCS industry, through economic incentives and promotion of larger scale CCS demonstration projects. In conclusion, with extended government support, we now have a solution which will allow the continued use of coal for power generation, in an environmentally responsible way whilst maximizing the recovery of important fossil fuel reserves (through CO_2 EOR) and mitigating GHG emissions (through CO_2 capture and sequestration) leading to a sustained progression of the modern world.

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