CARBON CAPTURE AND STORAGE (CCS) - ENHANCED OIL RECOVERY (EOR): GLOBAL POTENTIAL IN INDONESIA

by: Utomo Pratama Iskandar and Ego Syahrial[1)]

Technological Assessor[1)] at "LEMIGAS" R & D Centre for Oil and Gas Technology

Jl. Ciledug Raya, Kav. 109, Cipulir, Kebayoran Lama, P.O. Box 1089/JKT, Jakarta Selatan 12230 INDONESIA

First Registered on 14 October 2009; Received after Corection on 15 December 2009

Publication Approval on: 30 December 2009

ABSTRACTS

Total global CO_2 emissions from fossil-fuel will still increase in the next ten decades. These are attributed to the heavy reliance of human activities with fossil fuels. The uncontrolled CO_2 emissions from combustion of fossil fuels cause the CO_2 concentration alteration in the atmosphere. As the result, this phenomenon cause global warming and change the climate globally. In the future, CO_2 emissions are predicted in range from 29 to 44 $GtCO_2$/year in 2020. Therefore it is necessary to abate the CO_2 emissions to the level that would prevent dangerous anthropogenic interference to the global climate system. The growth of energy efficiency improvements, the switch to less-carbon intensive fuels and renewable resources employment is still low in the context CO_2 emissions mitigation. Carbon Dioxide Capture and Storage (CCS) as a third option for these mitigation options might facilitate achieving CO_2 emissions stabilization goals. As a part of the commitment and participation on combating the global warming, Indonesia has signed the Kyoto Protocol in 1998 and ratified it in 2004 through Law No. 17/2004. On the other side, Indonesia oil production has been declining since in the last ten years but demand for this energy is still high. In this frame CCS-Enhanced Oil Recovery (EOR) by CO_2 injection might answer the global warming challenges and alongside contribute to increase the oil production in the near future. This paper presents a preliminary study of CCS-EOR potential in Indonesia. A brief explanation of geological setting and reservoir screening for site selection also presented. Then some discussions about CCS-EOR global potential will be highlighted as well as the analysis. It is hoped that this study would provide a standard guideline for determining CCS- EOR potential in Indonesia.

Key words: Emission Mitigation, Climate Change, Carbon Dioxide Capture and Storage (CCS), Enhanced Oil Recovery (EOR)

I. INTRODUCTION

Projection in the year 2008 showed more than 26 $GtCO_2$/year emitted to atmosphere from the combustion of fossil fuels (cenimar.com, 2008). This is attributed mainly to large stationary emissions sources and much dominated by the power plant. CO_2 emissions also result from some industrial and resource extraction process as well as from the burning of forest during land clearance. In case of Indonesia, besides a number of electric power plants that are fuelled with coal, forest fires almost happened every year that contribute to increasing CO_2 emissions to the atmosphere.

The CO_2 emissions tend to have an inclining curve by each year (Figure 1). This astonishing figure will continue to rise as rising global population, higher standard of living and increased demand for energy could result in as much as 9,000 Gts cumulative CO_2 being emitted to the atmosphere by the end of this century. In the future, CO_2 emissions are predicted in range from 29 to 44 $GtCO_2$/year in 2020 (Metz et al. 2005).

The uncontrolled CO_2 emissions accelerate the CO_2 concentration alteration in the atmosphere. As the result, reflected heat from earth will be detained by this green house gas and as the consequence average earth temperature will increase too. This phenomenon is well known as global warming that has the great impact to change the climate globally. As an archipelagic country, Indonesia will have tremendous impact from climate change such as, decreasing agriculture productivity, changing in the use and function in forestry, reducing groundwater in both quantity and quality, and decreasing of coastlines area as the sea level increase (Brioletty *et al.*, 2007).

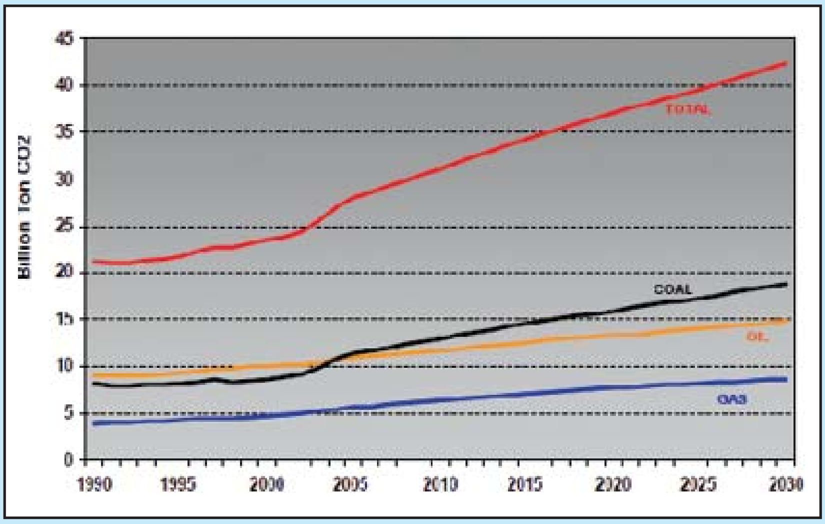

Figure 1
World Energy-Related CO_2 Emissions by Fuel Type

Those impacts mean a catastrophic condition will be faced by life on earth. Therefore it is needed to stabilize the CO_2 concentration in the atmosphere to a level that would prevent dangerous anthropogenic interference to the global climate system. Intergovernmental Panel on Climate Change (IPCC) has suggested that the amount of CO_2 released to atmosphere over this century would need to be held to no more than 2,600 to 4,600 Gts. Energy efficiency improvements, the switch to less-carbon intensive fuels and renewable resources employment only contribute in small size to CO_2 emissions mitigation. The United Nations Framework Convention for Climate Change (UNFCCC) has considered Carbon Dioxide Capture and Storage (CCS) as a third option for global warming mitigation. This mitigation option might facilitate achieving CO_2 emissions stabilization goals.

In general, CCS is a process consisting of three-step operations. The first phase is the capture portion, whereby carbon dioxide is captured and compressed at an industrial emission source, such as a coal-fired power plant or a manufacturing facility. The next phase is the transportation of the capture carbon dioxide. The methods can be done via a dedicated pipeline infrastructure or tankers to the injection site where the carbon dioxide will be stored. Finally, storage of the carbon dioxide occurs when it is injected into a geological formation. Geological formations such as depleted oil or gas reservoirs, deep saline aquifers, and coal seams offer a huge storage capacity.

In order to mitigate CO_2 emissions to the atmosphere, the international world agreed to involve CO_2 abatement through the Kyoto Protocol. The Kyoto Protocol requires 35 industrialized countries and the European Community to reduce GHG's emissions by an average of 5% below 1990 level in its first commitment period from 2008 to 2012 (Syahrial *et al.*, 2007). As developing country, Indonesia has showed its commitment and participation on combating the global warming by signing the Kyoto Protocol in 1998 and ratifying it in 2004 through Law No. 17/2004.

To notice with those current issues above and coupled with the global energy situation constraints, the Government has issued the Presidential Regulation Number 5 of 2006 (or PerPres No. 5/2006) concerning National Energy Policy (Figure 2), which includes among others to reduce the consumption of fossil fuels from 95% to 83% in the next two decades (2005 – 2025), and, at the same time, increasing the role of new and renewable energy from 5% to become 17%. In regards to fossil fuels reduction, the role of natural oil declined from 54% to 20%, natural gas rose from 27% to be 31%, and coal also increased from 14% becoming more than 33%.

Optimizing the energy consumption pattern, as directed by the PerPres 5/2006, Indonesia can achieve a significant reduction of CO_2 emission by 2025 that is at a level of 950 $MtCO_2e$ or about 16% reduction compare to business as usual (BAU) scenario (Figure 3). From the simulation, this expected CO_2 emissions could be more curbed when CCS is implemented as early as 2015.

Besides global warming issues, Indonesia at the moment faces declining oil production since in the last ten years. Although government has deployed the use of natural gas as in many sectors but the domestic demand for oil is still high. In terms of CCS-EOR technology, utilizing depleted oil reservoirs could help Indonesia to maintain the production stable. Many promising depleted oil reservoir in Indonesia can be reactivated to improve the oil recovery by injecting CO_2. From the perspective of CCS, enhanced oil recovery represents an opportunity to store carbon at low net cost, due to the revenues from recovered oil/gas. At the meanwhile oil recovery that produces from EOR gives contribution to national oil security supply. In this context CCS-EOR might answer the global warming challenge by reducing GHG emissions and at the same time contribute to increase the oil production in the near future.

This paper describes a preliminary study of CCS-EOR potential in Indonesia globally. Introduce with explanation of geological setting and followed reservoir screening for site selection. Then some discussions about CCS-EOR global potential will be presented as well as the analysis. It is hoped that this study would provide a standard guideline for determining CCS-EOR potential in Indonesia.

II. GEOLOGICAL SETTING

Site characterization, selection and performance prediction are crucial for successful geological storage. Before selecting a site, the geological setting must be characterized to determine if the overlying cap rock will provide an effective seal because a well-sealed cap rock over the selected storage reservoir is important to ensure that CO_2 remains trapped underground, if there is a sufficiently voluminous and permeable storage formation, and whether any abandoned or active wells will compromise the integrity of the seal.

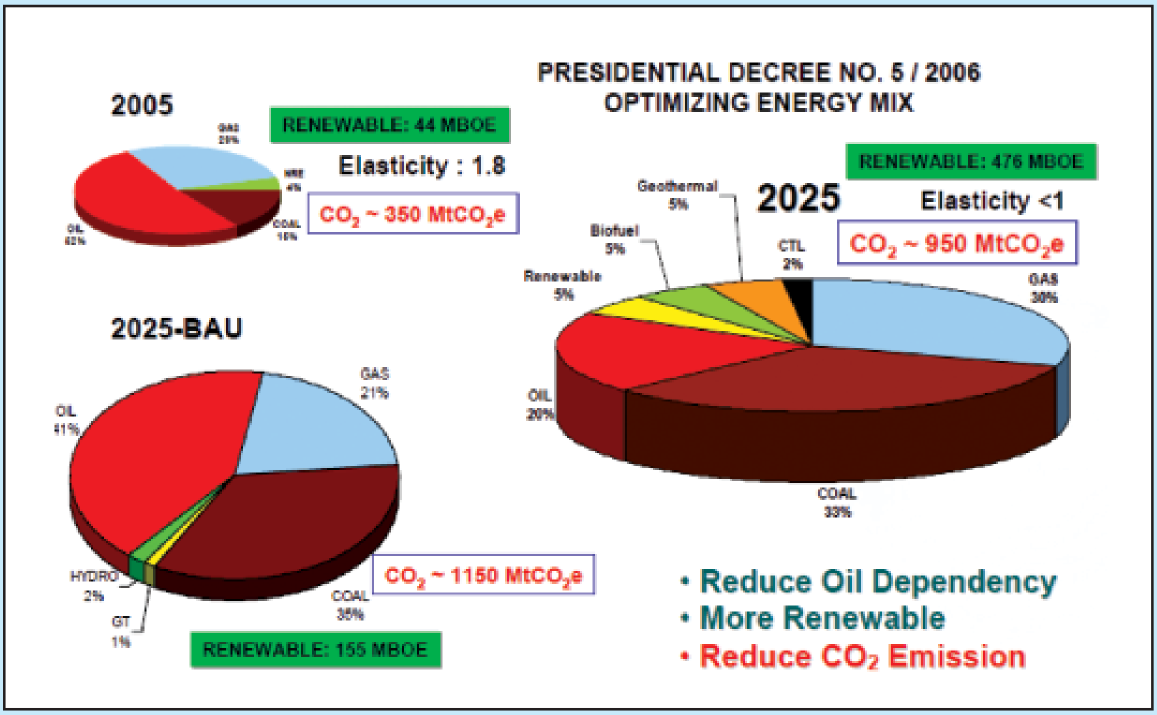

Figure 2
Policy: Energy Mix Target

LEMIGAS SCIENTIFIC CONTRIBUTIONS
VOL. 32. NO. 3, DECEMBER 2009 : 228 - 238

There are three potential regions that could be suitable for CO_2 geological storage based on geological setting. First, South Sumatra basin, back-arc basin that formed at the end of the pre-Tertiary to the beginning of Tertiary times. This region comprise of mainly fluvio-deltaic marginal marine, locally lacustrine and coaly facies of the Late Eocene to Middle Oligocene Lemat, and Late Oligocene to Early Miocene Talang Akar Formations. The reservoirs mostly are Eocene-Oligocene sandstones of the Talang Akar Formation, carbonate reef of Baturaja and sandstone of Air Benakat Formations. Intraformational shales and claystones within Talang Akar and Gumai Formations are the main seal that formed in this region and the

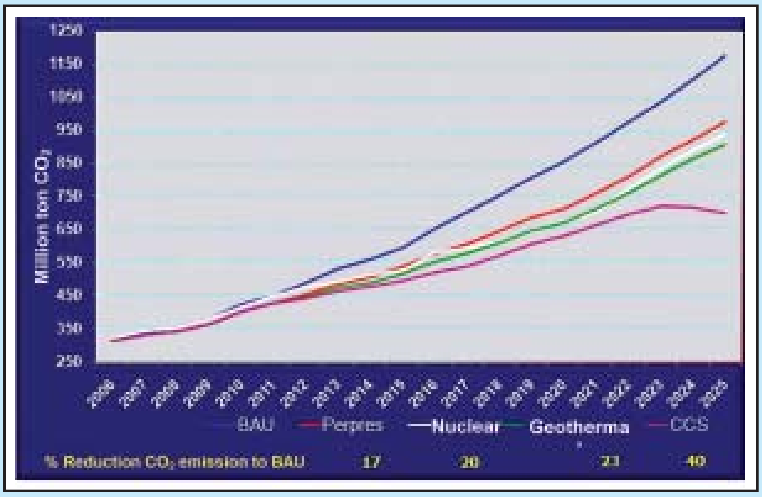

Figure 3
The effort to reduce CO_2 emission in energy sector through various programs, which are diversification and conservation (Presidential Instruction), nuclear and geothermal electric power plant and the implementation of CCS

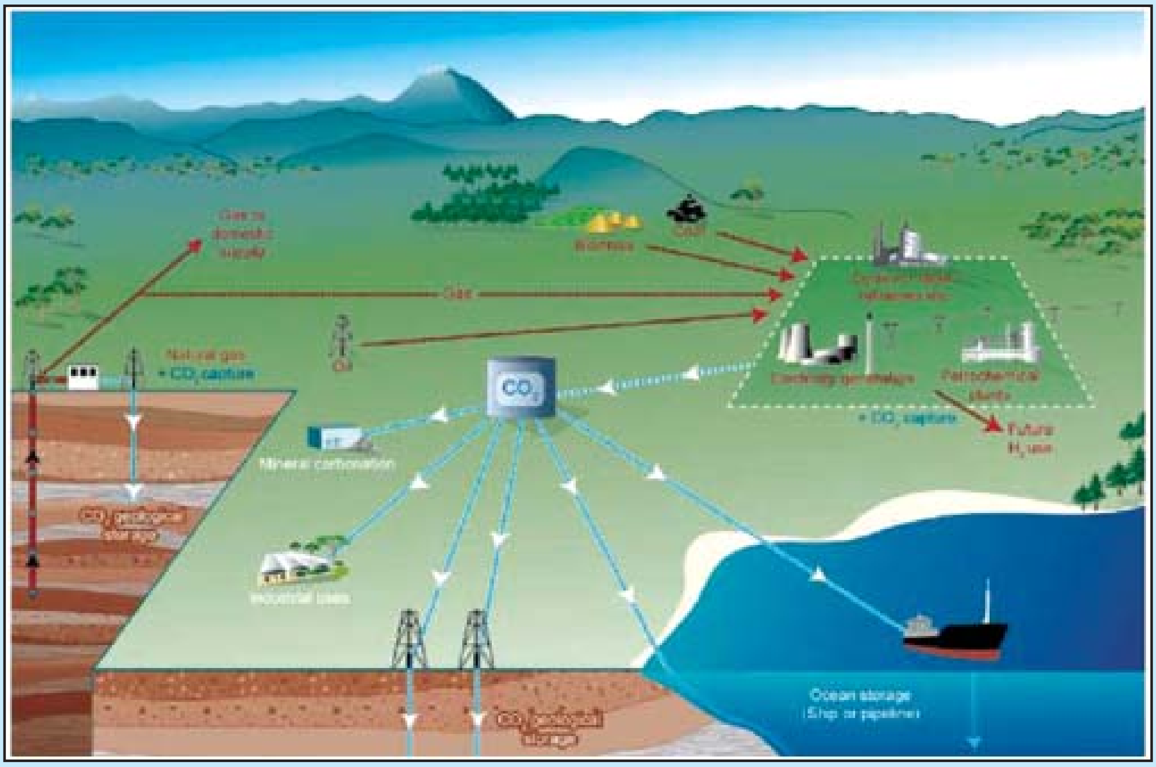

Figure 4
Schematic diagram of possible CCS system showing the sources for which CCS might be relevant, transport of CO_2 and storage options (Metz *et al*., 2005)

traps are provided by anticlinal structural or combined structural and stratigraphic traps.

Second potential areas for CO_2 underground storage is Natuna Basin. East & West Natuna basins were formed as a result of the India-Asia collision in late. Natunas source rock consist of, Eocene to Oligocene shale of Benua/Lama Fm., Keras, Barat lacustrine shales Fm., & Lower Gabus Fm. of mudstones, carbonaceous sandstones and coal. Seal system in this basin divided into West Natuna in which Barat and Arang Formations predominantly comprise of shales, and East Natuna where Regional shales of Muda Formation exist. Trap systems also separated, with anticlinal and fault structural closures combined with stratigraphic traps located in West Natuna and Reef buildups located in East Natuna.

Last potential area for CO_2 storage is Kutai Basin which is located in East Kalimantan. This basin divided into three different zones based on petroleum system, west, central and east and then summarized in Table 1.

III. CARBON CAPTURE AND STORAGE (CCS) – ENHANCED OIL RECOVERY (EOR)

Carbon Dioxide (CO_2) Capture and Storage (CCS) is a process consisting of the separation of CO_2 from industrial and energy-related sources, transport to storage sites and store into geological formation (Figure 4). Capture of CO_2 can be applied to large point sources such as, biomass energy facilities, major CO_2-emitting industries, natural gas production, synthetic fuel plants and fossil fuel-based hydrogen production plants. There are many potential technical storage methods such as geological storage (in geological formations, such as oil and gas fields, un-minable coal beds and deep saline formations), ocean storage (direct release into the ocean water column or onto the deep seafloor) and industrial fixation of CO_2 into inorganic carbonates (Metz *et al.* 2005). Geologic formations such as depleted oil and gas reservoirs, deep saline aquifers, and coal seams offer a huge storage capacity.

Table 1
Petroleum System in Kutai Basin

Kutai Basin Zones	Source Rock	Reservoir Rocks	Trap and seal
West	Mature shale age of Oligocene in age	Oligocene reefal carbonates and deltaic sandstones	Structural and stratigraphic traps, shale and fault seals
Central	Mature shale age of Early Miocene	Miocene deltaic sandstones	Structural and stratigraphic traps, shale and fault seals
East	Mature shale age of Early Miocene	Mid–Late Miocene to Pliocene turbidite sandstones	Structural and stratigraphic traps, shale and fault seals

Table 2
Storage Capacity for Several Geological Storage Options (Metz *et al.*, 2005)

Reservoir type	Lower estimate of storage capacity ($CtCO_2$)	Upper estimate of storage capacity ($CtCO_2$)
Oil and gas fields	675[a]	900[a]
Unminable coal seams (ECBM)	3-15	200
Deep saline fprmations	1.000	Uncertain but possibly 10^4

[a] These numbers would increase by 25% if 'undiscovered' oil and gas fields were included in this assessment

Available evidence suggests that, worldwide, it is likely that there is a technical potential of at least about 2,000 $GtCO_2$ (545 GtC) of storage capacity in geological formations (Metz *et al*., 2005). The estimates of the technical potential for different geological storage options are summarized in Table 2. The estimation of the storage capacity could be much larger if any related information and agreed methodology is available. In this case, oil and gas reservoirs, deep saline aquifer, and coal seams are considered the most prospective geological formations for CO_2 storage. For oil and gas reservoirs, estimation was conducted based on the replacement of hydrocarbon volumes with CO_2 volumes. Eventhough saline formations occur in sedimentary basins throughout the world, both onshore and on the continental shelves, but estimating the capacity is quite challenging due to lack of data and various trapping mechanism can occur. Current storage capacity in coal beds is much smaller and less well known and needs some demonstration project to provide actual storage capacity. Despite the broad ranges in the storage capacity, it can be concluded that the capacity is sufficient for tens and possibly hundreds of years.

Oil and gas sectors in Indonesia have played an important role for economic development and they still will contribute for several decades. In the last ten years, Indonesia oil production has been declining. With the current original oil in place (OOIP) of about 61.1 BSTB, 32.6% of them has been produced, or equivalent to 19.9 BSTB (Figure 5). With the existing recovery technique, only 7.8% of the total OOIP would remain in reservoirs or that is equivalent to 4.8 BSTB. Therefore, 59.6% of the total OOIP or equivalent to 36.5 BSTB will be the target for EOR. In order to meet the oil demand in domestic scale, there should be a serious effort to increase the oil production. Since Indonesia's oil and gas reservoirs mostly have reached their mature stage, optimization these reservoirs using enhanced oil recovery technique is one of possible option to keep the production stable. By utilizing depleted hydrocarbon fields where there is still some oil and gas present, which cannot be produced cost-effectively by pressure depletion and water flooding, enhanced oil recovery (EOR) through CO_2 flooding offers potential economic gain from incremental oil production. Conventional primary production can recover around 5–40% of the original oil in place (OOIP). Secondary recovery that uses water flooding can give additional recovery 10–20% of OOIP. From various enhanced oil recovery methods, CO_2 flooding has been successful to increasing oil recovery in particular fields in the world with an incremental oil recovery of 7–23% (average 13.2%) of OOIP (Metz *et al.* 2005). The United States is the world leader in enhanced oil recovery technology using some 32 million tons of CO_2 per year for injection to the reservoirs.

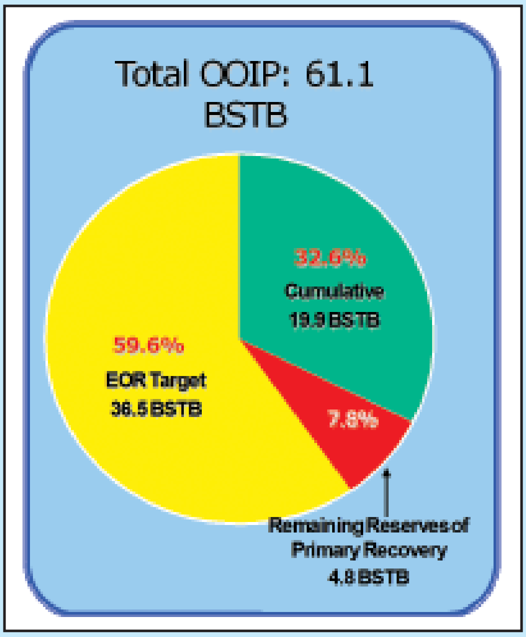

Figure 5
Current Situation Indonesia's Oil Production

As CO_2 injected into oil reservoirs, oil is mobilized through miscible or immiscible displacement, which may increase oil recovery. This process is referred to as enhanced oil recovery with CO_2 (CO_2-EOR). The CO_2 changes the oil properties by decreasing both the viscosity and density. In this method, the integrity of the CO_2 that remains in the reservoir should be well-understood and very high, as long as the original pressure of the reservoir is not exceeded. The CO_2 miscible flooding is considered more advantageous that an immiscible flooding, because it results in higher oil recovery factor. When CO_2 is injected into the reservoirs, oil, water, CO_2, and also natural gas are produced at production well. This produced CO_2 prior re-injected to the injection well, is usually separated and recycled. Although the main purpose of CO_2-EOR is to increase oil recovery, but

LEMIGAS SCIENTIFIC CONTRIBUTIONS
VOL. 32. NO. 3, DECEMBER 2009 : 228 - 238

most of the injected CO_2 can remain in the reservoir which may be caused by pore-scale capillary trapping mechanism. This trapping mechanism makes CO_2 become immobile in the existence of capillary pressure. Average retention reported from several reservoirs is 71% (CO2 net, 2004).

Opportunities for enhanced oil recovery (EOR) have increased interest in CO_2 storage. Although not designed for CO_2 storage, CO_2-EOR projects can demonstrate associated storage of CO_2. The CO_2 storage in case of miscible EOR ranges from 2.4 to 3 tonnes of CO_2 per tonne of oil produced (IEA, 2004). Estimates for storage potentials vary widely from a few Gt to several hundred Gt of CO_2, depending on how many cost and geological constraints are considered. Global capacity for CO_2-EOR opportunities is estimated to have a geological storage capacity of 61–123 GtCO2 (Metz *et al*., 2005).

As aforementioned, reservoirs where the injection of CO_2 causes additional oil or gas production are especially interesting for CO_2 storage, hence depleted or nearly depleted oil and natural gas fields are considered to be suitable for CO_2 storage reservoirs for several reasons. First, oil and gas and often CO_2 have been retained there for million years. Thus, it is demonstrating their integrity and safety. Second, these reservoirs are generally well studied; so much information related geological structure and physical properties have existed. Third, computer models have been developed in the oil and gas industry to predict the movement, displacement behaviour and trapping of hydrocarbons. Finally, some of the infrastructure and wells already in place may be used for handling CO_2 storage operations. The Weyburn project in Canada, around 5,000 t CO_2 (with purity 95%) per day has been injected into carbonate reservoir since 2000 with the purpose of enhanced oil recovery and also to store CO_2 permanently (Davison *et al*., 2001). This makes the Weyburn project different from conventional EOR project, where the main purpose is to maximise oil recovery with minimal CO_2 use. Nevertheless, if the main purpose is to store CO_2 under geological storage, the current EOR practise by minimizing injected CO_2 quantities should be adapted for storage purposes.

For enhanced CO_2 storage in EOR operations, oil reservoirs may need to meet additional criteria (Metz *et al*. 2005). For miscible floods, the reservoir pressure must be higher than the minimum miscibility pressure (10–15 MPa) needed for achieving miscibility between reservoir oil and CO_2, depending on oil composition and gravity, reservoir temperature and CO_2 purity. To achieve effective removal of the oil, other preferred criteria for both types of flooding include relatively thin reservoirs (less than 20 m), high reservoir angle, homogenous formation and low vertical permeability. For horizontal reservoirs, the absence of natural water flow, major gas cap and major natural fractures are preferred. Reservoir heterogeneity also affects CO_2 storage efficiency. The density difference between the lighter CO_2 and the reservoir oil and water leads to movement of the CO_2 along the top of the reservoir, particularly if the reservoir is relatively homogeneous and has high permeability, negatively affecting the CO_2 storage and oil recovery. Consequently, reservoir heterogeneity may have a positive effect, slowing down the rise of CO_2 to the top of the reservoir and forcing it to spread laterally, giving more complete invasion of the formation and greater storage potential

The commercial basis of conventional CO_2-EOR operations is that the revenues from incremental oil compensate for the additional costs incurred (including purchase of CO_2) and provide a return on the investment. Any estimates for onshore EOR storage costs all show potential at negative net costs. These include a range of –10.5 to +10.5 US$/tCO2 stored for European sites (Metz *et al*. 2005). These studies show that use of CO_2 enhanced oil recovery for CO_2 storage can be a lower cost option than saline formations and disused oil and gas fields. The potential benefit of EOR can be deduced from the CO_2 purchase price and the net storage costs for CO_2-EOR storage case studies. The indicative value of the potential benefit from enhanced oil production to CO_2 storage is usually in the range of 0–16 US\$/tCO_2. In some cases, there is no benefit from EOR. But in general, higher benefits will occur at high-oil-price scenarios. At 50 US$ per barrel of oil, the range may increase up to 30 US\$/tCO_2 (Metz *et al*. 2005).

In areas with suitable hydrocarbon accumulations, CO_2-EOR may be implemented because of the added economic benefit of incremental oil production. Given this benefit, CO_2-EOR can increase the Indonesia's conventional oil supply substantially. In the meanwhile CO_2 injection into geological formations is promising strategy for the long-term storage of anthropogenic CO_2, moreover the EOR revenues can offset part of

LEMIGAS SCIENTIFIC CONTRIBUTIONS
VOL. 32. NO. 3, DECEMBER 2009 : 228 - 238

the CCS cost such as CO_2 capture, transport and injection. This technique is likely needed to sustain the Indonesia's fossil fuel-based economy by increasing the remaining oil reserves and to maintain high standard of living alongside reduce the CO_2 emissions.

IV. RESERVOIR SCREENING

Reservoir screening for CCS-EOR selected based on CCS and EOR point of view, storage integrity, CO_2 sources and remaining oil reserves. The integrity of reservoir is necessary to ensure and also to minimize the possibility of leakage during the project and post project. Satisfactory and well characterized cap rock is needed to cover this. The remaining oil saturation is also prominent factor to undertake CCS-EOR as economically feasible. Oil production revenue could offset the high cost of CCS. Thus sufficient remaining oil reserves determine whether CCS-EOR appear viable or not.

Reservoir screening criteria for site selection based on the data availability and continued with laboratory and reservoir simulation works. There are four major steps for reservoir screening to determine suitability of reservoir that can meet the need for CO_2 injection and storage:

a. Pre-screened phase to the reservoirs at the chosen field based on the following criteria: original oil in place > 5,000,000 STB, and depth > 2,500 feet.
b. Injection of immiscible fluids must often suffice for heavy- to-medium-gravity oils (oil gravity 12–25 °API). The more desirable miscible flooding is applicable to light, low-viscosity oils (oil gravity 25–48 °API).
c. The screening continued based on reservoir data, for each reservoir provided with data such as oil viscosity, current reservoir pressure and temperature, current oil saturation, formation thickness, porosity, permeability, and rock type.

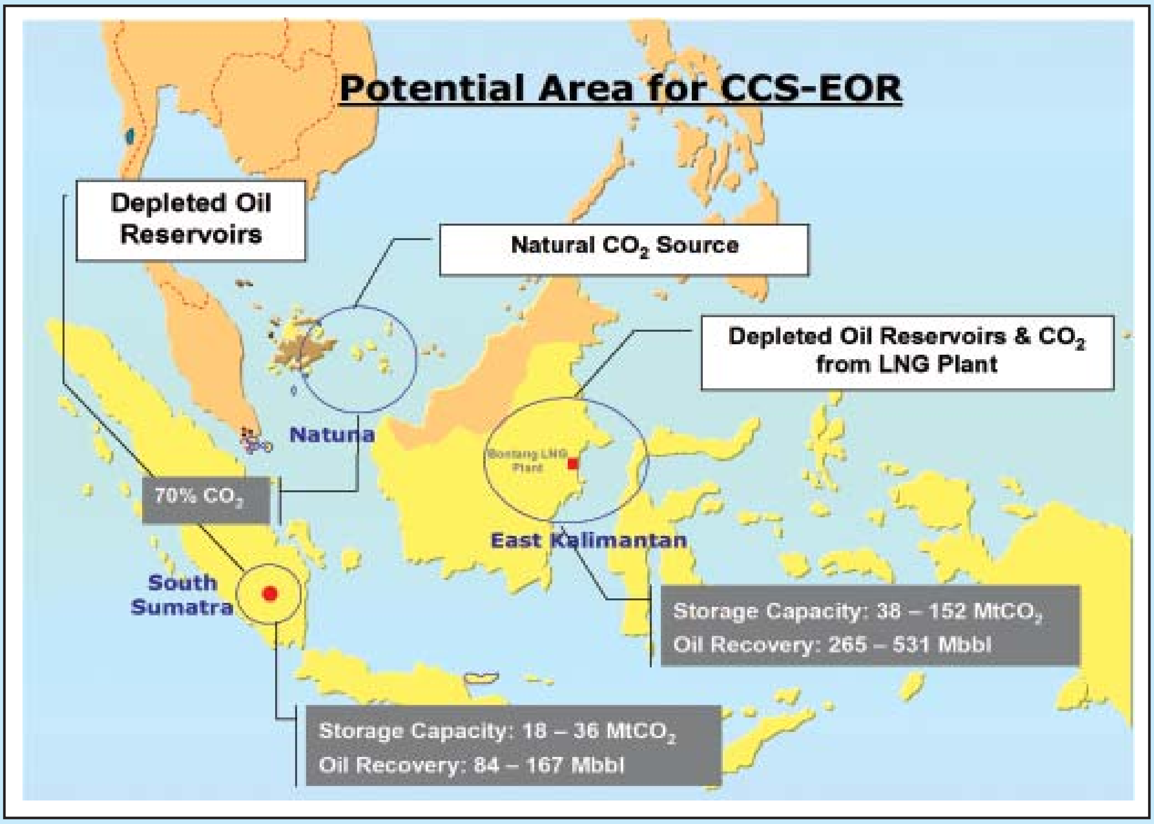

Figure 6
Area for CCS-EOR Potential in Indonesia

LEMIGAS SCIENTIFIC CONTRIBUTIONS
VOL. 32. NO. 3, DECEMBER 2009 : 228 - 238

d. The next step is to estimate the minimum miscibility pressure (MMP) for each of these reservoirs using industry-standard correlations. To accomplish this, both Yellig-Metcalfe and Holm-Josendal correlations are employed to estimate the MMP based on reservoir temperature.

CO_2 sources should complement the CCS-EOR project integrity. Many large point sources of CO_2 are concentrated in proximity to major industrial and urban areas. Many of them are within 300 km of areas that potentially hold formations suitable for geological storage. Preliminary research suggests that, globally, a small proportion of large point sources are close to potential storage locations. CO_2 sources are critical factor to guarantee the project life.

V. CCS-EOR GLOBAL POTENTIAL

This study at the moment only restricted to determine CCS-EOR potential globally based on inhouse study. Using Rule-of-Thumb Approach methods were first applied to estimate potential oil recoveries and storage volumes from CO_2 injection. To accomplish this several input assumptions are required as follow:

a. Incremental oil recovery (% OOIP) from the CO_2 – EOR project based on field experiences is usually in the 8-16% range.

b. Gross CO_2 utilization ratio (MCF/BBL): the total amount of CO_2 injected for the project including CO_2 recycle volumes that based on experience is usually in the 5-10 Mcf/bbl range.

c. Net/gross utilization ratio (fraction): the fraction of the total injected volume of CO_2 that is actually purchased (*i.e.*, purchased CO_2 divided by total injected CO_2, which includes recycle volumes). This is the volume of CO_2 assumed to be left in the reservoir at the end of the project life (*i.e.*, sequestered) that based on experience, this value is usually in the order of 0.5.

In Indonesia, we found that there are three regions could be categorized potentially to be used for CO_2 storage as well as EOR (Figure 6). Based on the aforementioned assumptions, it is estimated that CO_2 volume of 38 – 152 million tons may be possible to be stored in the depleted oil reservoirs in East Kalimantan region, and potential oil recoveries of 265 – 531 million barrels could be obtained. Moreover, many depleted oil and gas reservoirs in this region are close to the CO_2 sources such as LNG/LPG plant in Bontang, oil and gas industry and coal power plant activities.

In South Sumatra region, CO_2 volume of 18 – 36 million tons may be possible to be stored in the depleted oil and gas reservoirs with potential oil recoveries of 84 – 167 million barrels. Another potential of CCS project is in Natuna area in which a giant gas reserves with 70% of CO_2 can be used as CO_2 source or to improve natural gas production and then stored into saline aquifer or depleted oil and gas reservoirs.

These potential areas currently appear as opportunity to develop further study to determine more specific oil and gas fields that can be deployed as CCS-EOR project. Most of West Indonesia apparently could be a viable project for CCS-EOR, besides the existing facility but also many large CO_2 sources concentrated in this area. CO_2 sources proximity would be take into consideration for project life.

VI. ANALYSIS

CCS-EOR could be as the first main entrance before to move further in “pure” CCS implementation project. This would be a good option for Indonesia that has significant sources of CO_2 suitable for capture, and has access to storage sites and experience with oil or gas operations. Many advantages that can be gained from CCS-EOR project particularly in Indonesia, besides give more additional oil or gas recovery, this project also helps worldwide to reduce CO_2 emissions. Although it is not mandatory for Indonesia, but at least in economic sides Indonesia could sell CER (Credit Emission Reduction) to developed country. Even though recently carbon market seems not very enthusiastic, but in the next decade carbon demand might be higher.

CCS-EOR is different with usual CO_2-EOR which consists of carbon monitoring programme to ascertain the carbon still remains in underground until no more additional incremental oil recovery. Monitoring plays important role to assure geological formation integrity. By doing this we could see CO_2 migration pathways, predict reservoir performance, geochemical interaction, and also the effect with surround environment. Many available methods to support monitoring activity such as seismic time-lapse surveys, noble gas tracers, pressure surveys, tomography and geomechanical monitoring. The surveys also can show that the caprock is an effective seal

LEMIGAS SCIENTIFIC CONTRIBUTIONS
VOL. 32. NO. 3, DECEMBER 2009 : 228 - 238

that prevents CO_2 migration out of the storage formation.

If we summarize the potential of CCS-EOR, it currently may the only technological approach that shows promise for enabling Indonesia to continue to use the fossil energy while at the same time, achieving sufficient carbon dioxide emissions reduction to address climate change. Although CCS technologies are compatible with most current energy infrastructures but CCS itself is a complex process spanning a wide range of scientific and technological aspects and also many technical issues should be considered. The associated cost of a CCS project requires significant amount of investment and economic justification, but with utilizing depleted oil and gas reservoirs that can generate revenues such as EOR, CCS project might be economically feasible under specific conditions.

Current knowledge about the legal and regulatory requirements for implementing CCS-EOR on a larger scale is still inadequate. There is no appropriate framework to facilitate the implementation of geological storage and take into account the associated long term liabilities. At present, only few countries have developed legal and regulatory frameworks for onshore CO_2 storage, but none have specifically developed for CCS-EOR. Lack of clear legal or regulatory framework could hamper CCS-EOR deployment. In this case Indonesia needs National regulatory framework to support this technology deployment. Supporting policy from local government also play the important role in order to accomplish the implementation.

There are some crucial issues still remain and need to be resolved before CCS-EOR can be fully implemented in a commercial scale. These includes the public acceptance for CSS itself due to the risks of leakage that could happen from injection well failures (abrupt leakage) or occur through undetected faults, fractures (gradual leakage) and leakage from ground movement and seismic activity. Long-term monitoring of leakage (seepage) and coverage area of monitoring are also crucial issues that need to be concerned. Other issues have to pay attention such project boundary issues and project involving more than one country, liability relating to the difference in time periods between the crediting period and the closure of the reservoir, implications of CCS activities for other CDM project activities.

Transfer of the technology to developing countries and their capacity to apply the technology considered as a barrier for further this technology deployment as well as funding issue to implement CCS-EOR in developing country. A pilot project for CCS-EOR implementation is crucial. It is necessary to make sure both technical and non-technical aspects of CCS-EOR implementation are accepted economically and ethically. The UNFCCC COP-13 in Bali year 2007 also encouraged to build more CCS pilot projects to gather more robust technical justifications before it can be deployed widely as an acceptable technology for the mitigation purpose. Those aforementioned issues are related to stabilization pathways and integration aspects of CCS-EOR and detailed understandings of those issues are necessary before this option can become a safe and economic sequestration option, and its development requires a focused R&D effort by government and industry.

VII. CONCLUSIONS

Several conclusions can be drawn from this study are as follow:

1. CCS-EOR could be as the first gate prior fully implements CCS project in Indonesia. Besides enabling Indonesia to continue to use the fossil energy, CCS-EOR also help to achieve sufficient carbon dioxide emissions reduction to address climate change.
2. However there are still remaining unresolved technical issues such as certain methodology to deploy CCS-EOR and non-technical issue such as regulatory framework.
3. More pilot-scale CCS-EOR projects in developing countries are required to gather more robust economic and technical justifications.
4. Transfer and diffusion of CCS-EOR technology from developed country to developing country as well as funding issues need to be resolved before CCS widely deployed.

REFERENCES

1. Brioletty, L., Syahrial, E., and Tobing, E., 2007, Peranan Teknologi Sekuestrasi CO2 Dalam Menciptakan Mekanisme Pembangunan Bersih di Indonesia: Proceeding of Society of Indonesian Petroleum Engineer, 9th National Symposium.

LEMIGAS SCIENTIFIC CONTRIBUTIONS
VOL. 32. NO. 3, DECEMBER 2009 : 228 - 238

2. Davison, J., Freund, P., and Smith, A., 2001, Putting Carbon Back Into The Ground, IEA Greenhouse Gas R&D Programme, 13-15.
3. European Carbon Dioxide Network (CO2 net), 2004, Capturing and Storing Carbon Dioxide: Technical lessons learned, R&D and Technology Exploitation For CO2 Sources, Transport, Geological Storage.
4. Holloway, S., Chadwick, A., Lauriol, I. C., and Arts, R., 2004, Best Practice Manual: Saline Aquifer CO2 Storage Project, Appendix A Statoil Research Center, 5-16.
5. IEA, 2004, Energy Technology Analysis: Prospects For CO2 Capture And Storage, International Energy Agency, 81-88.
6. Metz, B., Devidson, O., Coninck, H., Loos, M., and Meyer, L., 2005, IPCC Special Report: Carbon Capture and Storage, 197-264.
7. Syahrial, E., 2007, Kajian Potensi Sekuestrasi Carbon Dioxide Pada Lapangan Minyak Tua Sangatta Kalimantan Timur, Diklat Fungsional Peneliti Tingkat Pertama.
8. Syahrial, E., Brioletty, L., Saptono, F., and Misfaroh, Z., 2007, Study of CO2 Sequestration Potential for Storage and EOR: Proceedings Indonesian Petroleum Association, 32th. Annual Convention.
9. www.cenimar.com, 2008, Carbon Dioxide (CO2)-Emissions Trend and Forecast for World.ˇ