WORKSHEET SCREENING OF CO_2 EOR SEQUESTRATION POTENTIAL IN INDONESIA

By: **Usman Pasarai**[1)], **Utomo Pratama I.**, and **Danang Sismartono**[2)]
Technological Assessor[1)], Researcher[2)] at "LEMIGAS" R & D Centre for Oil and Gas Technology
Jl. Ciledug Raya Kav. 109, Cipulir, Kebayoran Lama, Jakarta Selatan 12230, Indonesia
Tromol Pos: 6022/KBYB-Jakarta 12120, Telephone: 62-21-7394422, Faxsimile: 62-21-7246150
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ABSTRACT

CO_2 injection into subsurface with the purpose to increase incremental oil production had been popularized in 1970s in US. Nowadays, this type of EOR methods not only offers more oil but also utilizing reservoir as CO_2 storage in the context of CO_2 emission abatement. The objective of this research is to produce simple and efficient worksheet on EXCEL base in order to asses and screen out quickly the potential of implementation of CO_2 EOR sequestration in depleted oil fields in Indonesia.

Key elements of this worksheet comprise engineering aspect and economical aspect. A sequence workflow of technical performance of CO_2 flooding was done using streamline simulator in which outstanding output from simulator needs robust data preparation and cautious parameter set up. For the case studied here, total incremental oil recovery at the end of the project is 4.52% from original oil in place (IOIP) or about 6.23 MMSTB. "Prophet" was used to simulate CO_2 sequestration during CO_2 EOR incorporating residual trapping. The amount of CO_2 trapped in reservoir was acquired by subtracting the total injected CO_2 with CO_2 produced.

The total capital expenditure for sequestration CO_2 EOR studied here is estimated $48.3 MM. It is expected that $16.5 MM will be placed in service by 1st year with the remaining $31.7 MM to be placed in service by 2nd year. Annual average operating cost was estimated to be $5.4 MM. As for fiscal terms, the following assumptions have been incorporated into the economic evaluations: (1) FTP 10%, (2) Investment Credit 17%, (3) Contractor Oil Split 26.6018%, (4) Government Split 73.3982%, and (5) Tax 44%.

The economic analyses were carried out based on the project life time 7 years and the sales of incremental oil amount 5.6 MMSTB with an assumption that price for oil was $68 per barrel based on monthly average OPEC Basket Price during April-09 until March-10. Economic results of the development with discount factor 7 percent as indicated has a Contractor DCF Rate of Return 53.3 percent, Contractor Net Present Value $31.3 MM, and revenue to the Government of Indonesia $188.2 MM. With this economic indicator, the project of Sequestration CO_2 EOR is economically feasible.

The developed worksheet enables to do quick judgment on the viability a CO_2 EOR sequestration project hence make it easier to someone who wants to screen out a large number of reservoirs rather than using detailed numerical simulator. It will much more saved time and decrease works intensity.

***Key words**: Screening CO_2 EOR, depleted oil field, CO_2 sequestration, streamline simulator, cash flow modeling*

I. INTRODUCTION

The increase of CO_2 concentration has made the world take action to mitigate its adverse impact to the climate such as, energy efficiency improvements, the switch to less-carbon intensive fuels and renewable resources employment. These means are considered still low in context of CO_2 emissions mitigation, since the CO_2 emission has raised up in the last century. One of the available technologies which are able to reduce CO_2 emissions in large scale is known as Carbon dioxide Capture and Storage (CCS) or CO_2 sequestration. These terms will be used interchangeably.

CO_2 sequestration in depleted oil reservoirs offers potential incremental oil/gas recovery through enhanced oil recovery (EOR). In certain amount, injected CO_2 will be detained in reservoir because of a number of trapping mechanisms and some will be produced at producer well, then afterwards to be recycled and re-injected. Hence, besides mitigating CO_2 concentration in the atmosphere another benefit is the revenue generates from additional recovery. CO_2 sequestration in conjunction with EOR has already been implemented in worldwide scale in Weyburn EOR project, Canada. It is the fourth largest CCS project in the world and has injected and stored about 10 million tonnes of CO_2 to date. This project combines EOR with a comprehensive monitoring and modelling programme to evaluate CO_2 distribution and storage.

One of the main geological storage options in Indonesia are oil and gas reservoirs. After more than a century of intensive petroleum exploitation, thousands of oil and gas fields in Indonesia are approaching the end of their economically productive stage. The future CO_2 sequestration potential will increase in time as more fields are depleted. These depleted oil and gas reservoirs are prime candidates for CO_2 storage.

The huge amount of depleted oil and gas reservoirs in Indonesia precents a challenge in selecting the appropriate reservoir for CO_2 sequestration and EOR purposes. The scope of work to screen out the suitable reservoir will be extensive and time consuming if it is carried out by geological modelling and detailed numerical simulation. Mostly, this kind of work

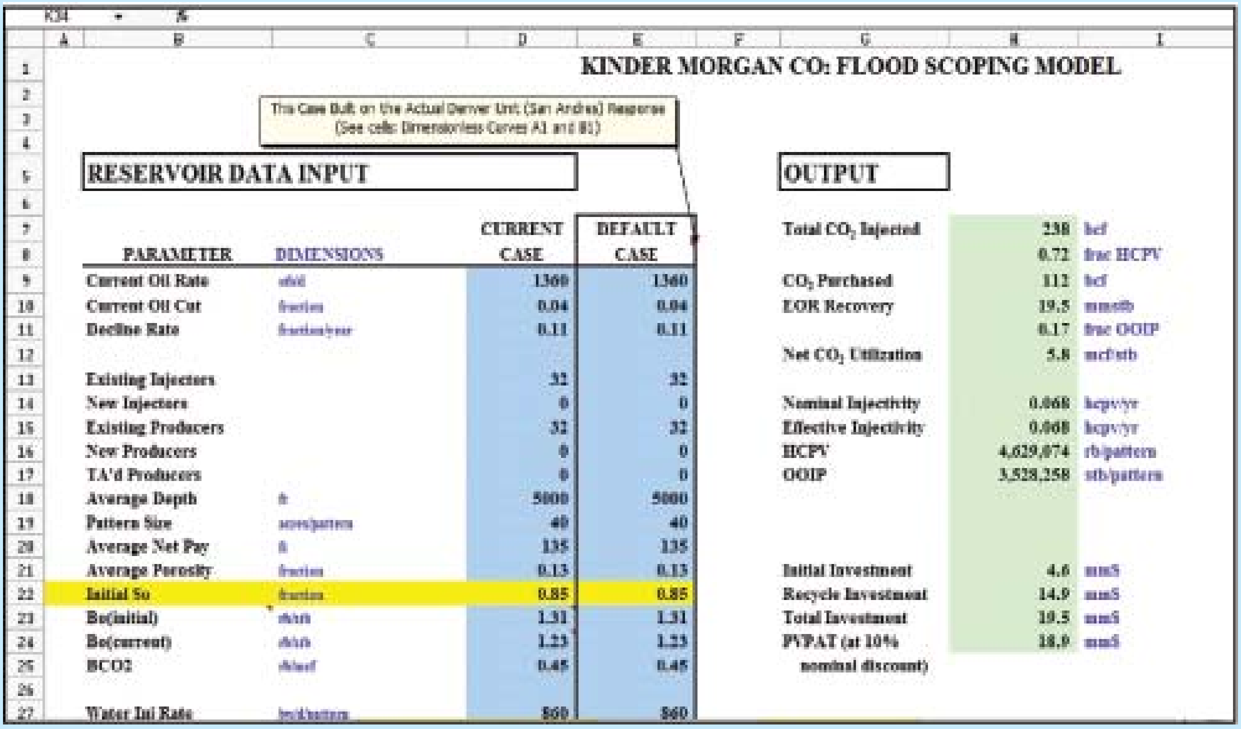

Figure 1
Interface KM CO_2 flood scoping model

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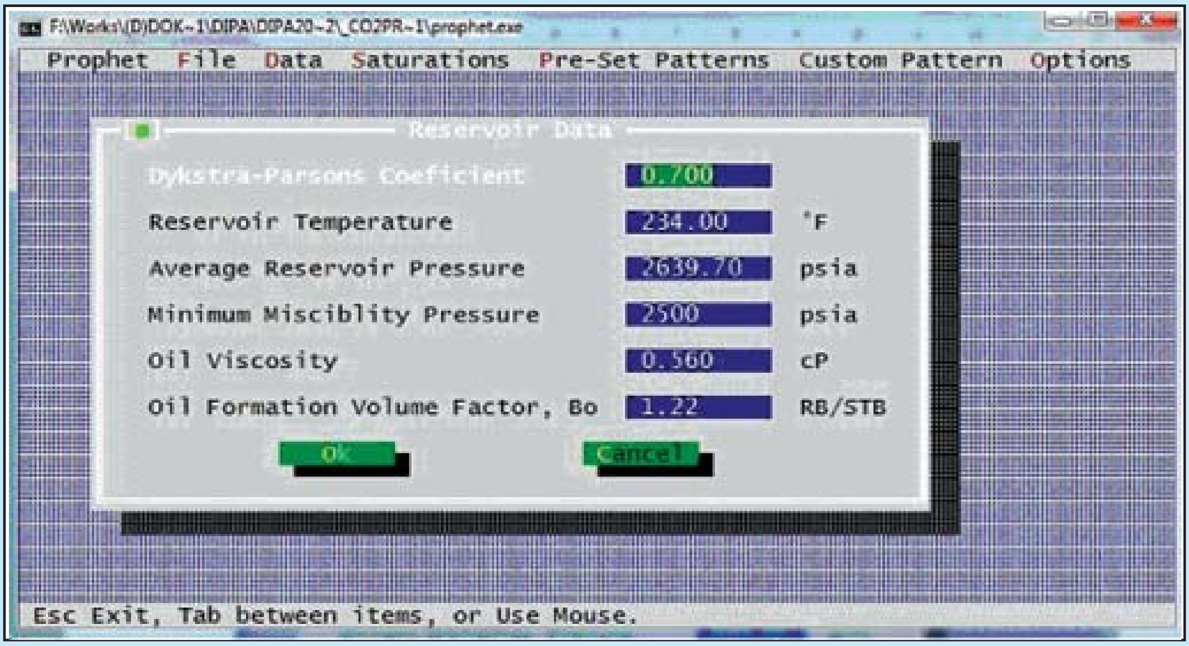

Figure 2
User interface of CO_2 Prophet

solely assesses the technical performance without taking notice of the economic feasibility. Therefore, this paper aims to develop simple and powerful EXCEL® based worksheet- to simplify and condense the scope of work of reservoir selection and identification by integrating technical and economic assessment.

II. CO_2 EOR SCREENING TOOLS

To yield meaningful predictions, reservoir simulators require accurate characterization of both the reservoir and its operational, while characterizing a reservoir accurately can be time consuming and somewhat expensive process. Therefore, there exist many tools to screen out a CO_2 EOR project such as CO_2PM, CO_2 Prophet, Kinder Morgan Predictive Tool, Maestro Screening Tool, Epic CO_2 Analysis Package. This paper discusses the development of a worksheet by integrating two CO_2 EOR screening tools into single worksheet, Kinder Morgan Predictive tool and CO_2 Prophet to assess both technical performance and economic feasibility from certain oilfield.

Kinder Morgan (KM) Predictive Tool provides a “scoping” assessment (initial assessment) on developing a depletion plan for a reservoir by identifying the primary factors that have the greatest impact on CO_2 flood project, see Figure 1. Those factors will have impact to the technical and economic success and are use to in finding the decision with the project - whether to abandon the project or move forward with detailed investigation. This screening tool simplifies running under Excel worksheet.

The process of scoping assessment in KM is by scaling up CO_2 flood performance in one reservoir which involves taking CO_2 flood performance from a similar reservoir and multiplying the performance by scaling variables. The similar, analogous reservoir may be another reservoir already under CO_2 flood, a pilot CO_2 flood in the same reservoir, or even detailed CO_2 flood predictions from another similar reservoir. Scaling variables are intended to account for approximate differences in reservoir properties. It has to be noted that the analogous reservoir must have similar characteristics and operation for the scale up process to yield acceptable results at the target reservoir. If the properties between reservoirs are not similar, the scale up process can provide misleading results.

A scoping quality design for a CO_2 flood may not be accurate enough when the financial risk of CO_2 flooding is great, which is the case when the capital investments before CO_2 flooding are large. However, there are maturing stages of using KM predictive tool. First, if scoping analysis shows that CO_2 flood might be economical and if significant risk is involved, then using a reservoir simulator to forecast performance would be useful and economically justified next step. The last one, if actual CO_2 flood performance from similar field is not available or the flood to be scaled up is not mature enough, it may be necessary to use reservoir simulator to predict performance.

In contrast, CO_2 Prophet was a streamline simulator that was developed as an alternative to the U.S. Department of Energy's CO_2 miscible flood predictive model, CO_2PM (Figure 2).CO_2 Prophet is screening tool which fall between crude empirical correlations and sophisticated numerical simulators. This simulator was designed to identify how key variables influence CO_2 project performance and economics prior to performing detailed numerical simulation.

There are two principal operations that CO_2 Prophet performed. It first generates streamlines for fluid flow between injection and production wells and then does displacement and recovery calculations along the streamtubes. The streamlines form the flow boundaries for the streamtubes. Secondly, a finite difference routine is used for the displacement calculations. A special advantage of the streamtube method from CO_2 Prophet is the avoidance of grid orientation effects. Then the effect of areal sweep efficiency is handled by incorporating streamlines and streamtubes. By doing calculations along the streamtubes the need for using an empirical correlation for areal sweep efficiency is eliminated. To simulate miscible CO_2 process, CO_2 Prophet uses a mixing parameter approach which is the same as that proposed by Todd and Longstaff. Mixing parameter models simulate the mixing and viscous fingering which occurs in miscible displacements by adjusting solvent and oil viscosities. These adjustments alter the fractional flow of solvent and oil.

III. STORAGE MECHANISMS IN CO_2-EOR

The injected CO_2 will generally occupy the pore volume previously occupied by oil and/or natural gas and usually trapped by capillary forces. But, not all the previously pore space will be available for CO_2 because some residual water may be trapped in the pore space due to capillarity, viscous fingering and gravity effects. Using miscible CO_2 flooding, more than 50% and up to 67% of the injected CO_2 returns with the produced oil. All produced CO_2 is typically captured/separated and recompressed for re-injection into the production zone to minimize operating costs. The remainder is trapped in the oil reservoir by various means either by physical trapping or chemical trapping, such as irreducible saturation and dissolution in reservoir oil that is not produced, and in pore space that is not connected to the flow paths into the producing oil wells. The CO_2 storage in case of miscible EOR ranges from 2.4 to 3.0 tonnes of CO_2 per tonne of oil produced.

Because CO_2 Prophet uses streamlines to generate sweep efficiency, then the effect of trapping mechanisms incorporated in CO_2 prophet is only residual trapping.

IV. STUDY CASE – THE X FIELD

The X Field lies within the Musi platform at western part of the South Sumatra Basin. This field comprises a carbonate reef of Baturaja Limestone with the top reservoir depth of 5,643 ft-ss and the bottom reservoir depth of 5823 ftss. The X reservoir filled

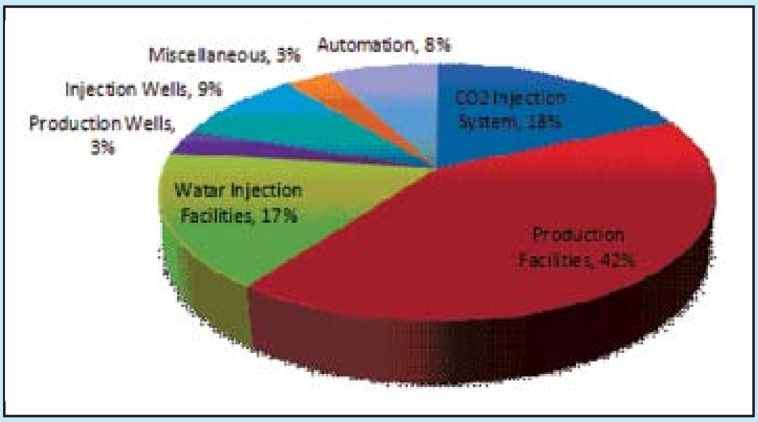

Figure 3
Cost distribution of CAPEX CO_2-EOR

by under saturated oil and solution gas with initial GOR of 454 scf/stb as the main drive mechanism of the field. The initial reservoir pressure and temperature are 2767 psig and 234 °F respectively. The reservoir fluid can be categorized as light oil with the API gravity of 35.

The X field started producing in September 1986 and initiated water injection in September 1987 to maintain reservoir pressure. The current average reservoir pressure is 2,625 psig. The cumulative production of oil when this study initiated is 53,612.38 MStb or 39% recovery factor. Oil production rate of X field has been declining since 1999, for this reason, CO_2 EOR has been considered as an option for increasing oil recovery.

V. COST SCHEME OF CO_2 EOR

SPE Monograph Volume 22: Practical Aspect of CO_2 Flooding describes cost scheme for CO_2-EOR in which the largest cost composition for CO_2 EOR field development laid on production facility installations up to 42% from total Capital Expenditure. The following largest cost portions are Injection System and Water Injection System which are 18% and 17% respectively. Figure 3 depicts cost distribution of CAPEX CO_2-EOR.

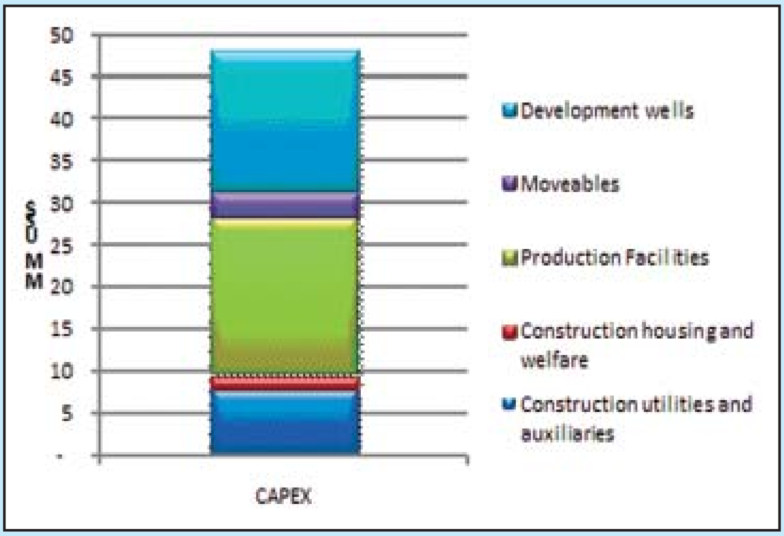

Figure 4
Cost distribution of CAPEX for the X field

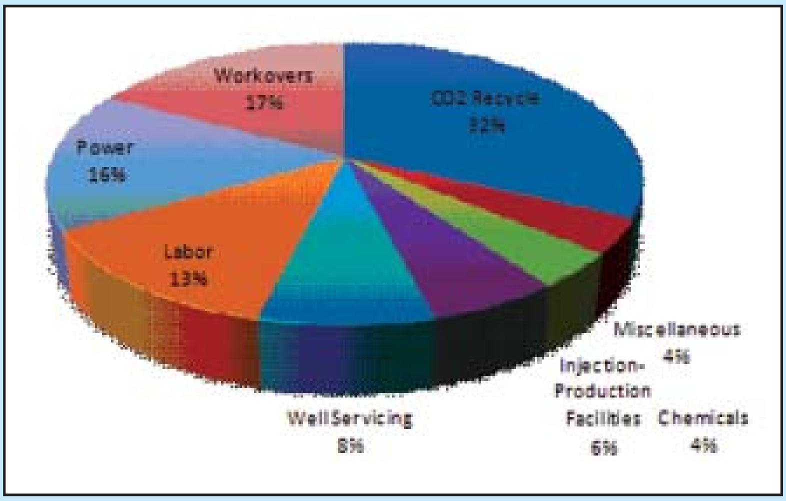

Figure 5
Cost distribution of OPEX CO_2-EOR

Capex component on simulating the X oil field is simplified into five cost component capital expenditure. They are Construction utilities and auxiliaries, Construction housing and welfare, Production Facilities, Moveables and Development wells. Figure 4 reveals cost distribution of CAPEX CO_2-EOR.

CO_2-EOR development total cost to the X field which is MM$ 48.3. Production facilities development cost reach 39% of total costs which is MM$ 18.9, well development for water injection and CO_2 Injection cost reach 34% which is MM$ 16.7.

Literature also described operating expenditure's cost component. Rule of thumb of operating expenditure's cost distribution as presented on Figure 5.

In this case study opex's cost showed as cost per unit of oil productions, which is operating cost about $ 2.75 per bbl oil production and CO_2 cost about $ 3.25 per bbl oil production.

VI. METHODOLOGY FOR DEVELOPING WORKSHEET

To develop reliable screening tool as aforementioned, it should cover two prominent aspects, technical and economic success. Technical performance gives justification whether the project is possible to carry out or not with current existing technology while the economic success determines the attractiveness of project to generate revenue.

In overall, there are two major steps that need to be accomplished to develop the worksheet, Technical Performance Assessment and Economic Assessment. As seen in Figure 6, technical performance assessment comprised three major steps which are data preparation, running simulation and generating the output.

The main challenge on conducting simulation is data availability. Data provided in certain field usually consist of only primary data. On the other hand, if we do the simulation using Prophet, we need minor data that may not be important in general, therefore extra effort is needed to obtain the appropriate data as simulator input. At this point, Prophet needs Dykstra Parson Coefficient which affects overall calculation.

The Dykstra-Parsons coefficient can have an extremely large impact on recovery. This coefficient is used to calculate the permeability variation between the layers in the model. The calculation of layer permeabilities is done internally in the program. Other data such as, gas specific gravity and oil viscosity are acquired from charts. To achieve optimum oil recovery and sequestered CO_2, the proper recovery method is CO_2 miscible flooding. Required data to perform the simulation is tabulated below.

The required input data can be entered using the panels. After all the input data have been entered, CO_2 Prophet can be executed by selecting "Do It" from the bottom menu. Prophet will compute sweep areal and recovery based on the inputs and will use default parameters if the inputs left blank. Some re-

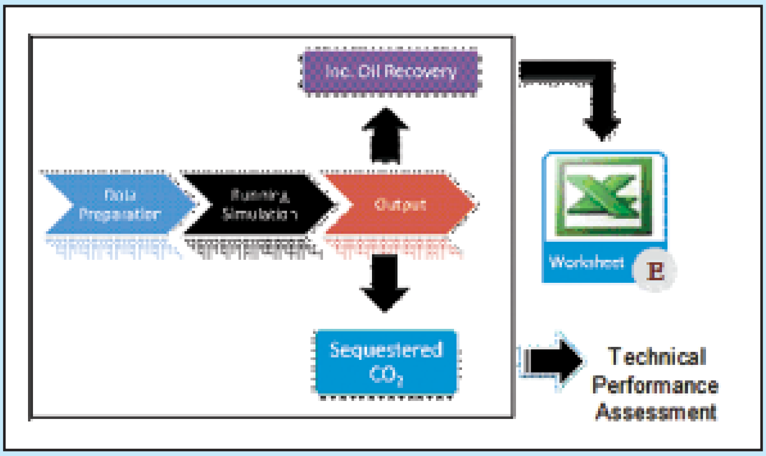

Figure 6
Technical performance assessment workflow

Table 1
Required data for running simulation

Parameter	Value	Unite
Porosity	0.398	Frac
Initial oil saturation	0.185	Frac
Reservoir temperature	234	^oF
Current average reservoir presure	2625	psig
MMP	Miscible	psig
Bubble point	1860	psig
Oil viscosity	0.56	cP
Oil formation volume factor	1.22	RP/STB
Solution gas-oil ratio (Initial)	454	Scf/STB
Oil gravity (Light)	36.5	^oAPI
Gas specific gravity	0.78	
Permeability	199	mD
OOIP	138	MMSTB
Dykstra parsone coefficient	0.7	
CO_2 injection rate	300	MMSCF/D
Pattern	5	Spot
Amount injected CO_2	3.674.44	HCPV

sulted parameters from running the program are as follows:

- Injected total
- Oil produced
- CO_2 produced
- Water produced

There are two important outputs to be used in worksheet. First is the amount of total injected CO_2 and CO_2 produced, secondly is oil produced. To calculate the amount of CO_2 retained in underground can be simplified using following equation:

$$CO_2\,Trapped = \sum Vol.Injected\ CO_2 - \sum Vol.Produced\ CO_2$$

Oil produced then will be served as a basis in production profile to justify economic feasibility.

Methodology for economic assessment comprised three main steps (Figure 7), first is data inventory including upstream data analysis, developing upstream cashflow model, and finally economic upstream analysis.

Each stage of economic assessment is explained as follows:

1. **Inventory and upstream, data analysis**

   This point is the most critical in analysing economic model, because it requires prudent analysis to the input data such as: project lifetime, number of well, oil incremental, and CO_2 requirement.

2. **Cash Flow Modelling**

   Cash flow modelling was done using Microsoft Office Excel by utilizing Visual Basic Editor so that each changes can be simulated quickly to generate the desired output target. Practically in developing economic assessment worksheet, at least there are three worksheets to be built, namely: main panel worksheet, data input (CO_2-EOR PSC Parameter, Production Data, CAPEX and OPEX and Price), and Output (CO_2-EOR PSC scheme, Cashflow projection, Graphics, Sensitivity analysis)

3. **Economic analysis**

   The final step is to exercise the model by incorporating the study case-X oilfield to determine model performance.

VI. RESULTS AND DISCUSSIONS

Simulation output showed the following parameters.

Project lifetime was estimated around six years with peak incremental occurred in the second years of project which is about 3,700 BPD and gradually went down to 680 BPD at the end of injection period. In overall the amount of incremental oil recovery produce up to 6.23 MMSTB or about 4.52% oil

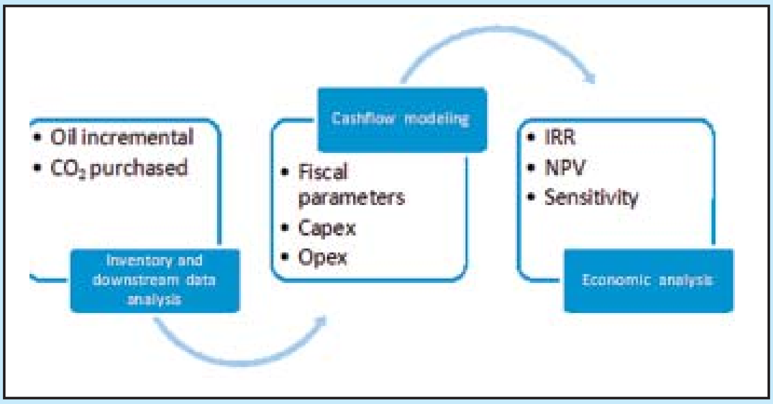

Figure 7
Economic performance assessment workflow

Table 2
Summary output from running simulation

Cummulative				
Time years	Oil MSTB	Water MSTB	Sequestered CO_2 Mt CO_2	Oil recovery % OOIP
0	0	0	0	0
1.0	1093	41559.6	2.89	0.79
2.0	2469	51413.8	3.66	1.79
3.0	3575.9	57847.7	4.17	2.59
4.0	4495.8	62677.4	4.57	3.26
5.0	5286.8	65914.2	4.86	3.83
6.0	5988.3	68664	5.10	4.34
6.4	6236.5	69731	5.18	4.52

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recovery from original oil in place (IOIP). Not only oil was produced at producer well but also water and CO_2 was produced. This can be used to determine the remaining CO_2 trapped in reservoir. By applying the previous equation on how to calculate the trapped CO_2, CO_2 that remained in reservoir is given in Figure 8.

Some basic assumptions were made to model the economic of CO_2 EOR sequestration the X Field such as:

- Model based on Standard Production sharing contract (PSC)
- oil price \$ 68 per barrel
- Discount rate 7%

Economic model estimated project investments required on developing this field is about MM\$ 48.3. Other prominent economic indicators were resulted as follow:

- Contractor DCF Rate of Return 53.3% (ROR by Incremental Oil)
- Contractor Net Present Value \$31.3 MM
- POT 2.81 years
- Government of Indonesia NPV \$188.2 MM.

Operational expenditure (Opex) was determined as cost per unit of oil produced with operating cost US\$ 2.75 per bbl and CO_2 purchased cost \$ 3.25 per bbl.

Based on economic indicators as described before, CO_2-EOR sequestration project was economically feasible. Figure 9 shows contractor cashflow trend and graph of revenue distribution per annum between governments's cost recovery and contractors. It shows positive cashflow in the third year of the project which means capital returns has occurred.

Positive cashflow is reached on 3rd year, it means capital return attained on that year.

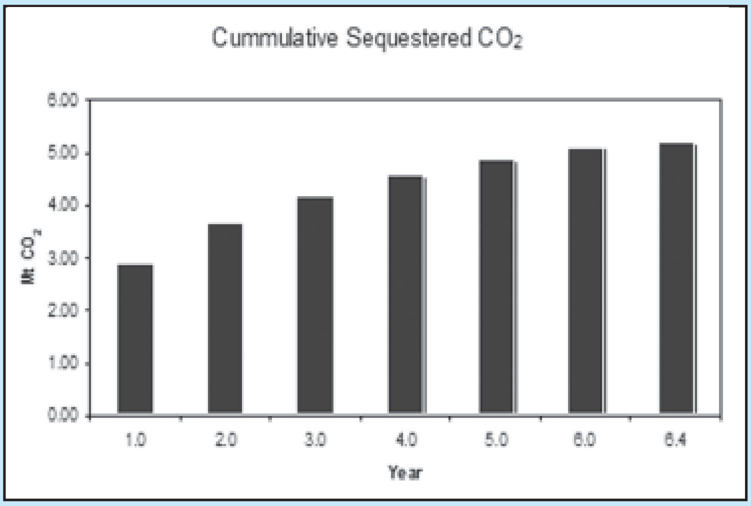

Figure 8
Cumulative sequestered CO_2 at the of the project

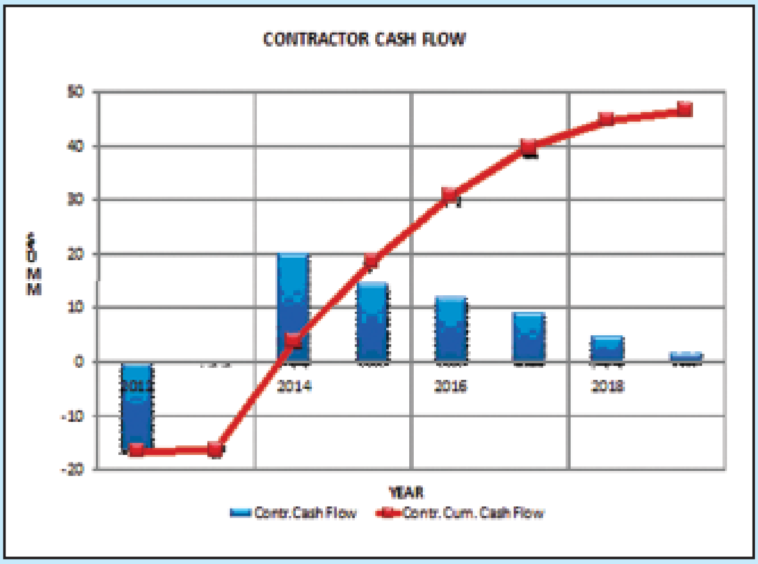

Figure 9
Cashflow profile of X field CO_2 EOR sequestration

VII. CONCLUSIONS

In summary, there are few points need to be highlighted as development of this worksheet:

- By combining two screening tools, mature worksheet capability to assess both technical and

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economic feasibility of CO_2 EOR sequestration project are provided.

- It is possible to do quick judgment on the viability CO_2 EOR sequestration project hence make it easier to someone who want to screen out a large number of reservoirs rather than using detailed numerical simulator.
- In terms of time and scope of works, the developed worksheet is more efficient without ignoring the quality of the calculation.
- If necessary then using a reservoir simulator to forecast performance would be useful and economically justified next step.

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