Utilization of CO_2 for Enhanced Oil Recovery

By

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Final Draft submitted in partial fulfillment of
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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Chemical Engineering Programme
Unversiti Teknologi PETRONAS
In partial fulfilment of the requirement for the
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Approved by

(Ir Abdul Aziz b. Omar)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
NOVEMBER 2002

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

ERNI YUSNIZA KHALED

ABSTRACT

The purpose of the project is to develop a framework, which will enhance students' skills in the process of applying knowledge, expending thoughts, solving problems independently and presenting findings through minimum guidance and supervision. The title for this research project is 'Utilization of CO2 for Enhanced Oil Recovery'.

CO2 is a colorless and odorless gas that exists in the atmosphere in small quantity. However it is one of major greenhouse gases that have a significant impact in society, economics and environment. The increase in anthropogenic or human-related in the accumulation of CO2 in atmosphere as the amount of CO2 emitted is greater than that consumed. In Malaysia, liquid hydrocarbon fuel has been the major contributing source of CO2 emission. CO2 emission from gaseous hydrocarbon fuel has been increased tremendously in the 1990s. as a result of the impact of global warming and climate change, there is a significant international effort including the emissions of CO2. This study is carried out to recommend technically viable CO2 management for enhanced oil recovery.

EOR refers to any process used to increase the ultimate recovery from the reservoir except the injection of plain water or low-pressure gas into a reservoir. It can be at the secondary stage or at the tertiary stage. US National Petroleum Council defined EOR in their Enhanced Oil Recovery report (1976) as; Enhanced oil recovery is the additional recovery of oil from a petroleum reservoir over that which can be economically recovered by conventional primary and secondary methods. A technically more restrictive definition, EOR consists of methods aimed at increasing ultimate oil recovery by injecting appropriate agents not normally present in the reservoir to induce new mechanisms for displacing oil.

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In the name of Allah, The Most Passionate and The Most Merciful

Firstly, *Alhamdulillah*, with His bless, I have been able to finish working on the Final Year Research Project successfully. This project, which entitled CO2 Utilization for Enhanced Oil Recovery, is done for the period of 14 weeks throughout this semester.

I would like to thank several people who helped me in achieving the objective of my project and in completing this final report. In particular, my deepest thanks go to my supervisor, Ir Abdul Aziz b. Omar, who contribute a great deal of attention and did not hesitate to provide me with any of his valuable time throughout the project period. I am also very grateful to PRSS staffs that had helped a lot in understanding and gave all information and encouragement.

To the FYP Committee in Universiti Teknologi PETRONAS (UTP), En Lukman Ismail and Puan Anis, thank you for the patience you have in handling the students.

To end with, thank you goes to my dearest family and friends, who always bring out the best in me and always keep me on the right track.

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ABBREVATIONS AND NOMENCLATURES

ANG	Angsi
atm	atmosphere
Bscf	Billion standard cubic feed
CFCs	chlorofluorocarbons
CH4	methane
CO2	carbon dioxide
EIA	Energy Information Administration's
EOR	Enhanced oil Recovery
EU	European Union
FCCC	Framework Convention on Climate Change
GDP	Gross Domestic product
GHG	Greenhouse Gas
GtC	Giga tonne Carbon
HFCs	Hydrofluorocarbons
IPCC	Intergovernmental Panel on Climate Change
JDS	Joint Delivery System
JE	Jerneh
LA	Lawit
LNG	Light Natural Gas
LPG	Liquid petroleum Gas
MMP	minimum Miscibility Pressure
N2O	Nitrous Oxide
OGT	Onshore Gas Terminal
OSC	Onshore Slug Catcher
PFCs	perfluorocarbons
PGU	Peninsular Gas Utilization
ppm	part per million
RDS	Resak Delivery System
SF6	sulfurhexafluoride
USA	United State of America
USD	United State Dollar
WAG	Water Alternating System

Chapter 1: INTRODUCTION

1.1 Background of Study

1.11 What is CO2?

CO2 is a colorless and odorless gas that exists in the atmosphere in small quantity. However it is one of major greenhouse gases that have a significant impact in society, economics and environment. The increase in anthropogenic or human-related in the accumulation of CO2 in atmosphere as the amount of CO2 emitted is greater that that consumed. In Malaysia, liquid hydrocarbon fuel has been the major contributing source of CO2 emission. CO2 emission from gaseous hydrocarbon fuel has increased tremendously in 1990s. As a result of global warming and climate change, there is significant international effort including the emissions of CO2. This study is carried out to recommend technically viable CO2 management for enhanced oil recovery.

Table 1: CO2 Physical and Chemical Properties

Molecular weight:	44,000
Density at 0°C/1bar:	1,98kg/m^3
Specific gravity:	1,50

- CO2 can exist in three states: a gas, a liquid or a solid
- At normal temperature and pressure, CO_2 exist as a gas
- Under a pressure of at least 60.3psia (415.8kPa abs), liquid CO2 will be obtained
- The normal temperature of solid CO2 (dry ice) is –78.4°C
- CO2 is non-flammable and not very reactive at normal temperature. However its does dissolve in water to form carbonic acid.
- CO2 is a normal constituent of the exhaled air from human and animals. However, high concentration of the gas (>4vol%) is hazardous.

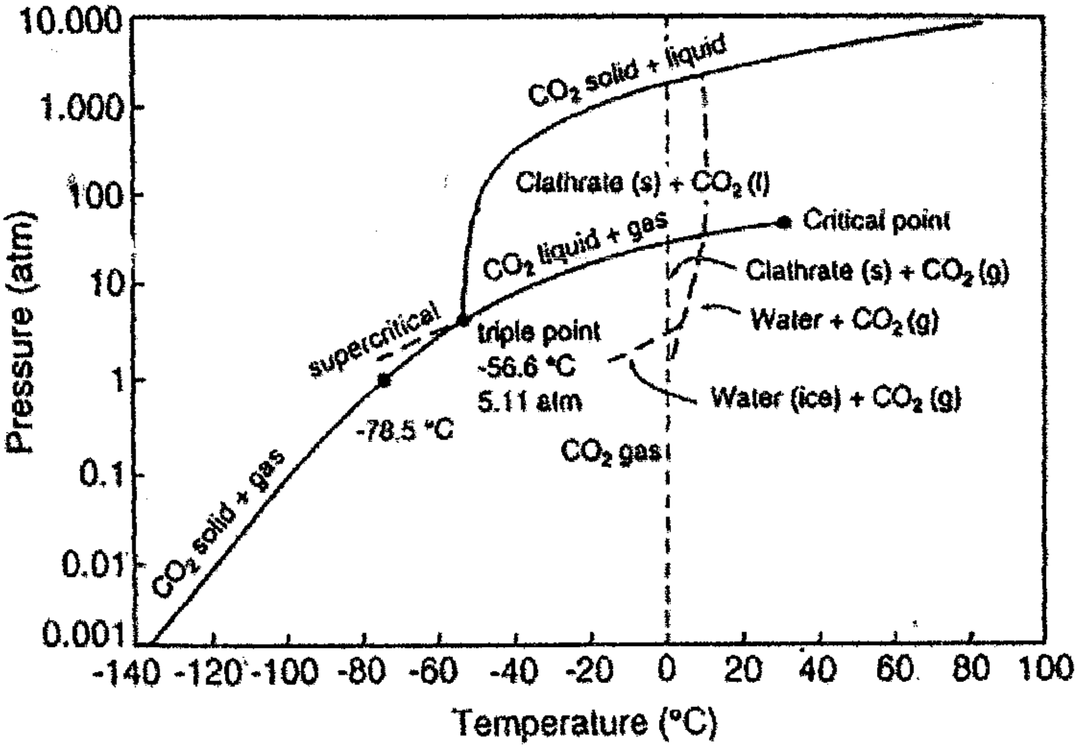


Figure 1: Pressure-Temperature (P-T) Diagram for Carbon Dioxide

1.12 CO2 Emission / Consumption

- Carbon dioxide in nature:

Carbon dioxide is the important link in the mutual dependence cycle between plants and animals in nature. Given off by animal life in respiration and absorbed by plants in the process of photosynthesis, the carbon dioxide cycle affects every living thing. The atmosphere is nature's great storehouse for carbon dioxide, containing billions of tons, even though carbon dioxide represents only three parts per 10,000. Not only animal respiration, but combustion and decay are continually contributing carbon dioxide to the atmosphere. In fact, wherever carbon or its compounds are burned or oxidized, carbon dioxide is formed.

- Carbon dioxide in industry:

The large quantities of carbon dioxide required for commercial use are obtained by a number of methods, chief between which is the recovery and separation of the carbon dioxide content of the exhaust gasses from combustion of a hydrocarbon - such as natural gas or oil. Carbon dioxide is also produced as a by-product from the production of ammonia, lime or phosphate, from the fermentation of beer or alcohol, and from natural carbon dioxide wells. The versatility of carbon dioxide in each of its three forms - as a gas, liquid or solid - has stimulated its application to many industrial problems. The ability to offer extremely fast cooling together with absolute control makes carbon dioxide the perfect super-coolant for manufacturing processes and transportation. Carbon dioxide's physical characteristics make it an ideal inerting agent and pressure medium, while its unique chemical properties give CO2 a role in many industrial processes that cannot be performed by any other substance.

The buildup of carbon dioxide accounts for about two-thirds of the human sources of excess greenhouse warming from long-lived gases. (Figure 2 shows the history of global CO2 emissions.)

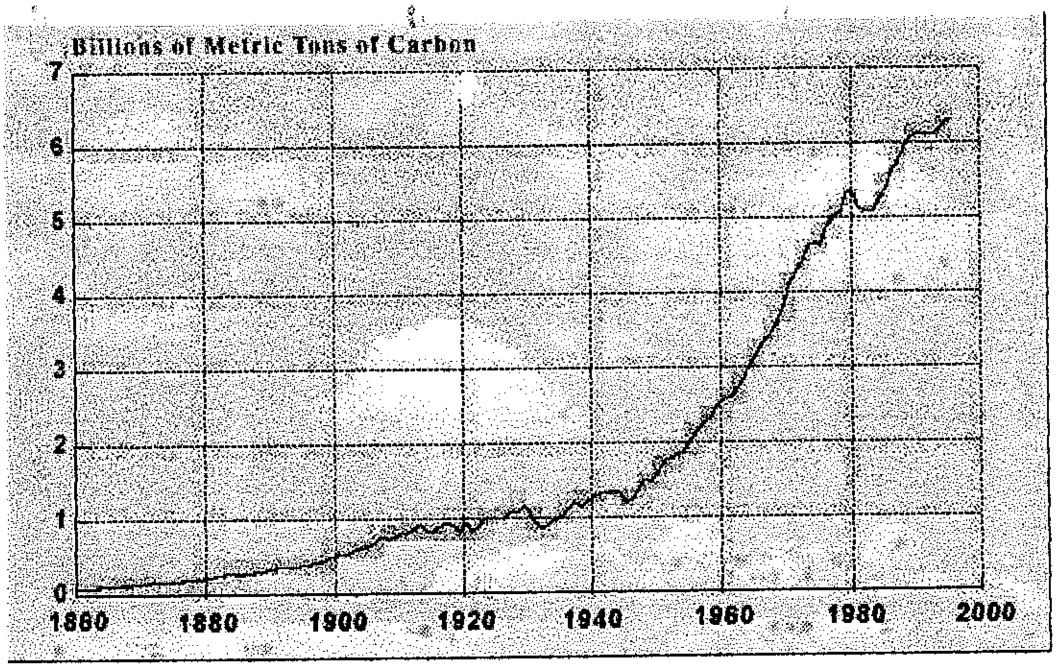


Figure 2: Global carbon dioxide emissions from fossil fuels

Each year, the burning of fossil fuels and biomass, along with other activities such as cement making, releases over seven billion metric tons of carbon to the atmosphere in the form of CO2, raising the atmospheric concentration of the gas by about half a percent annually. Figure 3 shows CO2 emissions for the United States for the period 1980 to 1996.

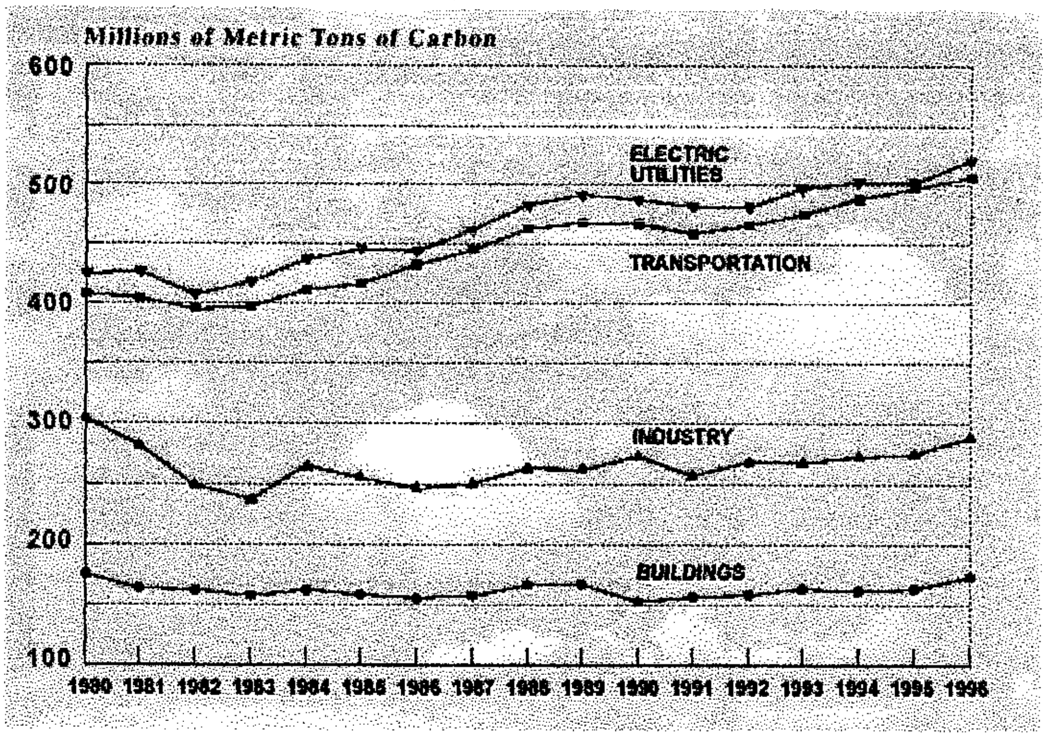


Figure 3: Trends in U.S. CO2 emissions

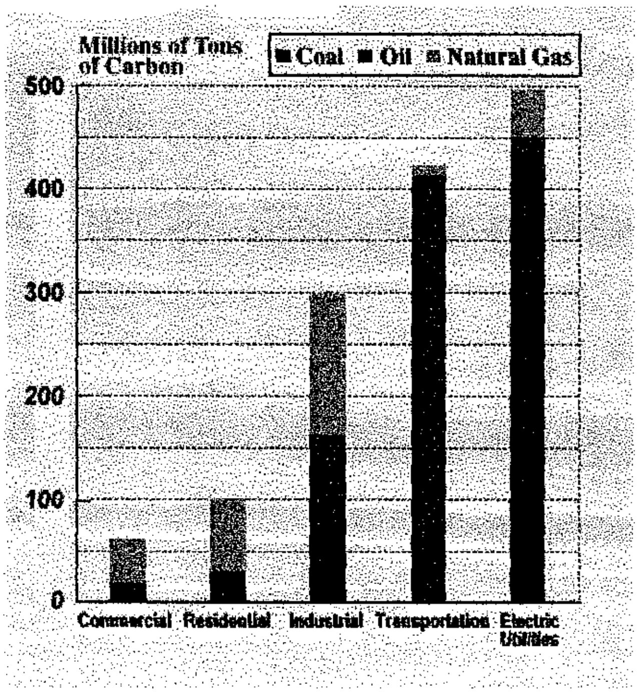


Figure 4: U.S. carbon dioxide emissions by fuel and sector (1994)

Note that electric-power production and transportation are by far the largest and fastest-growing sources. With current global emissions of some 6.3 billion metric tons per year (1995), fossil fuel combustion is the best quantified and the largest source of CO2 from human activity. Since preindustrial times, the global CO2 concentration has increased almost 30 percent, from 280 parts per million (ppm) to about 360 ppm today. (See Figure 5.) Carbon dioxide stays in the atmosphere 50 to 200 years.

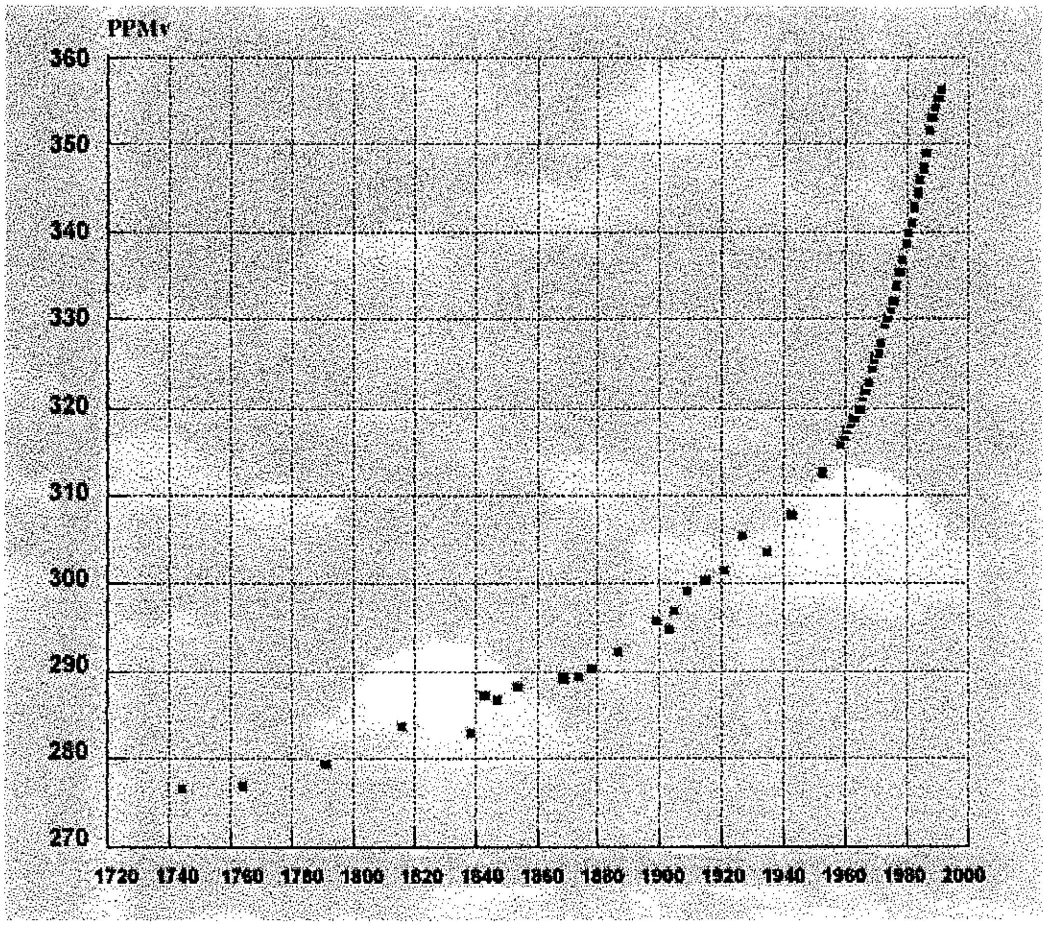


Figure 5: Global CO2 concentration

While electricity generated has been growing, the CO2 emission intensity has been declining due to the net effects of expanded nuclear capacity, improved thermal efficiency of thermal power generation and increased thermal power stations fired by LNG, which offers low CO2 emissions compared with other fossil fuels.

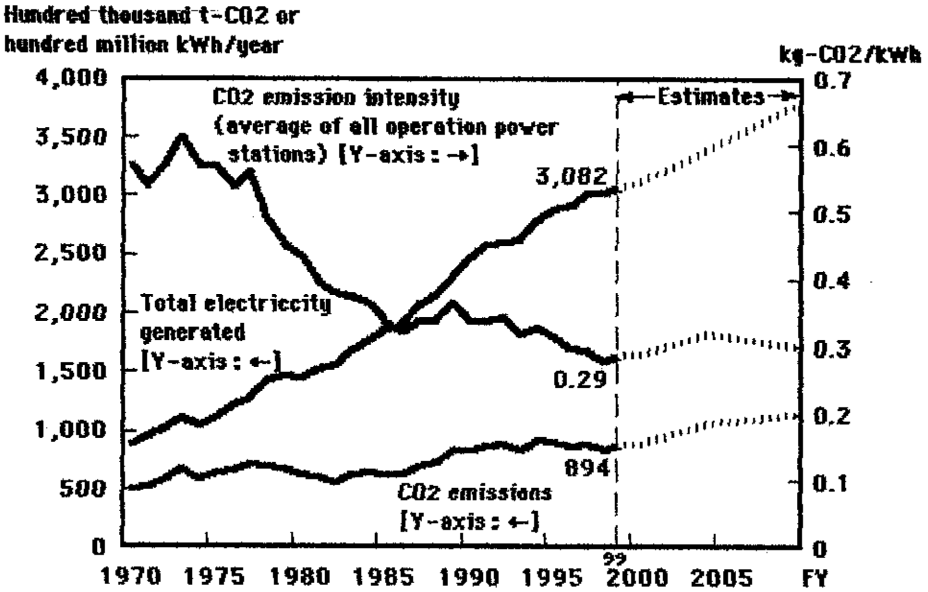


Figure 6: CO2 emission intensity (per kWh electricity by all operational power stations) and CO2 emissions

The CO2 emission intensity has been on the decline due to the net effects of increased thermal efficiency of thermal power generation as well as expansion of thermal power stations fired by LNG, which has smaller CO2 emissions compared to other fossil fuels.

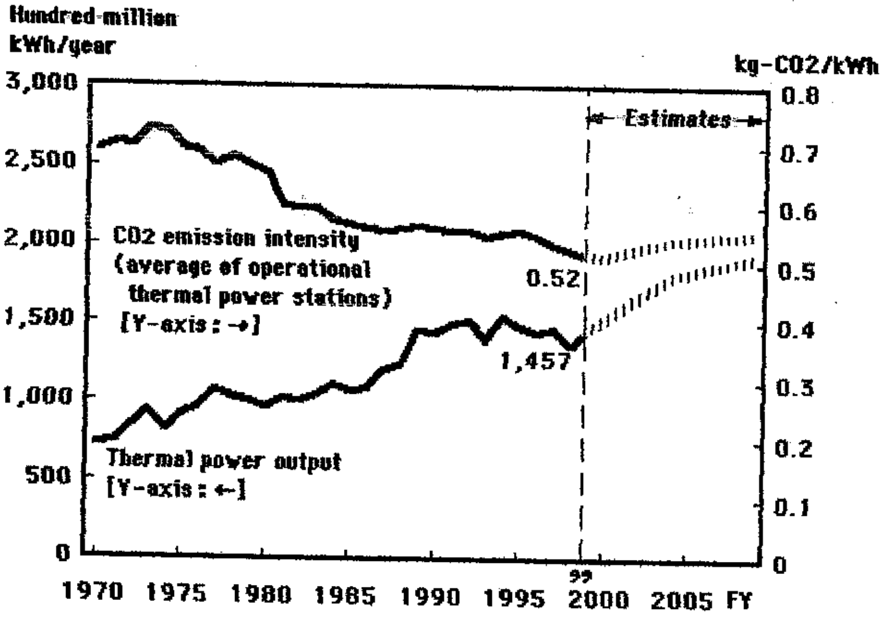


Figure 7: CO2 emission intensity (average of operational thermal power stations)

CO2 emissions have been reduced through a variety of measures, such as the promotion of the optimal generating configuration with an emphasis on nuclear, hydroelectric and LNG-fired thermal power stations, improvements in the thermal efficiency of thermal power generation, and reductions in the transmission and distribution loss rate.

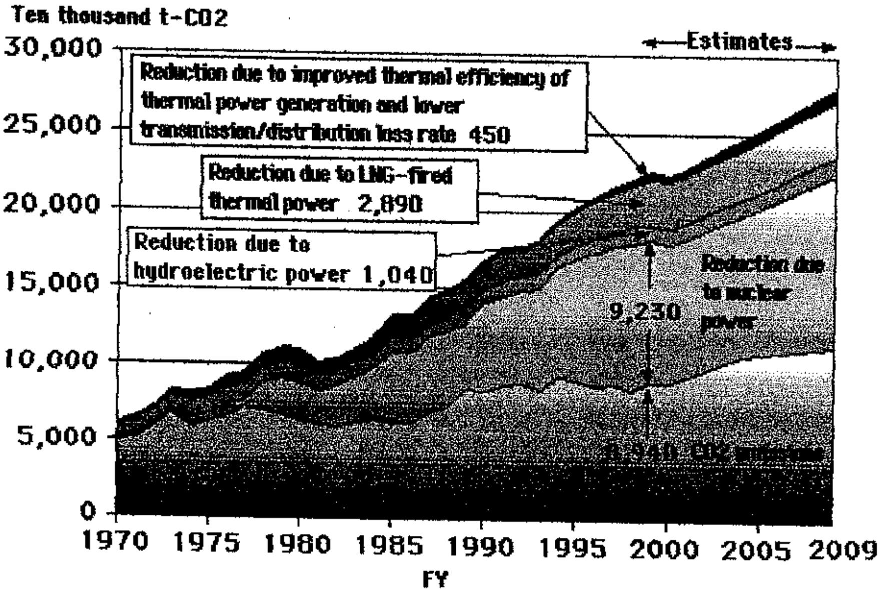


Figure 8: Reduction of CO2 emissions by the optimal generating configuration, etc

Note 1: The amount of CO2 emissions reduced by improving the thermal efficiency of thermal power generation and lowering the transmission/distribution loss rate was calculated with fiscal year 1970 as the base year. The reductions due to the expanded use of nuclear power, hydroelectric and LNG-fired stations were calculated on the assumption that these facilities served as replacements for thermal power stations other than LNG-fired ones.

Note 2: The amount of CO2 sequestered in the green tracts of land we own is estimated at about 140,000 t-CO2 annually.

The CO2 emission intensity (average for all operational power stations) of TEPCO is lower than the intensities for the major European countries and the United States, although it is higher than the intensities for Canada, where hydroelectric power holds a larger percentage share of the total capacity, and France, where nuclear power predominates.

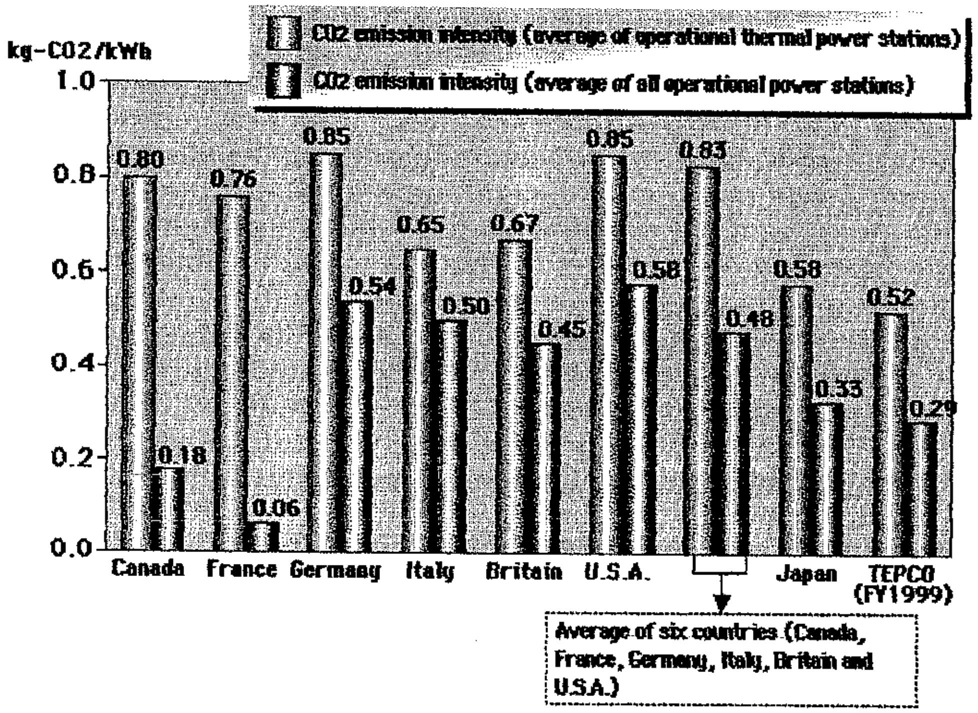


Figure 9: International comparison of CO2 emission intensities

1.2 Problem Statement

1.21 Background on Climate Change Concerns

The United Nations Framework Convention on Climate Change (FCCC), negotiated in Rio de Janeiro in 1992, became effective in March 1994 after the first 50 nations ratified the treaty. Many meetings have been held under UN auspices and more than 160 nations have now ratified the treaty, but disagreement remains concerning the whole issue of global climate change. For example, there is a lack of agreement among:

- Scientists concerning the nature, causes and import of potential climate changes.
- Nations on the steps that should be taken to limit emissions of greenhouse gases (GHGs) that may contribute to climate change and which nations should take action and/or bear the economic cost of the action.
- Policy makers in the U.S. (and other countries) on the need for and nature, effectiveness, timing and economic impact of measures that might be taken to limit GHG emissions.

The FCCC set an ultimate objective of "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic (man-made) interference with the climate system..." The convention did not specify targets or timetables for achieving this objective but did require the developed countries to report on the policies and measures they adopt "...with the aim of returning individually or jointly to their 1990 levels...anthropogenic emissions of carbon dioxide and other greenhouse gases..."

As detailed in Attachment A, the FCCC assigns the lead responsibilities in "combating climate change" to certain "developed" countries. It lists other countries (principally from the former Soviet Union and Eastern Europe) that emit large amounts of GHGs, but recognizes that these nations may not now have the resources needed to reduce emissions. The other 100+ nations that have ratified the FCCC have only limited obligations to reduce GHG emissions. *Note that a number of the nations in this latter group are large and/or rapidly developing countries those are now or may become competitors of the U.S. in international markets (e.g., China).* Nations in each of the three categories are listed in Attachment A of this report.

The United States and other industrialized countries of the world now contribute a large share of the anthropogenic GHG emissions. However, the *growth*s in GHG emissions in the years ahead are expected to come, overwhelmingly, from "developing" countries such as China and India. *In fact, the increases in GHG emissions from developing nations are expected to greatly exceed any reductions that might be made by the industrialized nations.* This fact contributes to the controversy surrounding the climate change debate.

Despite the disagreements, parties to the treaty, including representatives of the U.S., will be meeting in Kyoto, Japan, in December 1997 to set targets and timetables for the reduction of greenhouse gases. Among the targets and timetables that have been proposed within the UN *for the "developed" countries (not all countries)* are the following three *alternative* requirements for reductions in GHG emissions below 1990 emission levels:

- A 20% reduction in carbon dioxide emissions by 2005.
- A 10% reduction in carbon dioxide emissions by 2005 and a 15-20% reduction by 2010.
- A 5 to 10% reduction in all greenhouse gases by 2010.

1.22 Greenhouse gas

Many chemical compounds found in the Earth's atmosphere act as "greenhouse gases." These gases allow sunlight, which is radiated in the visible and ultraviolet spectra, to enter the atmosphere unimpeded. When it strikes the Earth's surface, some of the sunlight is reflected as infrared radiation (heat). Greenhouse gases tend to absorb this infrared radiation as it is reflected back towards space, trapping the heat in the atmosphere.

Many gases exhibit such "greenhouse" properties, including those that occur naturally in the atmosphere, such as water vapor, carbon dioxide, methane, and nitrous oxide, and those that are man-made, such as chlorofluorocarbons (CFCs), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6).

Atmospheric concentrations of several important greenhouse gases (carbon dioxide, methane, nitrous oxide, and most man-made gases) have increased by about 25 percent since large-scale industrialization began some 150 years ago. The growth in their concentrations is caused by human (anthropogenic) activity. In particular, anthropogenic carbon dioxide emissions have increased dramatically since the beginning of the industrial age due largely to the burning of fossil fuels and deforestation

Given the natural variability of the Earth's climate, it is difficult to determine whether any change can be attributed to human activity. Evidence accumulated by the Intergovernmental Panel on Climate Change (IPCC), indicates that global mean surface air temperature has increased between approximately 0.3 and 0.6°C (0.5 and 1.1°F) since the late 19th century. Although there is considerable uncertainty about whether this temperature increase has been caused by anthropogenic greenhouse gas emissions, the IPCC has concluded that the balance of evidence suggests that there has been a discernible human influence on global climate.

1.23 Sources of Greenhouse Gases

As explained in more detail in Attachment B, greenhouse gases (GHGs) come from a variety of natural and human activities, particularly the production and use of energy. GHGs include water vapor, carbon dioxide, methane, nitrous oxide, and others. Water vapor is recognized as the most prevalent GHG by far, but most water vapor comes from natural sources and is not subject to control. Those who are expressing the most concern about the potential for "global warming" are, instead, focusing their attention on GHGs that result from anthropogenic (man-made) activities, with the greatest attention focused on emissions of carbon dioxide (CO_2).

The burning of fossil fuels (coal, oil and natural gas) are the primary sources of carbon dioxide emissions in the U.S. In addition, non-fuel uses of energy (e.g., for making fertilizers or steel) and a variety of other activities are also sources of GHGs. Tables included in Attachment B provide data on:

- Sources of GHG emissions, including carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), CFCs, HCFCs, and "criteria pollutants."
- "Global warming potential" (GWP), which varies widely among the various GHGs.
- The relationship between carbon dioxide (CO_2), carbon, and carbon equivalents of GHGs.

The following table shows the Energy Information Administration's (EIA) estimates of U.S. carbon dioxide (CO_2) emissions *from fossil energy consumption* by each end-use sector:

Table 2: Estimated CO_2 Emissions for 1993, 1994 and 1995 - in Million Metric Tons of Carbon

End Use	1993	1994	1995
Residential	271.6	268.6	270.9
Commercial	212.1	214.1	218.6
Industrial	453.7	463.3	462.9
Transportation	437.5	450.4	457.2
Total Energy	1375.0	1396.5	1409.4

EIA has also produced estimates of U.S. methane (CH_4) emissions. These estimates are shown in Attachment C. Methane emissions in the U.S. are much smaller than carbon dioxide emissions, but are considered important because the "...heat-trapping capacity of methane is 21 times that of carbon dioxide..." and "after weighting emissions by the global warming potential of each gas, methane represents 10 percent of all U.S. anthropogenic emissions."

Actions to require reduction in methane emissions would be particularly important for the people of Texas because significant economic activities in Texas contribute to methane emissions. These include oil and gas production, chemical production, transportation and combustion of fossil fuels (automobiles, electric generating plants and industrial facilities), and rising of cattle and other farm animals.

1.24 Greenhouse Gas Emissions from Sources Other than Energy

In addition to Texas' uses of energy, a variety of other activities in the state contribute to GHG emissions. Data are not readily available on a state-by-state basis to estimate the amounts of emissions. However, it is important to recognize that these activities would be counted as contributing GHG emissions, and measures might be established to force or encourage reductions in the activities and/or the emissions resulting from them. These other activities, along with emission data, where available, are as follows:

1. Fertilizer. The use of fertilizer results in GHG emissions in at least two ways:

- Natural gas and liquid petroleum gas (LPG) are used in producing fertilizer.
- Nitrogen based fertilizers are a source of nitrous oxide (N_2O),which is a greenhouse gas.

2. Raising livestock. Cattle and calves (Texas had 14,800,000 in 1994,) are one of the sources of methane (CH_4) that is also a greenhouse gas. Methane results from incomplete digestion and from animal wastes.

3. Other activities. A variety of other activities, while making up relatively small portions of Texas' Gross Domestic Product (GDP) also involve GHG emissions. These include (but are not limited to) the following:

a) Various industrial activities that are dependent upon adequate and reasonably priced energy but require lesser amounts than the industries listed above; e.g., companies that are in such industries as electronics, industrial machinery and equipment, transportation equipment, food processing, construction, and trucking and warehousing industries.

b) All industries that are dependent upon raw materials produced elsewhere and require significant amounts of energy and/or emit methane or other greenhouse gases in order to produce those raw materials (e.g., production of iron, steel, aluminum). Also, significant amounts of CO_2 are released during calcination of limestone for cement production, lime manufacture, limestone and dolomite consumption, soda ash manufacture and consumption, and industrial carbon dioxide manufacture.

c) Military activities, which are important in the Texas economy, require substantial amounts of energy; e.g., fuel for military aircraft and ships.

d) Methane (CH_4) is released from incomplete combustion of fuels in automobiles, aircraft, ships, and locomotives.

e) Methane (CH_4) released from landfills, domestic and commercial wastewater treatment facilities, and burning of crop residues.

1.25 Greenhouse gas emissions - Current Scenario

Amongst the pollutants mentioned by the Kyoto Protocol, the following greenhouse gas emissions are inventoried: carbon dioxide, nitrogen oxides and methane. Other gases included in the protocol will be inventoried in the future, such as fluoridation hydrocarbons, perfluorocarbons and sulphur hexafluoride.

The carbon dioxide emission in 1989 was of 194,826 Gg (considered to be a reference value), and the level for 1994 was of 125,597 Gg, following that an updated inventory for greenhouse gases will be conducted and validated in 2001, from the perspective of the new data reporting system.

Table 3: GHG emissions forecast (Gg CO_2 equivalent /year)

	2000	2005	2010
Reference scenario			
Total emission of CO_2	162,334.8	187,794.0	228,535.7
Total emission of CH_4	33,531.0	36,740.0	43,125.0
Total emission of N_2O	8,480.0	10,240.0	12,704.0
Total emission	**204,345.8**	**234,774.0**	**284,364.7**
Minimum scenario			
Total emission of CO_2	158,445.9	178,926.0	201,447.5
Total emission of CH_4	33,445.0	33,712.0	36,368.0
Total emission of N_2O	8,128.0	9,024.0	10,112.0
Total emission	**200,019.0**	**221,662.0**	**247,927.5**
Maximum scenario			
Total emission of CO_2	150,807.9	156,432.0	167,655.5
Total emission of CH_4	32,879.0	32,164.0	32,227.0
Total emission of N_2O	7,744.0	7,904.0	8,256.0
Total emission	**191,430.9**	**196,500.0**	**209,138.5**

In Kyoto, Japan, 1-11 December 1997, 167 countries reached an agreement, known as the 'Kyoto-Protocol', which establishes the terms and rules of monitoring the gas that determine the greenhouse effect for the earth. The Kyoto Protocol provides that till 2012, the medium quantity of GHG (six gases in particular) to be reduced with 5.2% below the level from 1990.

The main methods that must be taken into consideration in order to achieve the objectives of the Kyoto Protocol are:

- The industry must become more efficient from the point of view of energy consumption, shifting from the use of fossil fuels with the high carbon content (coal) to fuels with a low-grade of carbon (natural gases) or alternate fuels.
- The energy sector, from extraction till consumption, must be restructured so that it becomes more efficient and less pollutant.
- The transportation must use low consumption and less pollutant means of transport
- The construction sector must be energy efficient
- The equipment and the products must have low energy consumption
- The forests will be protected and even extended.

1.3 Objectives and Scope of Study

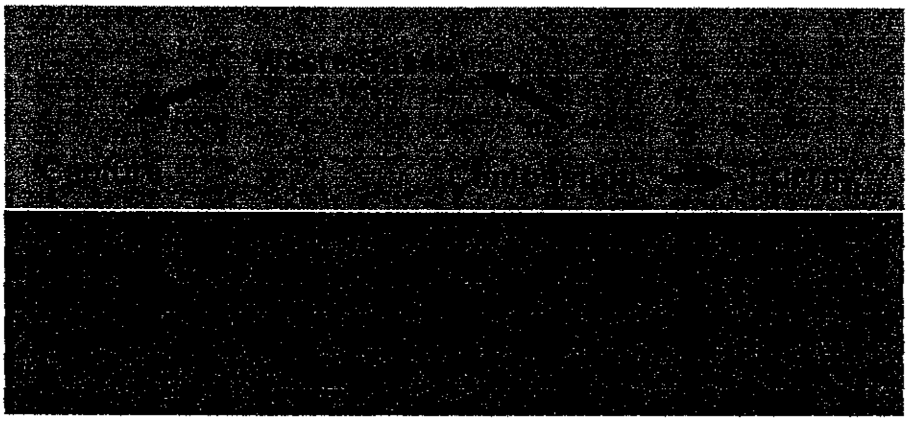
The main objective of this study are:

- To review of technologies for CO2 utilization by enhanced oil recovery
- To review current status of CO2 production from various field in Peninsular Malaysia
- To investigate the technical applying carbon dioxide and hydrocarbon miscible flooding in selected oil field.
- Beside that, by doing this study, an experimental research on feasible candidate fields to establish the behavior of reservoir rock and fluid under EOR conditions.
- To investigate the technical feasibility of increasing oil recovery efficiency and reserves of major producing field though an EOR process utilizing CO2 gas injection.

Chapter 2: LITERATURE REVIEW AND/OR THEORY

2.1 EOR – Definition

EOR refers to any process used to increase the ultimate recovery from the reservoir except the injection of plain water or low-pressure gas into a reservoir. It can either be at the secondary stage or at the tertiary stage. US National Petroleum Council defined EOR as 'Enhanced oil recovery is the additional recovery of oil from a petroleum reservoir over that which can be economically recovered by conventional primary and secondary methods'. A technically more restrictive definition is EOR consists of methods aimed at increasing ultimate recovery by injecting appropriate agents not normally present in the reservoir to induce new mechanisms for displacing oil.



This graphic represents a Carbon Cycle as it is unique to the energy industries. The normal situation is that waste gases, especially CO2, from refining processes and fuel combustion are mostly vented to the atmosphere after taking out only some of the most noxious by-products. Our goal should be to capture as much of this waste gas from energy production as possible, and put it to good economic use, or return it to the underground reservoirs where it originated. In theory, all the waste CO2 gas from fossil fuel combustion has a place back in the earth from whence the fossil fuel came. The extraordinary expense of producing the fossil fuels and connecting the reservoirs to the surface has already been taken. How much more could it cost to use that same facilities to start returning the spent carbon back down the same wells into the same reservoirs? Other economic uses of CO2 exist, such as dry ice for shipping and bubbles in soda pop, but using it for EOR has a much, much larger potential, and we take the carbon out of the environment for good.

- EOR – Worldwide

Worldwide, over two million barrels of oil per day (bopd) are being produced from various EOR projects. In 1998, of 199 active U.S. EOR projects producing a total of 759,965 bopd, 66 projects were miscible CO2 floods accounting for over 179,000 bopd of production. U.S. EOR from steam injection accounted for 419,349 bopd of production, while hydrocarbon gas injection accounted for 102,053 bopd. Almost all U.S. steam floods are located in California, because of the state's abundance of shallow, "heavy" oil, and almost all U.S. CO2 floods are in west Texas, because there's a source of CO2 nearby to flood the deep, "light" oil reservoirs. (The above numbers do not include waterflooding, even though waterflooding an oil reservoir is common practice, many times as a pre-requisite to gas flooding, and accounts for significant enhanced oil production worldwide. Today, in California alone, active waterflood projects were injecting 2.2 million barrels of water per day adding about 140,000 bopd of production.)

- EOR with CO2

Basically, a miscible gas flood of an oil reservoir works because an injected gas becomes miscible, or becomes one liquid phase, with the oil, and helps the oil move through the rock reservoirs and up and out the wells. A gas (like CO2) is continually added to an oil reservoir by being compressed and pushed in, and when it is produced back out with the enhanced oil, it is recaptured and reinjected along with new gas, produced back out, added to new, re-injected, and so on, until as much enhanced oil has been produced as possible. MEI owns an interest in a mature CO2 flood of an oil reservoir in west Texas, started in 1983, which now adds 10 million cubic feet per day (cfpd) of new CO2 (piped in from New Mexico) to 30 million cfpd of CO2 being recycled from the enhanced oil production. That's 40 million cubic feet of CO2, weighing 2,000 tons, handled and re-handled, every day.

2.2 EOR – Benefits

The issue of emission and sequestration of green house gas, especially CO2, becomes much hot and attracts international society to pay attention. By utilizing CO2 using EOR technique, we can obtain benefits such as:

- Monitoring CO2 by converting a waste product into useful product.
- EOR is one of the promising options for CO2 utilization. Thorough this option the benefit both to economic and environment can be obtained
- One of CO2 storage technique
- EOR can increased oil production
- Cost saving through efficient operation of high CO2 utilization.
- Development of in-house expertise and facilities with regard to CO2 technologies
- Conformance to natural gas specification – avoidance of associate penalty

2.3 EOR – Economic Factors

The economic for a CO2 – EOR project primarily depends on several factors and involves uncertainties in many aspects. Uncertainties in measuring reservoir characteristic and predicting reservoir behavior and the variations in the costs of drilling wells and the cost for the equipment can vary the cost up to US$25 per tonne of CO2. the major aspects to take into consideration while installed of EOR system are:

- Reservoir condition
- Tax
- CO2 separation process involves
- Rate of production
- Distance to the source

US National Petroleum Council 1981 estimated cost elements before taxes as shown on the chart:

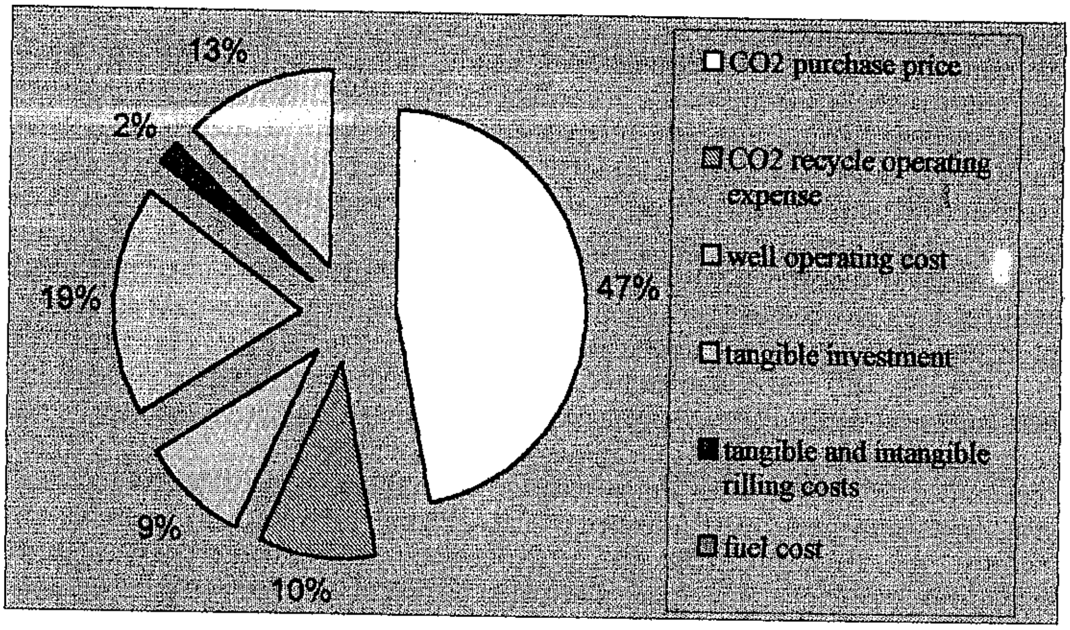


Figure 10: Chart shown undiscounted cost element before taxes

In practice, the operating cost for an EOR project is 5% to 10% of the capital cost (assume 6% for the cost estimation). The cost that consider under Capital Cost are such as:

- Feasibility study, project engineering and design
- CO2 delivery / resale pipeline
- Producing well workovers and installation of high capacity lift system
- New development well
- Injection distribution system
- Surface production facilities
- Water injection plant including filtration and treating
- CO2 recompression plant including dehydration

And for operating cost, the elements that consider under it are:

- Fixed annual field operating cost for surface production facilities & direct overhead
- Fixed well operating cost
- Unit lifting, treating and handling cost to produce fluids

- Water treating and injection plant
- CO2 recompression and dehydration plant

The brake down can be summarize into these two categories:

Main controller contributor	*Other cost distributor*
1. Compression • to maintain CO2 in the supercritical state during transport and injection, requires a minimum pressure of 82atm. • Use IFP study on Dulang as a basis. Maximum 5 recompression units (1-12bars, 15-40bars, 40-80bars & 160-320bars) at the injector • *Assume 4% inflation rate* 2. Pipeline • A function of internal diameter, pipe thickness, length and water depth. • Determine pipeline diameter from the flow rate • Multiply by 2 to allow for corrosion 3. Injection well • Use 3.5MMUSD/well drilling cost • Assume 5-spot pattern (1-10 ratio) • Assume 6% operating cost	• Equipping the injectors = USD150000/well • Surface facilities for injectors = USD55000/well • Surface facilities for producers = USD25000/well • Work-over for producers = USD100000/well

2.4 EOR – Limitation

Economically successful EOR projects are difficult to predict because ultimately they are dependent on the vagueries of the geology miles below the earth's surface, and the price of oil, both of which are difficult to predict with certainty. Traditionally, the farther away from abundant, naturally occurring CO2 in a relatively pure state, the less economic viability there was for a CO2 flood. The west Texas CO2 floods are near the CO2 deposits produced in New Mexico, and that's why distant California has no active CO2 floods. But that's changing as the energy industries wake up to the fact that their waste CO2 is a valuable resource for EOR.

The screening criteria that determine the suitability are based of the statistic on successful commercial IOR operation and were updated according to Table 10.

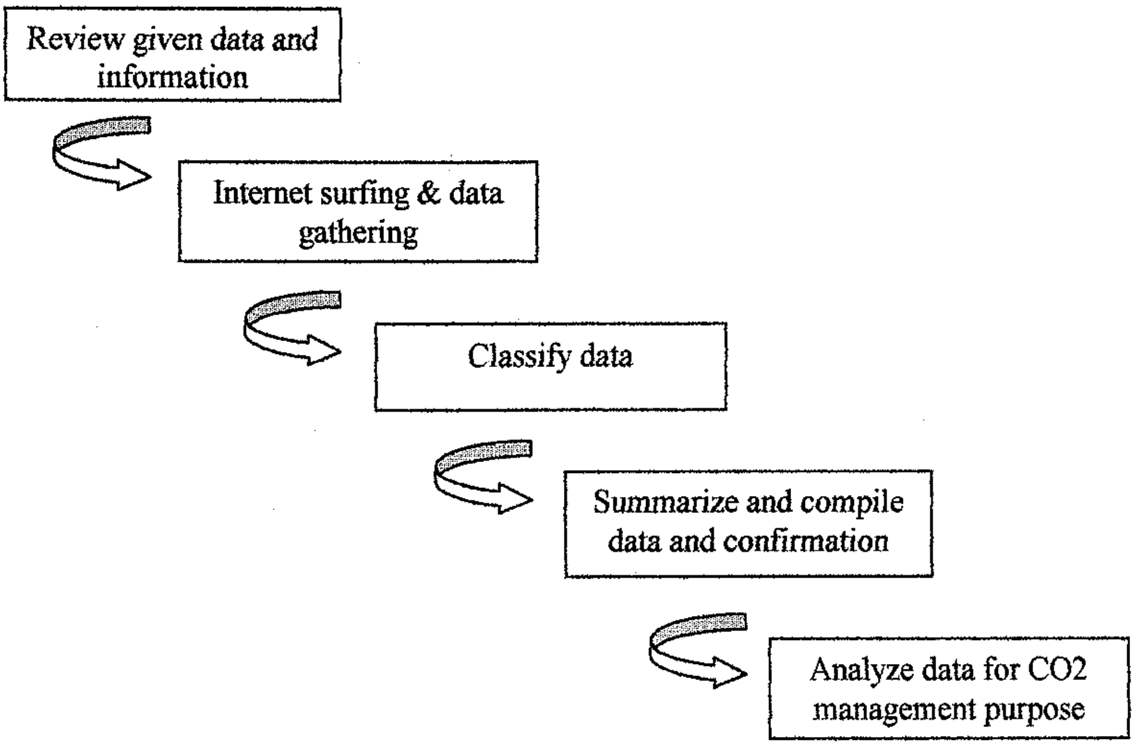
Table 4: Screening Criteria for EOR

EOR Process Criteria	CO_2 Miscible	Immiscible CO_2
Depth, m	>600	>200
Temperature, °C	>30	-
Oil Saturation, %	>25	>50
Initial Pressure, kPa	>MMP	<MMM
Oil Density, kg/m3	<920	<980
Oil Viscosity, mPa.s	<10	<600
Gas Cap present	No	No
Bottom water present	-	No
Active water drive	-	No

Chapter 3: METHODOLOGY/ PROJECT WORK

3.1 Data Gathering Process

The data was gathered and reviewed as shown in the systematic procedure below:



3.2 Miscible/Immiscible Displacements Techniques

An injected gas becomes miscible with oil when enough light hydrocarbons concentrate in the gas for the gas and liquid to become mutually soluble. If NGL is not the injected gas, other gases such as carbon dioxide, flue gas or nitrogen can be used. All of these gases become miscible only when their density is high, generally greater than 0.5. Thus, they work best at high pressure.

For carbon dioxide, the minimum pressure is 1,070 psig at 88 °F (31 °C), i.e., when CO2 becomes supercritical and its gas and liquid are no longer separate phases. At those conditions, which are conveniently close to the pressure and temperature of many fields, carbon dioxide's density is high enough for it to be a good solvent for oils, which contain a significant volume of light hydrocarbons. As the temperature increases (CO2 density decreases), or the API gravity decreases (light hydrocarbons decrease), the pressure needed to attain miscibility increases. So at 170 °F (75 °C), carbon dioxide develops miscibility at pressures greater than 2,500 psig.

Nitrogen on the other hand becomes an efficient miscible displacement only for light oils, temperatures greater than 240 °F (115 °C) and pressures greater than 5,000 psig, where its density is high enough to extract light-hydrocarbons from the oil. Flue-gas works well at lower pressure and temperature, since it contains around 13% carbon dioxide.

The following photographs illustrate a CO2 miscible process for a selected reservoir. The experiments were conducted in an etched glass model at 105 °F (41 °C), at pressures of 1,000, 1,500 and 2,500 psig. The models were viewed with a stereomicroscope so that each millimeter in the original photograph is 50 microns.

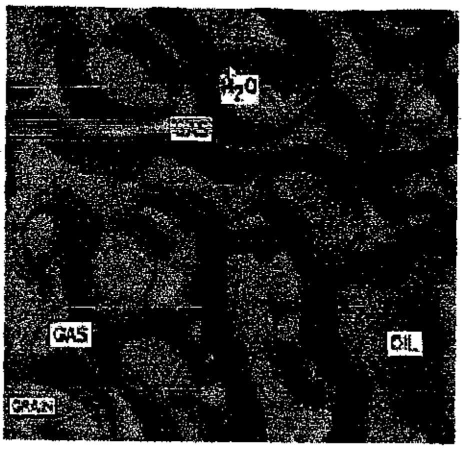


Figure 11 – 1000 psi - Immiscible Carbon Dioxide

The gas and oil phases are separate– Oil spreads between gas and water - Gas can diffuse into pores and form a isolated Gas Bubble - This helps displace the oil.

Figure 12 – 1,500 psi – Miscibility Begins to Develop

A clear Middle Phase forms and spreads between the oil and gas. The interfacial tensions are very low. Oil recovery will be high and the displacement will appear to be above the Minimum Miscibility Pressure (MMP).

Figure 13 – 2,500 psig – CO2 Has Developed Miscibility with the Oil

Well above the MMP - The miscible fluid is the very light fluid flowing in a channel past the darker bypassed oil. The miscible fluid is Extracting NGL from the bypassed oil.

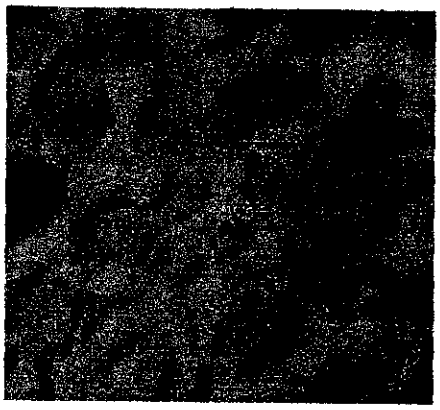


Figure 14 – Lower Liquid Begins to Condense

After some time, the light hydrocarbons have been depleted from the bypassed oil and the Lower Liquid (dark spots) begins to condense from the miscible fluid. The condensed phase appears to coat the wall of the model (wet),

As more lower liquid condenses from the miscible bank, the lower liquid phase coalesces into a continuous phase, Figure 15. The dark lower liquid phase (a heavy-oil containing some CO2) is miscible with the bypassed oil, but immiscible with the CO2 rich gas phase. The dark lower liquid may wet surfaces because it was enriched in the

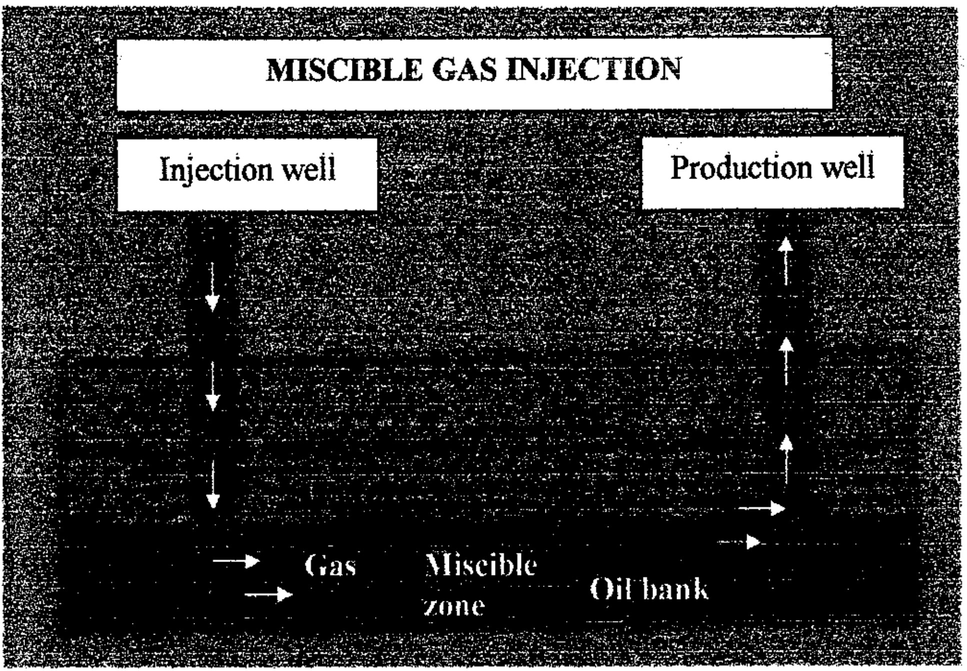


Figure 16: Miscible Gas Injection Diagram

The oil and the injected gas remain in two phases. The gas pushes the oil towards the producing well. Injection pressure < MMP. The purpose of immiscible gas injection is normally to maintain the reservoir pressure. Similar to the miscible gas injection of the gas only or alternated with water for better sweep efficiency.

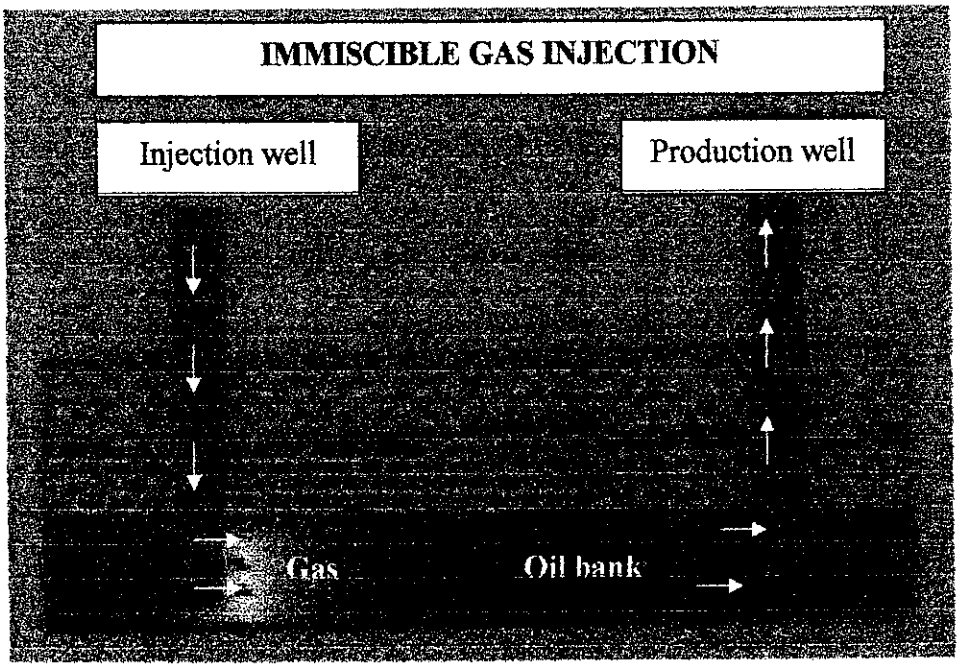


Figure 17: Immiscible Gas Injection Diagram

Chapter 4: RESULT AND DISCUSSION

4.1 Current Gas (CO2) Production

Offshore gas is currently transported through five major pipelines, namely Lawit (LA), Jerneh (JE), Angsi (ANG), Resak Delivery System (RDS) and Joint Delivery System (JDS) to onshore terminals. (Appendix 1) Current Peninsular Gas Utilization (PGU) sales gas demand is 1.8Bscf/day with average growth of 6% per annum. Current natural gas production is 2.3Bscf/day.

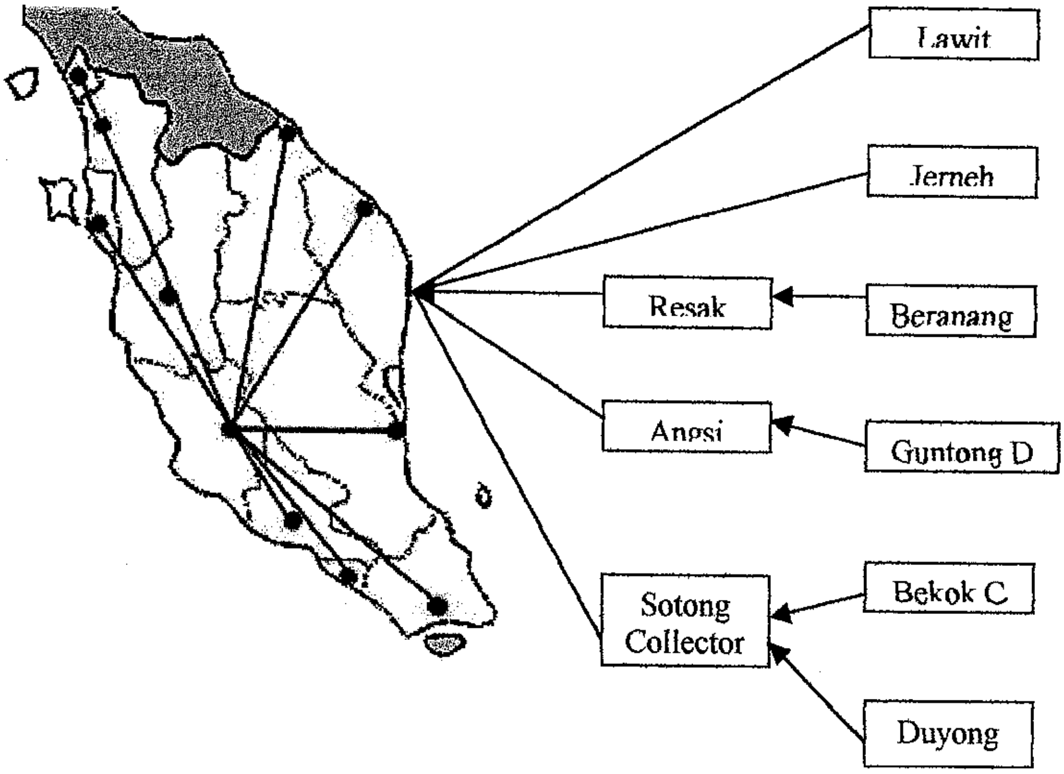


Figure 18: Current Production Gas Network

Gas receives at Onshore Slug Catcher (OSC) has been increasing at an average rate of 17% per annum.

Table 5: Average Composition of OSC (1997-2000)

Component	Mol%
C1	85.36
C2	5.31
C3	2.34
C4	1.31
C5	0.33
C8+	0.25
CO2	4.90
H2O	0.01
N2	0.20

Gas received by Onshore Gas Terminal (OGT) is predicted to peak in 2001 at rate of 1152MMscf/day.

Table 6: Average Composition of OGT (1998-2005)

Component	Mol%
C1	79.07
C2	8.28
C3	3.96
C4	1.66
C5	0.26
C8+	0.31
CO2	5.77
H2O	0.01
N2	0.66

Gas from offshore is currently collected at OSC and OGT before treatment at gas processing plant (GPP). Current annual CO2 production from GPPs' AGRUs is estimated at 3.2 Mega tonne. PGU sales gas demand is projected to increase to more than 2Bscf/day by 2002. Current PGU gas demand is 1.8Bscf/day. Increasing demand will require development of high CO2 content fields eventually. The initial forecast PGU sales gas demand for year 2001 is 1.8Bscf/day, for year 2005 is 2.5 Bscf/day and for year 2010 is 3.5Bscf/day. After the life of fields has been extended, the revised forecast PGU sales gas demamd from GPP is lowered to 2.0Bscf/day. To sustain the gas demand, development of new fields, inclusive of the high CO2 gas fields would be necessary in the future. The provision for CO2 capture facilities also need to be considers such as the separation, utilization and storage, due to increasing CO2 amount.

4.2 Current Reserves

Gas reserves can be classified into three categories that are pre-development, production and development (Appendix 2). Pre-Development Reserves are expected to be recovered from new wells on undrained portion of the reservoir or where a relatively large expenditure is required to recomplete an existing well or transportation facilities for or improved recovery projects. For Producing Reserves is refer to gas reserve that are currently producing. While Developed Reserves are defined as the estimated quantities of petroleum expected to be recovered from existing wells which including reserves behind pipe. Improved recovery reserves are considered developed only after the necessary equipment has been installed or when the costs to do so are relatively minor.

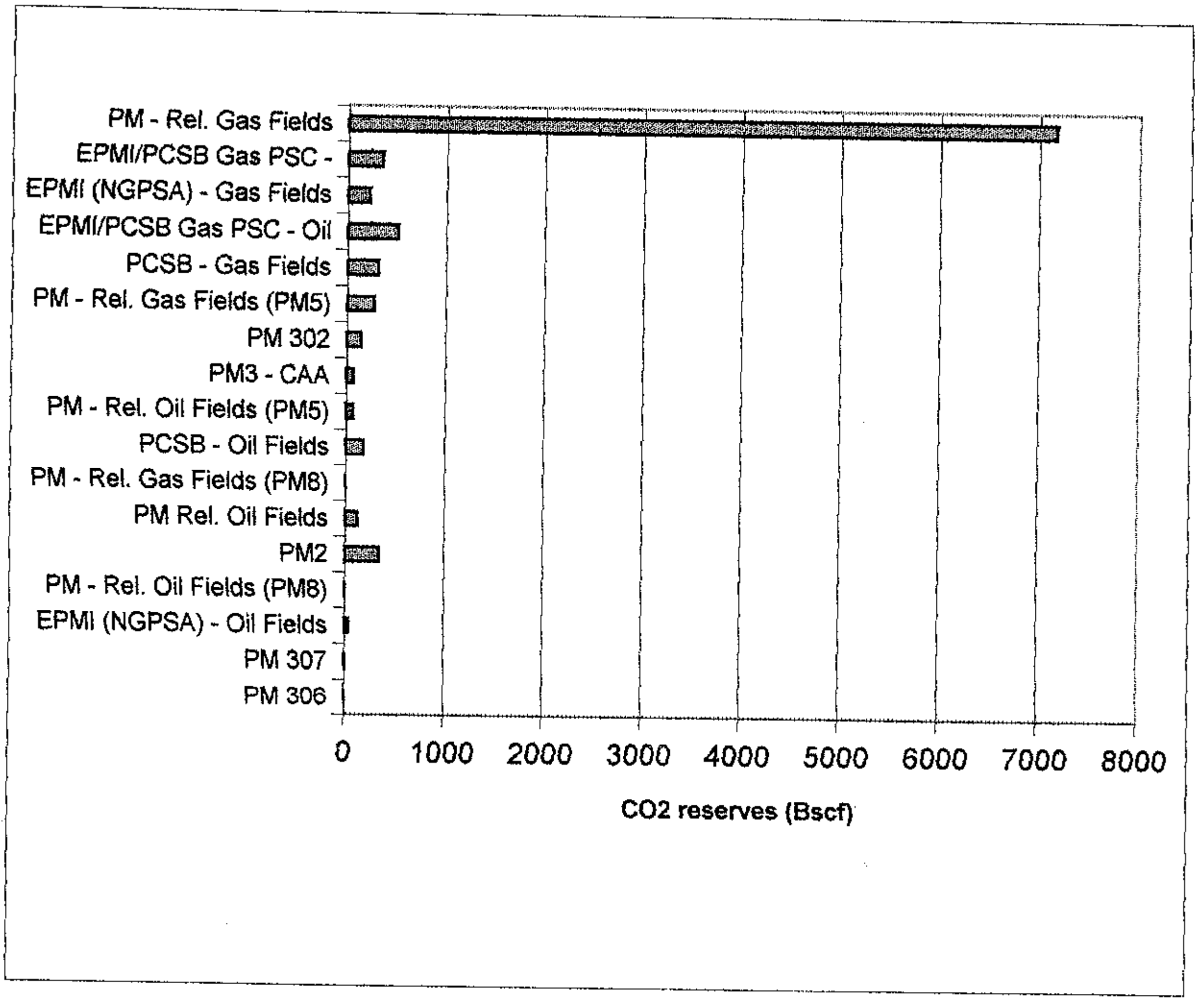


Figure 19: CO2 Reserve from Respective Oil and Gas Fields

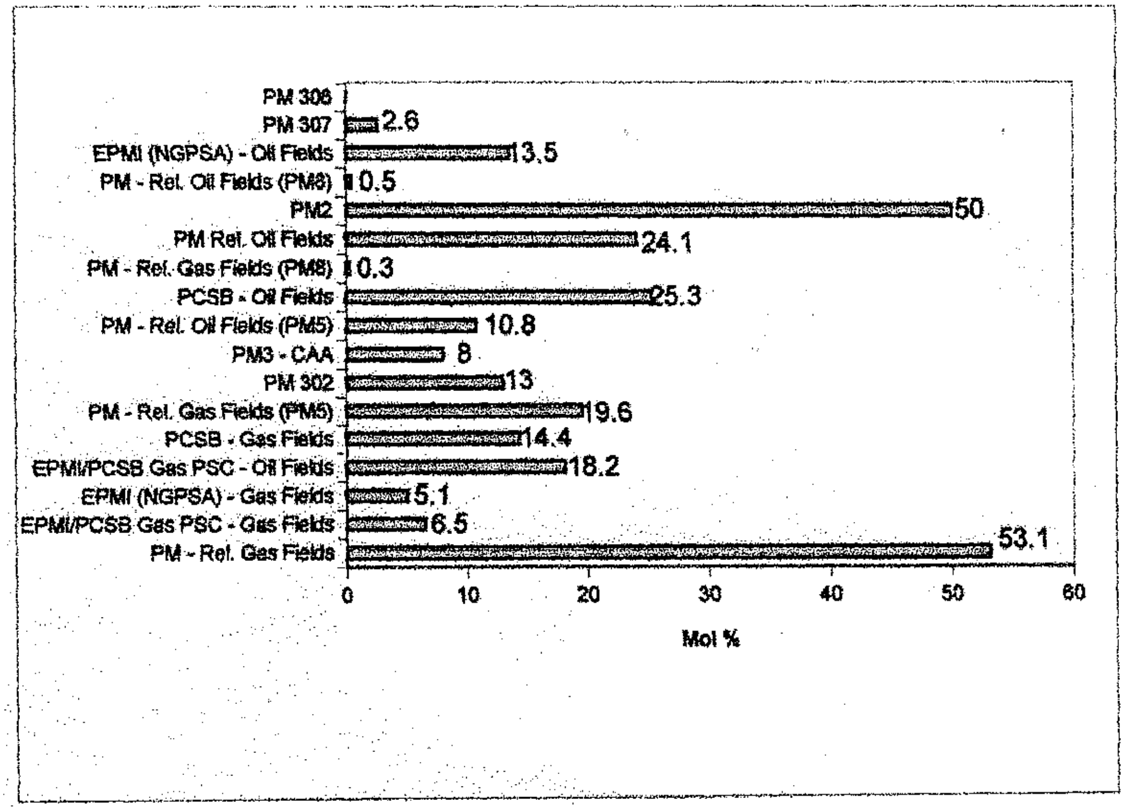


Figure 20: Average CO2 Content for Each Oil and Gas Fields

Chapter 5: Conclusion and Recommendation

CO2 is one of the major greenhouse gases emitted from developed countries ands it is increasing annually. Petronas production fields itself have contribute about 3.2 Mega tonne of CO2 emissions. It makes annual CO2 emission in Malaysia nearly reached 100 Mega tonne, which is still small, compare to USA that emitted 1.5Gtc. Annual global CO2 emission is 6.8 Giga tonne. The total amount of CO2 in atmosphere is 790 Giga tonne carbon, and the total concentration is 360ppmv. The greenhouse gases absorb infrared radiation while letting sunlight though. This heat is there radiated bask towards the surface of earth causing climate warming. The significant impact on society, economics, and environment are raising sea level, wild weather, disruption of ecosystem, thinning ice and hotter time. The recent Kyoto Protocol to United Nation Framework Convention on Climate Change (UNCCC) would, if ratified, required developed nations to reduce their net carbon emissions in the period 2008-2012 by at least 5% of total emission level in 1990. At present, CO2 is mainly used as a feedstock for the chemical production, as well as for enhanced oil recovery (EOR). Small quantity of CO2 has traditionally been used for flood and biomedical applications.

The availability of natural sources in West Malaysia an reduction in the number of hydrocarbon reserves are some of the driving factors for utilization of C)2 in enhanced oil recovery. EOR is one of the promising options for CO2 utilization. Through this option we will benefit both economically and environmentally. In worldwide, over 2 million bscf are being produce from various EOR project. Total gas reserve in West Malaysia is around 25,606Bscf and the total CO2 reserves from those gases are around 9,812Bscf. It is recommended to start EOR with Tiong, Tapis or Guntong since they fall in the most potential group with high gain and low risk. The gas field could be the source of CO2 for the EOR operation to sustain the gas demand; development of new fields, such as Inas/Sepat, Bujang and Ular/Gajah would be necessary in the future. Current CO2 reserve in the reservoirs of Peninsular Malaysia region is about 9.81trilion scf. This represents potential excess CO2 that could be emitted to atmosphere after removal from natural gas to achieve sales gas specification. It is thus important to store/utilize CO2 in order to delay/reduce CO2 emission.

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2) http://www.purgit.com/co2msd.tyml

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4) *Source*: Marland, et al. 1994 "Trends '93: A Compendium of Data on Global Change," Oak Ridge National Laboratory

5) *Source*: EPA, 1995 "Inventory of U.S. Greenouse Gas Emissions and Sinks: 1990-1994" p. A 10

6) *Source*: Neftel et al, 1994 "Trends '93: A Compendium of Data on Global Change," Oak RIdge National Laboratory, p. 13 and p. 19.

7) R.H Perry & Green, 1994; Perry's Chemical Handbook, 6th edition.

APPENDIXES

Appendix 1: Pipeline Distributed Gas Production

Flow into JE	• Jerneh • Bujang
Flow into LA	• Lawit • Bintang • Dammar • Bergading • Inas/Sepat
Flow into JDS	• Tiong • Bekok • Guntong A/B/C • Be-J-15 BD • Tiong/Kepong BD • Tapis I/K • Tapis / IBA • Pulai • Duyong existing • Duyong revisit 3 • W Natuna • MASA
Flow into Angsi	• Guntong D • Seligi AG • Seligi Cap BD • Larut

	• Serok • Angsi • Besar • Telok • Bindu • Gu/Tu/Pa BD
Flow into RDS	• Resak • PM-3 • Melor • Laho • Tangga Barat • Tujoh • Bedong • Bundi • Guling • Noring

Appendix 2: Status of Fields

Producing

- Bekok
- Lawit
- Duyong
- Angsi
- Tiong
- Jerneh
- Pulai
- East Bunga Kekwa – Cai Nuac

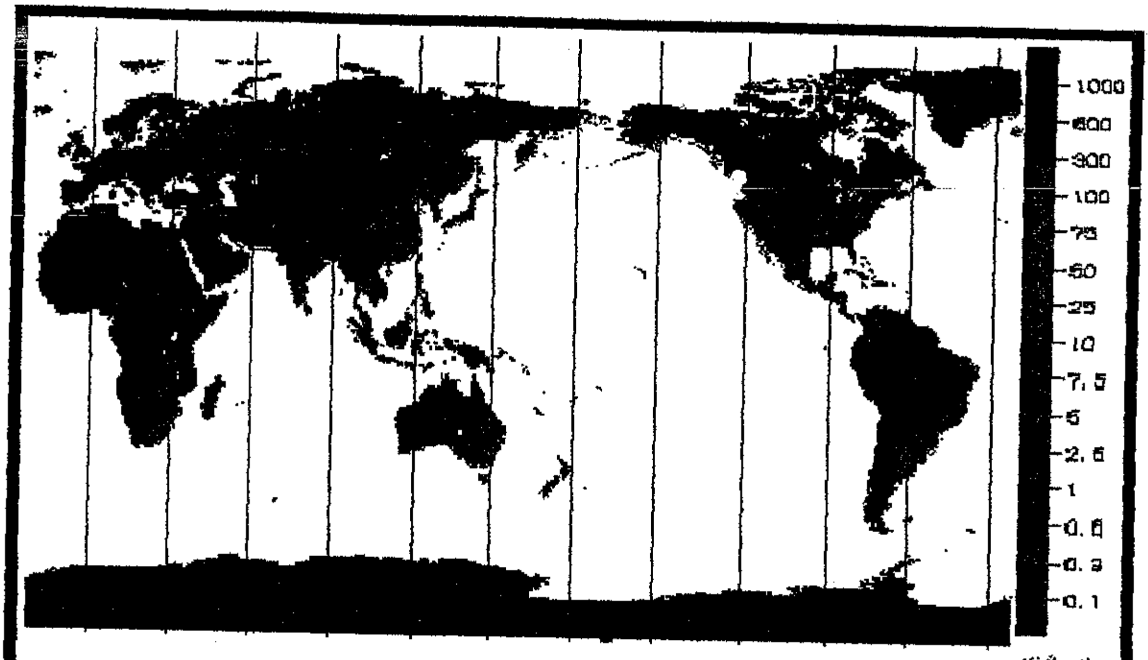
Developed

- Resak
- Bunga Raya
- North Bunga Pakma
- Anding
- Bunga Pakma
- Bunga Senja
- Bunga Orkid

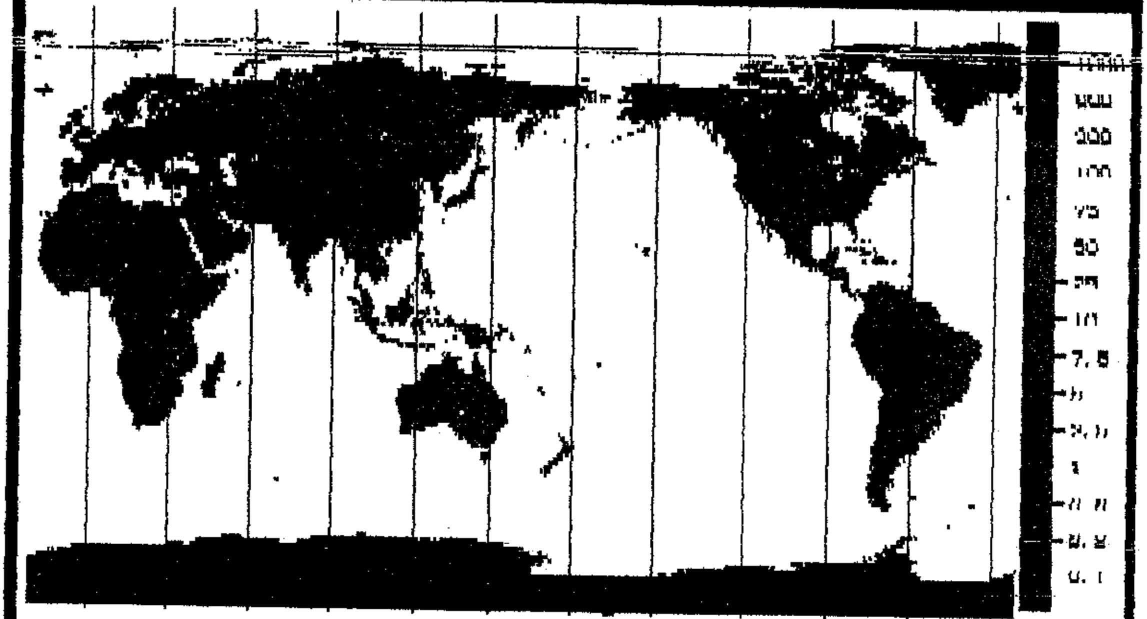
Pre-Developed

- Guntong
- Sepat
- Brantai
- Bintang
- Bujang
- Mesah
- South Bundi
- Inas
- Meranto (PM6)
- West Belumut
- Damardulang F/B1
- Belumut
- Tangga
- Anoa
- Ledang
- Serok
- Larut
- Bundi
- Lawang
- Ular
- Semangkok Timur
- Irong (PM(9)
- Tujoh
- Telok
- Tangga barat
- Noring
- Laho
- Bdong
- Melor
- Bergading
- Peta Kiri
- Delah (PM12)
- Duyong Barat
- Bindu
- Palas
- Beranang
- Tabu
- Tapis
- Besar
- Larut Liku
- Semangkok
- Guling
- Seligi
- Telok Kemang

Appendix 3: World CO2 Emission and Consumption



CO2 Emission From Fuel Consumption, 1986



CO2 Emission From Fuel Consumption,2100 (BaU)

Appendix 4: Global Carbon Cycle (Billion Metric Tons)