ENVIRONMENTAL STUDY ON CO_2 STORAGE IN THE DEEP SEA: AN OVERVIEW

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ABSTRACT

Global warming is an important environmental issue caused by the accumulation of CO_2 in the atmosphere that may result in climate change with several impacts. Such gas must be reduced by various ways of action from cross-sectoral human activities including scrapping or sequestration technique. The gas can be delivered by pipes or tanker ship following the sequestration to be stored by injecting method. One of the proposed storage sites for such gas which still in the scientific polemic is in the deep sea. The problems appeared such as the overall processes are considered as a high cost technology for the developing countries excluding additional energy cost. Furthermore the basic legal system to regulate and to control the activity is not yet provided in Indonesia. This paper presents a short discussion from several aspects with the aim to obtain problem solving if such gas would be stored in the deep sea. It is also suggested from the scientific point of view that profound study on CO_2 storage should be undertaken from laboratory scale as well as in the deep sea. Since the chemical-based scrapping or sequestration of CO_2 and its storage need high cost investment and operation, so at least the biological-based sequestration combined with environmental oriented physical-chemical based are offered.

Keywords: *global warming, CO_2 storage, deep sea, environmental impacts*

I. INTRODUCTION

CO_2 is one of the gas emissions derived from anthropogenic activities particularly from the industries which is increased day by day and accumulated at the atmosphere to give the green house effects. Those effects may cause the increase of global average temperature and consequently the climate change happened and followed by various impacts (physical, biological, social, human health, etc). Other gas which represents green house gases (GHG) are among others: methane, CFC, emission from petroleum activities, emission from the combustion of fossil fuel derived from vehicles, industries and power plants. To be honest it is acknowledged, for many years the measurements of air quality have been implemented (in ambient, road sides as well as emission from muffler and stack) in the various environmental studies in Indonesia, but never to measure CO_2 level due to the absent of that parameter in the national standard since the last 30 years up to 1990's as presented in Table 1.

The consideration of un-involvement of CO_2 in the air quality measurement might be caused by the general opinion that almost such gas will be adsorbed by the plant leaves to carry out photosynthesis and the remains will be "diluted" by the air. So, it was simply considered to be safe in the atmosphere. On the contrary the facts and evidence show the denudation of forest (illegal logging) and forest fires that are frequently found mean that photosynthesis area is decreasing annually, meanwhile the emission of CO_2 and other green house gases are always increasing from time to time as the result of human activities. Since then the CO_2 is recently "accused" as an air pollutant to cause global warming and climate change. But, uncontrolled of SO_x and NO_x emissions also have

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a big role in causing acid rain with the pH of less than 5,5 which is capable to cause damage to bridges, buildings, temples, etc. as well as causing acidification of soil and lakes, and human health disturbances.

Unlike the carbon monoxide (CO), the CO_2 is odorless and colorless gas. Human can avoid the intoxication of CO due to the inflicting odor. The impacts on human beings, mammals and other vertebrates from intoxication of CO_2 might be similar with the intoxication of carbon monoxide (CO). Hypoxia will appear, and furthermore followed by asphyxiation before they fall unconscious. Death may occur after the damage of brain. The appearance of hypoxia is caused by the affinity between haemoglobin and oxygen is less than the affinity between haemoglobin and CO or CO_2. Now, everybody is feeling startled to understand the scientific information on CO_2 emission connected with the global warming issue.

Table 1
Air Quality and Noise Standards

No	Parameters	Unit	Standard
1.	Hydrocarbon (HC)	$\mu gr/m^3$	160
2.	Carbon monoxide (CO)	$\mu gr/m^3$	30
3.	Nitrogen oxides (NO_2)	$\mu gr/m^3$	400
4.	Sulfur dioxides (SO_2)	$\mu gr/m^3$	900
5.	Particulate Matter 10 µ (PM_{10})	$\mu gr/m^3$	150
6.	Particulate Matter 2.5 µ (PM2.5)	$\mu gr/m^3$	65
7.	TSP (Dust)	$\mu gr/m^3$	230
8.	Lead (Pb)	$\mu gr/m^3$	2
9.	Noise	dB (A)	55

Source:
1. Government Regulation No. 41 of 1999 regarding Air Pollution Control
2. Ministerial Decree of Minister for Environment No, 48/MENLH/II/1996 regarding Standards of Noise Level.

Based on the World Development Report (1998/1999) from the World Bank, stated the total amount of CO_2 emission in 1995 in the world reached up to 22,700 million tons. Though Indonesia shares only in a small amount (± 1,3 % of total CO_2 emitted in the world) but the Indonesian people are suffering from the impacts of global warming and climate change due to the emitted CO_2 from several point sources of other countries. To minimize the quantity of such gas in the air, the CO_2 must be reduced by various ways of action from cross sectoral human activities. Scrapping as stated in the Carbon Capture & Storage (CCS) method though is a good solution, but it needs environment oriented considerations. Since the gas will be captured, we prefer to use CO_2 capture as declarative sentence rather than Carbon capture. The capture of CO_2 or sequestration is followed by the accumulation in special tanks under certain pressure then to be delivered by pipes or tanker ship and furthermore such gas will be injected to be stored. One of the proposed sites for CO_2 storage is in the deep sea. In our point of view, “deep sea” is defined as the oceanic zone (open oceans) with the depth of 2,000 meters deep or more including its seabed and not in the neritic zone.

Some serious problems have appeared from sequestration and the storage activities in the deep sea such as: high cost technology, non environment oriented process, unavailability of legal system in Indonesia as a basic rule, and others. The objective of this paper is trying to obtain problem solving from the environment aspect if CO_2 would be stored in the deep sea.

II. FATES OF CO_2 AND ITS IMPACTS IN SEAWATER ENVIRONMENT

CO_2 is a soluble gas and easy to obtain in seawater as a free gas with higher concentration rather than in the air. This is caused by the pH of seawater is usually in alkaline condition (7,5 – 8,3) meaning that the concentration of certain cations (Mg^+ and Ca^+) are in excessive amounts more than the total amounts of anion equivalent. This condition enables to drive the simple dissociation reaction or balance reaction between CO_2 and H_2O to form carbonic acid (weak acid) and the reaction continues to produce bicarbonate and carbonate substances as shown be-

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low. The speed of the reaction depends on the sea-water temperature.

$$CO_2 + H_2O \leftrightarrows H_2CO_3$$

$$\downarrow\uparrow$$

$$2H^+ + CO_3^{=} \leftrightarrows HCO_3^- + H^+$$

If the CO_2 decreased in concentration and the gas was taken up by marine phytoplankton and other saline plants to carry out photosynthesis and growth, so the carbonates and bicarbonates will give off the CO_2 in the water column. Carbonate and bicarbonate substances are very important as buffer system in the marine environment. Additionally, carbonate with silicate substances are used to form and develop the shell of several marine organisms. Though the dissolved CO_2 in the sea water is measurable by simple titration method, but there is no limitation of CO_2 level for marine biota at the open sea with its significant hydro-dynamic properties (e.g. currents, waves and tides). Even in the Indonesian national standard (Ministerial Decree of Minister of State for Environment No. 51/MENLH/2004 Appendix III on Seawater Quality Standard for Marine Biota) it is not explicitly stated. Requirements for artisanal fishery (*tambak*) and freshwater fish pond are clearly stated. The CO_2 concentration in the brackish water fishpond and/or freshwater fishpond is considered as starting to be critical for fishery in the tropics if the value gives 12 mg/liter with the oxygen content (DO) is around 2 mg/liter. The presence of CO_2 naturally in the water fishpond is usually less than 10 mg/liter.

Unlike in the water of pond, the environmental conditions in the open ocean particularly in the photic zone, the dissolved oxygen is expected more than 5 mg/liter with its BOD value is not more than 10 mg/liter. Down to the disphotic zone, the oxygen content in the water is less. But in the deep sea with the depth of more than 2.000 meters or at the abisal plain or at the abiso-pelagic zone, with no sun light (aphotic) in the water column, usually the oxygen content decreases drastically but never nil. Such conditions as in the aphotic zone are also found in the marine trenches. According to Fairbridge (19..) and Wijaya *et al.* (2005) there are four marine trenches in Indonesian waters covering the southern and western frontier of Indonesian EEZ and in the internal seas viz.:

- Java trench, stretches from the west of Bengkulu until south of Flores.
- Sangihe trench, stretches from Sangihe islands until Peleng island.
- North Sulawesi trench stretches along the north of north Sulawesi, but still at the southern part of Pacific Ocean.
- Makassar Strait trench stretches along the strait.

Fairbridge stated the Java trench has the average depth of 7.5 km deep, stretches along 4.500 km with the average width around 80 km more or less. If the CO_2 will be stored at the depth between 200 - 1000 meters, this zone is called as Pycnocline Zone or Thermocline Zone. Both of these zones coincide with one another and so are called "*deep scattering layer*". Within the layer the deeper the water, the density will increase rapidly followed by rapid decrease in water temperatures. Additionally, at the certain time there will be an upwelling current in vertical direction somewhere across through the scattering layer to bring the organic matter from abisal or hadal (deep sea floor) up to epipelagic zone to enrich the nutrient for that zone. So, this zone (between 200 – 1,000 m) is not a safe place to store the CO_2 because the condition enables to influence or disturb the dissociation reaction and at any time the gas could follow the upwelling currents and then will be a toxicant to marine life in epi-pelagic zone due to the increasing concentration of CO_2. The acidification of seawater will occur and disperse to follow the general pattern of surface currents as well as tides currents. Then it has the ability to destroy the coral reef and other marine organisms. The death of many polyps and zooxanthellae will due to the decrease in pH together with the increase in temperature of seawater, at last all over the coral turns white (bleaching process). The zooxanthelae is very important algae (there are 10 species but one of them is *Gymnodinium microadriaticum*/Pyrrophyta) which gives the corals most splendid and beautiful color. The areal cover of coral reef in Indonesia was estimated around 60,000 km^2 (or 15 % of total area cover in the world) with very high species diversity. One of the growth requirements for coral reef is the temperature fluctuation may not excess from $27^o \pm 2^oC$ or around 70^oF. In 2004 the BPPT (Research and Application Technology Board) stated that since the beginning of that year, as the impact of global warm-

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ing it was estimated ± 61 % of the total area cover of coral reef is in damage condition and 15 % is in critical situation. The death of many coral reefs means the damage of marine germ-plasm and this condition shall affect to the marine fishery productions. Unless the storage site is at the depth of more than 2,000 meters, so the change of water density and water temperature are very small or relatively stable. This condition may not disturb the dissociation reaction. But the question is if the gas storage located at the depth of more than 2,000 meters deep then can that place be guaranteed as a completely safe place?

Actually, the free CO_2 concentration in the marine environment has a complex dynamic relation with several parameters such as pH, temperature, and salinity. If the value of pH remained constant, the concentration of CO_2 may be increased followed by the increase of salinity and the decrease of water temperature. However, scientists pointed out, the pH is considered to have merely a little share in the process, but the water *temperature* and water *pressure* give the main effects to CO_2 concentration in the seawater. The general scientific acknowledgement stated the air pressure at the seawater surface is 1 atm (atmosphere) or equivalent with the pressure of 76 Cm Hg. If we dive at 10 meters deep the water gives the pressure as much as 2 atm and at 20 meters deep the water pressure will be 3 atm. So, we can imagine at 2,000 meters deep the water pressure will increase up to ± 201 atm. And at 7,000 meters deep the water pressure will be ± 701 atm. Such high pressures make the gas easily to dissolve into the seawater followed by the decrease of dissolved oxygen. The dissolved and dispersed CO_2 would then become part of the global carbon cycle (IPCC, 2005). It was stated in the report that it is ideal for storing CO_2 away in the deep ocean for even longer period of time including forming solid CO_2 hydrates and/or liquid CO_2 lakes on the sea floor, and dissolving alkaline minerals such as limestone to neutralize the acidic CO_2.

Although the benthic organisms as epi-faunas are scarce in the deep sea, it may be expected to obtain the specific bizarre species as well as in the marine trenches, such as giant isopods, deep ocean sea-cucumbers (*Scotoplanes*) and stalk coelenterate *Umbellula* at the depth of 1500 m and 5000 m. Additionally the nekton of the deep sea can also be found such as dragon fish, lantern fish, angler fish, coffin fish, culper eel and others. The oceanographic research expedition in Mariana Trench at the depth of 11 km deep located at the northeast of the Philippines which had been carried out by American and French scientists also discovered some of those bi-

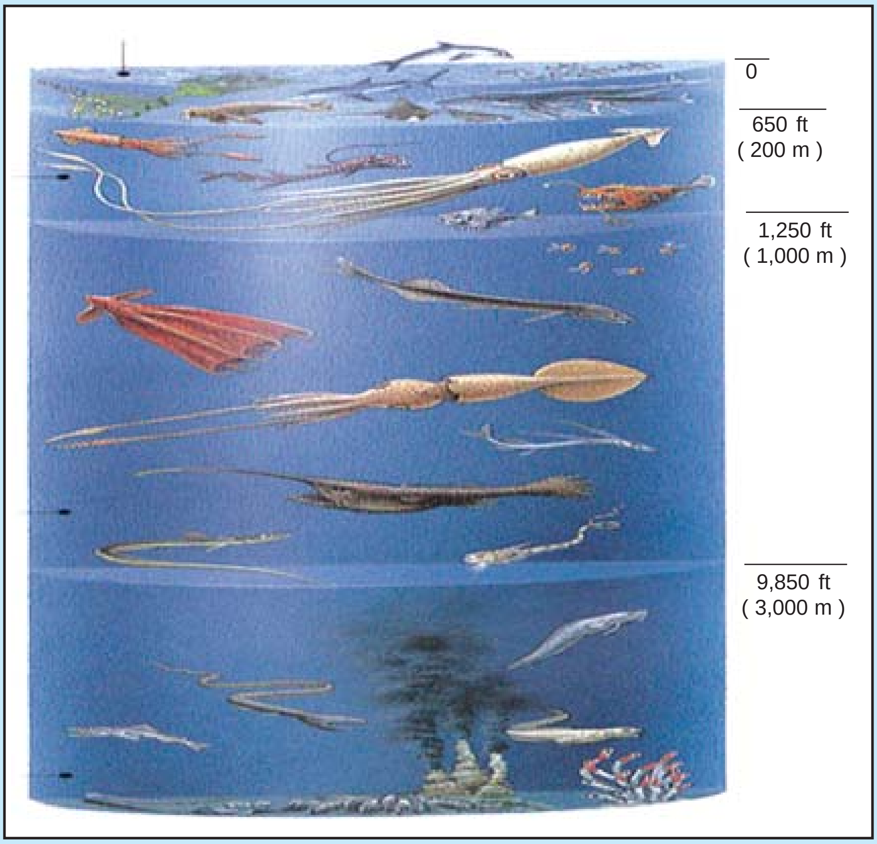

Figure 1
Some specific bizarre species in the deep sea based on the depth segmentations

zarre species in 1960's. Some deep sea species are shown in Figures 1, 2, and 3. It is unclear how or whether the species and the ecosystem would adapt to chemical changes.

According to other reports, the residence time of CO_2 in the atmosphere takes place along 7 years without any additional new emissions, but 40 % of these quantities will be decreased naturally. Part of these quantities will be used for photosynthesis of terrestrial vegetations and, invasion (I) process of such gas which penetrates into the seawater column. The invasion of CO_2 is also utilized for photosynthesis of aquatic vegetations (such as phytoplankton, sea grass, sea weed and *aufwuchs*), as raw material for making shell of marine organisms, the growth of coral reefs, and making balance to the pH of seawater. On the contrary there is an evasion (E) process of such gas coming out from seawater column through the interfacial layer to the atmosphere. Those processes are called as CO_2 exchange rates which the value can be calculated by using the ^{14}C isotope based on the Broecker (1963) formula:

$$I\,C_A\,A_{A\text{-}S} = E\,C_S\,A_{A\text{-}S} + \lambda\,C_O\,N_O$$

Where:

- I = Invasion rate of CO_2 (molar/m^2/year) through the interfacial layer between the atmosphere and seawater column
- E = Evasion rate of CO_2 (molar/m^2/year) through the interfacial layer between seawater column and the atmosphere.
- C_A = ^{14}C concentration in the mean of atmospheric CO_2 (molar $^{14}CO_2$/molar CO_2)
- C_S = ^{14}C concentration in the mean of CO_2 at the seawater surface (molar $^{14}CO_2$/molar CO_2)
- $A_{A\text{-}S}$ = Interfacial area between atmosphere and the seawater column (m^2)
- Co = ^{14}C concentration in the average CO_2 of the oceanic water (molar $^{14}CO_2$/molar CO_2)
- No = Total CO_2 in the oceanic water (Molar)
- (λ) = Decay constant of ^{14}C (year^{-1})

Since the natural process is always running to reach an equilibrium condition, and the reaction speed of CO_2 to form $CaCO_3$ which settles down on the sea floor and the influx of CO_2 from the river drainage can be ignored, so the rate of invasion (I) is equal to the rate of evasion (E) from the column of seawater to the atmosphere every 1 m^2 per year. Therefore the above Broecker's formula is changed up to:

$$I = \frac{(\lambda)(C_o / C_A) * No}{\{1-(C_s / C_A)\} * A_{A-S}}$$

Result of the calculation of C_O/C_A from the literature pointed out as much as 0,85 ± 0,05 and the estimation of $\{1-(C_S/C_A)\}$ was 0,050 ± 0,015 respectively.

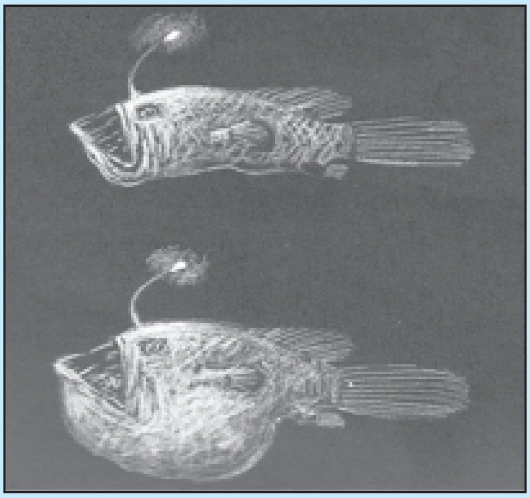

Figure 2
The lantern fish *Melanocetus johnsoni* are most abundant at depth between 1,500 – 2,000 meters deep (Source: Gross, 1972)

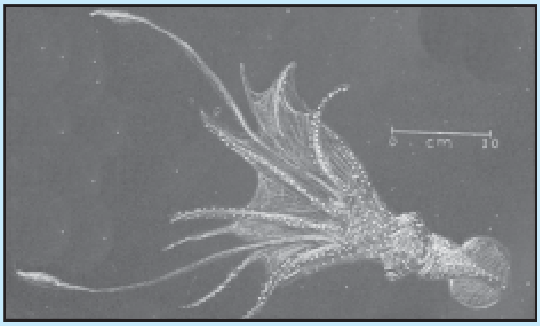

Figure 3
Giant Octopus *Histioteuthis bonnelliana* lives at about 1,000 meters depth. The membrane between tentacles is uncommon. (Source: Gross, 1972)

of the sea, so the value of invasion (I) can be estimated. The wind speed in the Antarctic Ocean is 5 times higher than any other place in the world. The calculation of the exchange rates in this ocean results 50 molars of CO_2 per m^2 per year. So the value of exchange rates at the surface of seawater at any place in the world commonly ± 10 molars of CO_2 per m^2 per year. Such value is considered as a minimum value of exchange rate of CO_2. But if it is assumed the invasion at any other place on the seawater surface in the world has the same value, so the value of (I) will be 20 ± 7 molars of CO_2 per m^2 per year. It was estimated that the square of Indonesian waters according to EEZ version is ± 6,000,000 Km^2. So, if we take the least between 10 and 13 let say 12 molars CO_2 per m^2 per year in Indonesian waters theoretically the value of (I) will be 6,000,000 x 1,000 x 12 = 72,000,000,000 molars CO_2 per year. Since 1 (one) molar is equal with molecular weight of such gas (= 44 grams), so the value of (I) is 3,168,000 tons or 3.2 million tons. That is considered as the least value of such gas which enters the seawater column in Indonesian waters per year. Another report study pointed out that the evident shows the CO_2 exchange rates between seawater and the air are also affected by the partial pressure of CO_2 Furthermore the report study stated that the average partial pressure of CO_2 from the air at the point of the seawater surface as much as 2.3 x 10^{-4} atm where the Chlorinity of seawater = 19 ‰ (or Salinity = 34.3 ‰), at the temperature (t) = 20°C, with the pH = 8.2

In case of the increasing temperature due to global warming, according to the report of UNEP/GEMS/IUCN (1992) stated, the global average increase of temperature is ± 4°C for the last 100 years. If it is assumed the seawater temperature in the tropics at present is increased up to 30° ± 1°C, so the partial pressure of CO_2 may be less than 2.3 x 10^{-4} atm meaning that the minimum value of (I) in Indonesian waters will decrease from 3.2 million tons CO_2 per year. On the contrary, it seems the balance constant of dissociation reaction particularly in the estuarine area and the terrestrial waters (fresh waters) will a little bit increase as presented in Table 2.

It could be understood, the greater the balance constant the smaller the concentration of CO_2 in the water. Since the balance constant depends on several factors such as water temperature, pH and alkalinity of the water, therefore the quantity of CO_2

Table 2
Balance Constants of dissociation reaction at the different water temperatures according to Rûtner

No.	Water Temperature (°C)	Balance Constant	Remarks
1.	15 ± 1	3.72 x 10^{-7}	
2.	25 ± 1	4.86 x 10^{-6}	
3.	30 ± 1	5.43 x 10^{-5} (*)	(*) predicted

Table 3
Fraction of CO_2 retained for ocean storage at two different depths starting in the year 2000

YEAR	Injection Depth	
	1,500 meters	3,000 meters
2100	0.91 ± 0.05	0.99 ± 0.01
2200	0.74 ± 0.07	0.94 ± 0.06
2300	0.60 ± 0.08	0.87 ± 0.10
2400	0.49 ± 0.09	0.79 ± 0.12
2500	0.42 ± 0.09	0.71 ± 0.14

Quoted from: IPCC Technical Summary (2005)

can be estimated by using the recognized formula of Rûtner as presented below:

$$CO_2\,(mg\,/\,liter) = \frac{44}{BC}\,x10^{-pH}\;x\;A$$

Where:

A = alkalinity

44 = molecular weight of CO_2

BC = Balance Constant depends on water temperature (see Table 2.)

With regard to IPCC report (2005) stated if the atmospheric concentration of CO_2 increases, the oceans are expected to take up additional CO_2 gradually over several centuries until a new equilibrium is reached. Furthermore the report also indicated there is no practical physical limit to the amount anthropogenic CO_2 that could be stored in the ocean. How-

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also indicated there is no practical physical limit to the amount anthropogenic CO_2 that could be stored in the ocean. However, on a millennial time scale the amount stored will depend on oceanic equilibration with the atmosphere. Stabilizing atmospheric CO_2 concentration between 350 ppmv and 1.000 ppmv would imply that between 2,000 and 12,000 Gt of CO_2 would eventually reside in the ocean if there is no intentional CO_2 injection. This range therefore represents the upper limit for the capacity of the global ocean to store CO_2 through active injection. The capacity would also be affected by environmental factors such as a maximum allowable pH change. Table 3 shows fraction of CO_2 retained for ocean storage simulated by seven ocean models for 100 years of continuous injection at two different depths.

If CO_2 emission from Indonesia in 1995 in the amount of 295 million tons was used in the estimation, so 60 % of it (= 177 million tons) was still in the atmosphere for at least 7 years (from 1995 – 2002) without additional and intentional release of new emissions from the domestic as well as from the neighboring countries.

The process is still unknown if thousands or million tons of CO_2 per year will be injected into the deep sea as a storage site, therefore it needs further study. Ocean storage has not yet been deployed or demonstrated at a pilot - scale, and it still in the research phase.

III. EFFORTS ON CO_2 CAPTURE AND TECHNICAL METHOD PRINCIPLES OF STORAGE IN A DEEP SEA

Ismukurnianto (2008) stated that petroleum industries in Indonesia have the main program to reduce CO_2 emission in the verities of conversions enabling the CO_2 as an air pollutant decreases down by more than 36,48 MMSCFD or 13315,2 MMSCF per year. This amount is not include with other industries and relevant activities. The latest data in 2009 from the EIA (2010) pointed out that total CO_2 emitted from the world reached up to 30.302.722 million tons. Indonesia only shares as much as 414,941 million tons or 1,369 % of total CO_2 emitted in the world. Sumiarso (2011) in his presentation stated the GHG sources from Indonesian energy sector based on the data in 2008 could be divided into 2 categories:

1. Emissions from energy supply for power plants utilizing fossil fuel as much as 112 million tons CO_2.
2. Emissions from energy utilization (direct combustion of oil, gas and coal) that may be sub divided into:
   - Transportation : 90 million tons CO_2
   - Industry : 109 million tons CO_2
   - Domestic : 22 million tons CO_2
   - Commercial, etc : 18 million tons CO_2

The total amount of CO_2 emissions from energy sector in 2008 was 351 million tons. Furthermore it could be understood the amount of CO_2 emissions from petroleum activities in Indonesia gave 178,532 million tons and from natural gas activity gave 84,265 million tons. So the oil and gas activities only shared in the amount of 262,797 million tons CO_2. Such amount should be reduced or sequestered by physical-chemical methods. The basic principles technology of CO_2 capture could be implemented as commonly described in the CCS methods:

- Precombustion technology
- Postcombustion technology
- Oxyfuel combustion technology

Rojey (2009) stated at the ‘postcombustion’ technology of sequestration for instance needs specific installations which are bulky and costly. Furthermore the author estimated that operational of those installations also requires fairly large amounts of energy, which can lead in some cases to almost double the energy consumption. Other reference also pointed out that at postcombustion as well as at the precombustion of sequestration need a high volume of water almost 90 % higher compared to conventional energy utilization. It certainly needs an environment oriented consideration to solve the problems.

After the CO_2 was sequestered from the atmosphere, then such gas can be transported by pipeline safely since the gas is a stable one, and non explosive. It is stated in the Rojey’s report that the gas is less dangerous to transport and to store compared to natural gas. In European countries, the gas could be delivered by tanker ship then moved to platform which has the submersible pipes to be injected in the deep sea. The gas storage could also be carried out from landbased pipelines directly to the sea floor of the deep sea or subseabed. But in Indonesia, it seems there is no platform in the deep sea zone.

The injected CO_2 in the deep sea may be in the form of gas or liquid. It is rarely in the solid form or

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hydrates of such gas. If the liquid gas is injected on the bottom of the deep sea, it will form a “lake” with more viscous substance than the seawater around it. Care should be taken to decide or to designate the point of the injected area considering the existence of the benthic organisms and/or nekton of the deep sea.

IV. THE LEGAL CONSTRAINTS

The storage of CO_2 in the deep sea involves several international marine environment protection instruments. One of those instruments is London Convention 1972 to regulate the dumping of wastes and other matter. The London Convention framework comprises the London Convention itself and its 1996 Protocol (London Protocol). The London Convention has been in force since 1975 and with reference to IEA and OECD (2007) pointed out that only applies to storage, conducted from aircraft and vessels and platforms in the water column. It does not apply to storage in the ocean sea-bed or its subsoil or from land-based pipeline. Additionally, the London Convention prohibits the dumping at sea of industrial wastes. Industrial waste includes waste materials generated by manufacturing or processing operations. In contrast, the London Protocol which had been entered into force in March 2006 is much more relevant to CO_2 storage. But, principally dumping of industrial wastes is prohibited. Furthermore it is pointed out that the deliberate disposal (“dumping”) into the sea of wastes from vessels or platforms is also prohibited. “Sea” is defined to include seabed and subsoil thereof, but does not include sub-seabed repositories accessed only by land. Thus, geologic storage by injection from vessels or platforms at sea directly into sub-seabed repositories is prohibited; while injection of CO_2 by pipeline from a land-based source to a sub-seabed repository is not prohibited. According to the data of 2005 from International Energy Agency (IEA), it showed that Indonesia was not a member of contracting parties of the Convention as well as the London Protocol. It means that the Convention and the Protocol have not been ratified by the government of Indonesia. It might be caused by the fact that internal seas of Indonesian waters have the average depth around 200 meters deep more or less. But the Philippines, Papua New Guinea and Australia are member of parties which are guided by the Protocol.

The other international marine environment protection instrument is the United Nations Convention on the Law of the Sea (UNCLOS), 1982. This convention was ratified by the government of Indonesia in the Law No. 17/1985 and it enables to store the CO_2 in the Indonesian EEZ or in the depth of Java trench. Unfortunately, the Law No. 17/1985 stated above is not followed up into Government Regulation to control intentional release of industrial wastes in the deep sea particularly connected with the storage of CO_2.

So, the global legal status of intentional ocean storage has not yet been decided. Indonesia also has not set up the legal framework or basic rules to regulate and to control the storage activity of CO_2 in the deep sea up to now. Some Indonesian regulations which should be taken into account connected with the marine environment protection are among others:

- Republic of Indonesia Law No. 32/2009 on Environmental Management and Protection.
- Republic of Indonesia Law No. 05/1990 on Biological Resources Conservation and its Ecosystem.
- Government Regulation No. 19/1999 on Marine Pollution Control and/or Acts of Sea Damaging.
- Ministerial Decree of Minister of State for Environment No. 51/MENLH/2004 Appendix III on Seawater Quality Standard for Marine Biota.

The anxiety will occur about the impacts to marine life and fishery production if the marine trenches which are located in the internal seas were used as the storage sites. The scientific polemic and/or debate appeared among Indonesian government officers concerning on the CO_2 storage in the deep sea due to such gas is considered as a pollutant conforms with the definition of pollution. Maybe the perception will change positively if such gas is considered as a commodity or reused material for other industries. The change perceptions will also be occurred if the profound study enabled to give the safe statement. Furthermore, it should be understood since the CO_2 capture and storage in the deep sea are relatively new breakthrough technology and high cost investment and operation, so from petroleum industries point of view there is still a question mark to be answered on cost recovery. As far as we know there is no regulation connected with the cost recovery for those activities up to now.

V. THE COST OF OCEAN STORAGE

Since the process of sequestration needs a high energy consumption and a big volume of water so the application of such technology should be studied carefully and profoundly. Choice leadership for alternative energy such as wind or steam power plant generated by solar energy or geo-thermal or generated by biomass instead of the energy generated by oil and gas and the use of desalinated seawater might be the best and more economical. Those efforts are the environmental oriented chemical-physical techniques that should be implemented. Furthermore, it should be understood that the Indonesian government policy stated that saving energy and better management on natural resources are necessities to conduct. It's better that Indonesia is not in a great hurry to implement CO_2 storage in a deep sea though from the scientific point of view is enable to do so. The IPCC report (2005) also stated the storage in a deep sea is less acceptable since it is considered as high cost for developing countries. At least the biological-based sequestration of such gas by the plants in order to reduce it, combined with the environmental oriented chemical-physical techniques as stated above might be the honest choice to be offered by the authors. Reforestation and rehabilitation programs on the old sites of denudation areas and/or forest fire are very important, while the re-greening along the coastal areas, within the area of petroleum activities and along roadsides of the big cities should be implemented not only by the ornamental plants but also using the particular species as a shade tree with the broader leaves or dense foliage to insure the maximum photosynthesis such as:

a. *Terminalia catappa*. (Indonesian name: ketapang)
b. *Hibiscus tiliaceus*.(Indonesian name: waru laut)
c. *Ravenala madagascariensis* (Indonesian name: pisang kipas)
d. *Ficus benjamina* (Indonesian name: beringin)
e. *Elaeocarpus ganitrus* (Indonesian name: mata dewa)

The last species stated above, had been studied by ITB in 2007 and the result pointed out that the species of *E. ganitrus* has also the ability to adsorb air pollutants such as NO_X, CO, and SO_X significantly.

VI. CONCLUSION AND SUGGESTIONS

This paper presents some points as our conclusions as follows:

a. Although the storage site is in the deep sea with the depth of more than 2.000 meters, the bizarre species of marine organisms are still found.
b. The physical, chemical and biological impacts will occur in seawater environment if the storage depth is less than 2.000 meters.
c. The overall processes are considered as a high cost technology for the developing countries like Indonesia excluding additional energy cost, so the lower and/or economical cost should be considered.

It is suggested that :

a. The basic legal system to regulate and to control the storage activity in the deep sea should be arranged like the other regulations to control effluents disposed into the receiving water bodies.
b. The CO_2 storage in a deep sea should be studied carefully and profoundly from the laboratory scale as well as in the deep sea.
c. At least the biological-based sequestration combined with environmental oriented chemical-physical techniques will be the honest choice to be offered by using particular species of plants.

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