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# Source Sink Matching for Field Scale CCUS $CO_2$-EOR Application in Indonesia

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**ABSTRACT -** The carbon capture utilization and storage (CCUS) referred in this paper is limited to the use of $CO_2$ to the enhanced oil recovery ($CO_2$-EOR). The CCUS $CO_2$-EOR technology can magnify oil production substantially while a consistent amount of the $CO_2$ injected remains sequestrated in the reservoir, which is beneficial for reducing the greenhouse gas emission. Therefore, this technology is a potentially attractive win-win solution for Indonesia to meet the goal of improved energy supply and security, while also reducing $CO_2$ emissions over the long term. The success of CCUS depends on the proper sources-sinks matching. This paper presents a systematic approach to pairing the $CO_2$ captured from industrial activities with suitable oil fields for $CO_2$-EOR. Inventories of $CO_2$ sources and oil reservoirs were done through survey and data questionnaires. The process of sources-sinks matching was preceded by identifying the $CO_2$ sources within the radius of 100 and 200 km from each oil field and clustering the fields within the same radius from each $CO_2$ source. Each cluster is mapped on the GIS platform included existing and planning right of way for trunk pipelines. Pairing of source-sink are ranked to identify high priority development. Results of this study should be interest to project developers, policymakers, government agencies, academicians, civil society and environmental non-governmental organization in order to enable them to assess the role of CCUS $CO_2$-EOR as a major carbon management strategy.

**Keywords:** CCUS, source-sink match, $CO_2$-EOR, $CO_2$ emission, carbon management.



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## INTRODUCTION

Indonesia is a long-standing producer of crude oil, though production has fallen steadily for more than 25 years (SKK Migas, 2019). Applying enhanced oil recovery (EOR) techniques in mature oil fields is one of main option of boosting oil production. The only type of EOR that has been deployed in Indonesia so far on a commercial scale is steam flooding. There may be extensive opportunities for EOR in Indonesia, given the maturity of many of the country's oilfields.

Carbon dioxide enhanced oil recovery ($CO_2$-EOR) as variant of EOR technologies that has been practiced for decades worldwide on a commercial scale to improve the recoverable oil is attracting interest for Indonesia recently. By implementing $CO_2$ EOR, it is also will make some $CO_2$ injected become stored in underground formation by the stratigraphic trapping, residual trapping and solubility trapping that happened in the reservoir. The volume of $CO_2$ that can be stored in this way depends on properties of the reservoir and the oil it contains, and on operational factors of oil production, including well spacing and the relative position of injection and producing wells (OECD/IEA 2015).

$CO_2$-EOR used with the purpose of storing $CO_2$ from anthropogenic sources is a type of carbon capture, utilization, and storage (CCUS) technology and has gained confidence as a climate mitigation strategy evidenced by stakeholder acceptance rather recently (IEA 2020). CCUS involves the capture of $CO_2$ from large point sources, including industrial processes or power generation that use either fossil fuels or biomass for fuel. The captured $CO_2$ is compressed and transported by pipeline, ship, rail or truck to be used as a feedstock to create valuable products, or injected into oil reservoirs to enhanced oil recovery before being permanently stored. CCUS referred in this paper is limited to the use of $CO_2$ for enhanced oil recovery, citied here as CCUS $CO_2$-EOR.

The CCUS $CO_2$-EOR is a potentially attractive to win-win solution for Indonesia in meeting the goal of increased oil production while also reducing $CO_2$ emissions over the long term. Energy use and $CO_2$ as the primary greenhouse gas (GHG) emissions in Indonesia are growing briskly in response to economic and population growth and continuing heavy reliance on coal and other fossil fuels. Under the nationally determined contribution to the United Nations Framework Convention on Climate Change, the Government of Indonesia is committed to reducing national emissions of $CO_2$ and other GHGs by 29% below a baseline trend by 2030 unconditionally and by up to 41% on the condition that international support for finance, technology transfer, and capacity building is made available.

The development of CCUS $CO_2$-EOR to date has been concentrated in the United States, which is home to almost half of operating facilities. This is due to in large part to the availability of an extensive $CO_2$ pipeline network and demand for $CO_2$-EOR. There are 15 CCUS $CO_2$-EOR projects in operation around the globe with capacity to capture up to 30 million tone ($MtCO_2$) each year (IEA 2020). Figure 1 shows the relative scale of the capture capacity from various industrial facilities including coal power plants. Most of the $CO_2$ captured comes from natural gas processing plant. The success of CCUS $CO_2$-EOR depends on appropriate pairings of sources and suitable oil reservoirs for $CO_2$-EOR as sinks. A good $CO_2$ source is able to supply constant $CO_2$ to the sink within certain period while suitable sink has injectivity correspond to the $CO_2$ supply rate and sufficient storage capacity (Usman *et al.* 2014; Chon *et al.* 2019).

Source-sink matching process involves analysis of matching the demand and supply of $CO_2$ in which the characteristics $CO_2$ produced from the industrial sources are matched to oil reservoirs properties. Although, natural $CO_2$ fields are currently the dominant

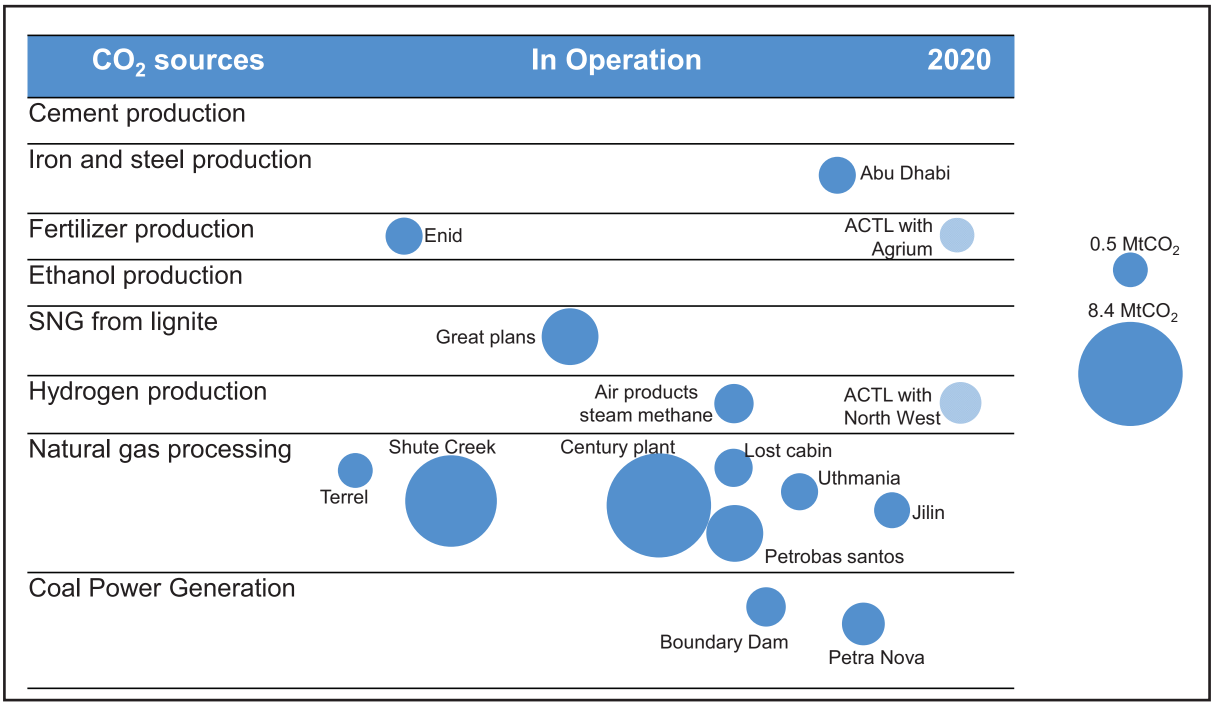


Figure 1
Large-scale commercial CCUS $CO^2$-EOR projects in operation in 2020 (Modified from IEA, 2020).

sources for the $CO_2$-EOR market, industrial sources of $CO_2$ needed in order to ensure adequate $CO_2$ supplies to facilitate substantial growth in oil production utilizing $CO_2$-EOR (ARI 2011). For CCUS $CO_2$-EOR case, the amount of $CO_2$ required is increased as the sink converted as $CO_2$ storage. Several factors affecting source-sink matching include $CO_2$ content, flow-rate, source type, source temperature, source pressure, formation pressure and fracture pressure. Source-sink matching provides the identification of potential CCUS $CO_2$-EOR that can be developed to find the least-cost pathway.

## DATA AND METHODS

Methodology used in this study includes data collection of the potential fields for $CO_2$-EOR, screening the $CO_2$-EOR suitable fields and ranking the fields, data collection for $CO_2$ sources from oil and gas processing plants, power plants, and other industrial facilities near the potential $CO_2$-EOR fields, matching between the potential $CO_2$-EOR candidates and $CO_2$ sources, and making prioritization for CCUS $CO_2$-EOR.

Choosing the $CO_2$-EOR suitable fields is performed using screening criteria provided by Taber Martin (1997) and modified by Al-Adasani (2011) as shown in Table 1. The oil fields screened are limited to the fields under operated by Indonesia's state-owned oil and gas company.

This study focuses only on large stationary source $CO_2$ emitters to which CCUS $CO_2$-EOR might be applied, such as coal power plant, oil refineries, gathering station, gas flare, industries such as fertilizer, ammonia, iron and steel, cement, and from naturally occurring underground reservoirs. The point sources are technically amenable to $CO_2$ capture and transportation to oil fields for $CO_2$ injection. The data inventory is executed through survey, received reports, and interviews to the operators.

A source-sink matching process based on Geographical Information Systems (Arc-GIS) is

Table 1
$CO_2$-EOR screening criteria (Taber, *et al.*, 1997)

| No | Oil and Reservoir Characteristics | | Recommended | Range of Current Projects |
|---|---|---|---|---|
| | ***Crude Oil*** | | | |
| 1 | Gravity | API | >22 | 27 to 44 |
| 2 | Viscosity | cP | <10 | 0.3 to 6.0 |
| 3 | Composition | | High percentage of intermediate hydrocarbons (especially $C_5$ to $C_{12}$) | |
| | ***Reservoir*** | | | |
| 4 | Oil saturation | %PV | >20 | 15 to 70 |
| 5 | Type of formation | | Sandstone to carbonate and relatively thin unless dipping. | |
| 6 | Average permeability | | Not critical if sufficient injection rates can be maintained. | |
| 7 | Depth and temperature | | For miscible displacement, depth must be great enough to allow injection pressure greater than Minimum Miscible Pressure (MMP), which increase with temperature [Ref 1] and for heavy oils. Recommended depths for $CO_2$ floods of **typical Permian Basin** oils follow: | |
| | | | Oil Gravity, °API | Depth must be greater than (ft) |
| | | For $CO_2$-miscible flooding | >40 | 2,500 |
| | | | 32.0 to 39.9 | 2,800 |
| | | | 28.0 to 31.9 | 3,300 |
| | | | 22.0 to 27.9 | 4,000 |
| | | | <22.0 | Fails miscible, screen for immiscible |
| | | For $CO_2$-immiscible flooding | 13.0 to 21.9 | 1,800 |
| | | (lower oil recovery) | <13.0 | All oil reservoirs fail at any depth |
| | At<1,800 ft, all reservoirs fail screening criteria for either miscible or immiscible flooding with supercritical $CO_2$ | | | |

established to facilitate data management, evaluation, modeling and generate information related to location-based CCUS $CO_2$-EOR implementation then visualize on informative map. The source-sink matching methodology is given in Figure 2, modified from Chen et al (2011).

Source and sink matching for CCUS $CO_2$-EOR applied using radial clustering method. For every candidate $CO_2$-EOR field paired with the potential $CO_2$ sources within radius of 100 km and 200 km to be a CCUS $CO_2$-EOR cluster system with the field candidate as sink at the center of radius. Data such as administrative territory boundary, road network, fields location, sources location, pipeline network, and oil and reservoir properties are needed for the Arc-GIS system development. All data is then integrated and synchronized in the map by making tables to be converted into GIS format. Collection of basic and thematic maps in GIS integrated in vector format. Raster format maps are converted into vector format through the digitization process.

Making prioritization for CCUS $CO_2$-EOR cluster development is based on the rank of selected oil fields. Ranking oil fields correspond to oil gravity, degree of miscibility as function of minimum miscible pressure (MMP), remaining oil, proximity to $CO_2$ source, existing infrastructure, and the amount of $CO_2$ availability. Range of values of those parameters is divided into three classes, which are Class A, B, and C reflects degree of conformity. Class A is least conformity given scored 1, Class B scored 3 has moderate conformity, and Class C is most conformity given a score of 5. Table 2 provides detailed classification of the parameter.

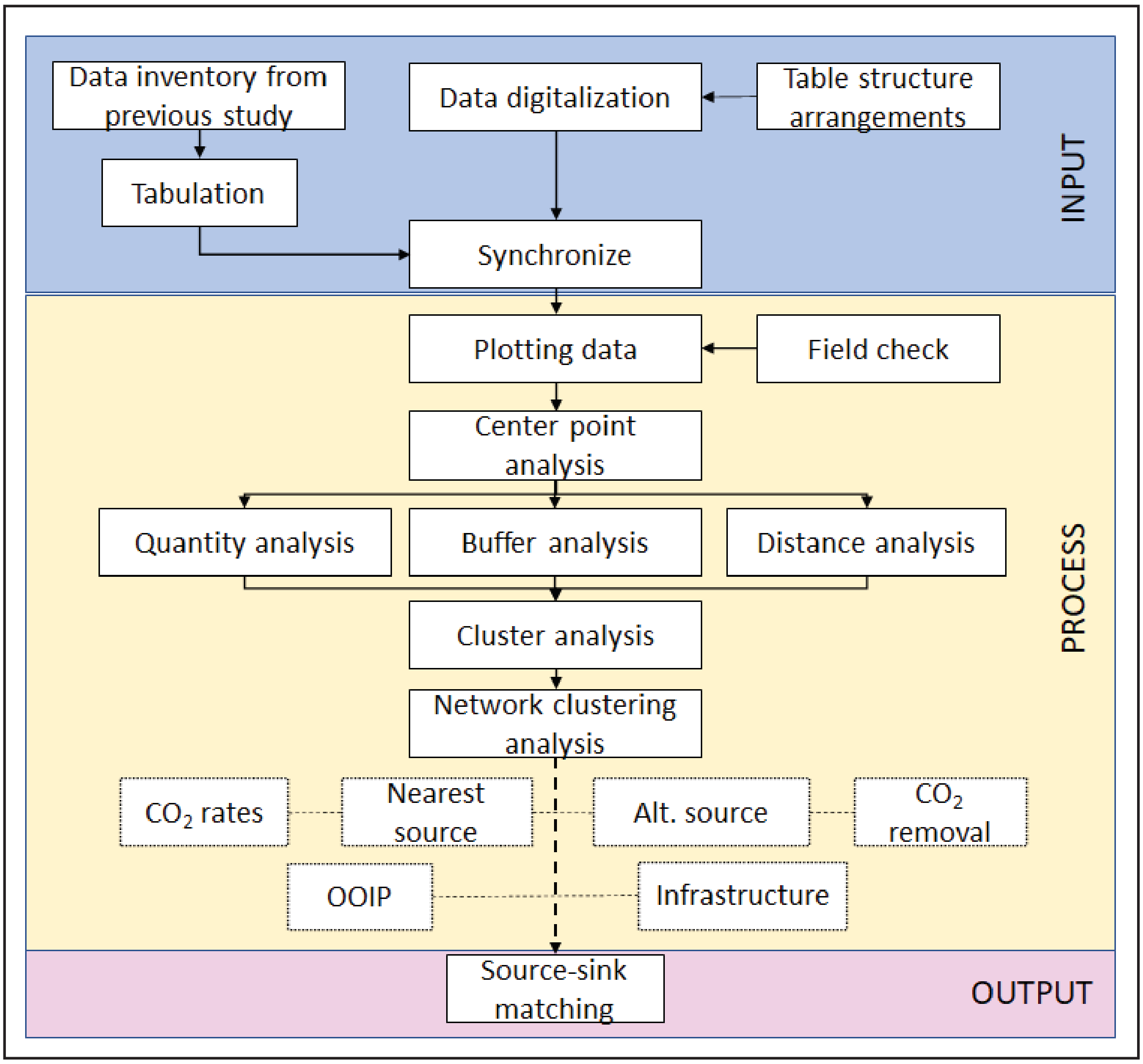


Figure 2
CCUS $CO_2$-EOR source-sink matching methodology (Firdaus, *et al*., 2019).

Each parameter is specified a weight that reflects its relative importance among the set of parameters based on expert judgment. Weighting parameter is determined using Pareto Chart method. Total of 40 experts gives their view of which parameters the most importance on making priority list for the source-sink matching process. Number of judgements and weighting scale for each parameter are given in Figure 3. The weighting scale for each parameter is the subtotal for that parameter divided by the total for all categories.

Table 2
Classification parameter (Chon, *et.al.*, 2019)

| Parameter | | Class A | Class B | Class C |
|---|---|---|---|---|
| Oil gravity | °API | <30 | 30 - 35 | >35 |
| Miscibility | | immiscible | near miscible | miscible |
| Remaining oil | MMstb | <100 | 100 - 200 | >200 |
| Proximity | km | >100 | 50 - 100 | <50 |
| Infrastructure | | offshore, far to $CO_2$ source | onshore, far to $CO_2$ source | onshore, close to $CO_2$ source |
| $CO_2$ amount | Kt/day | <10 | 20-Oct | >20 |

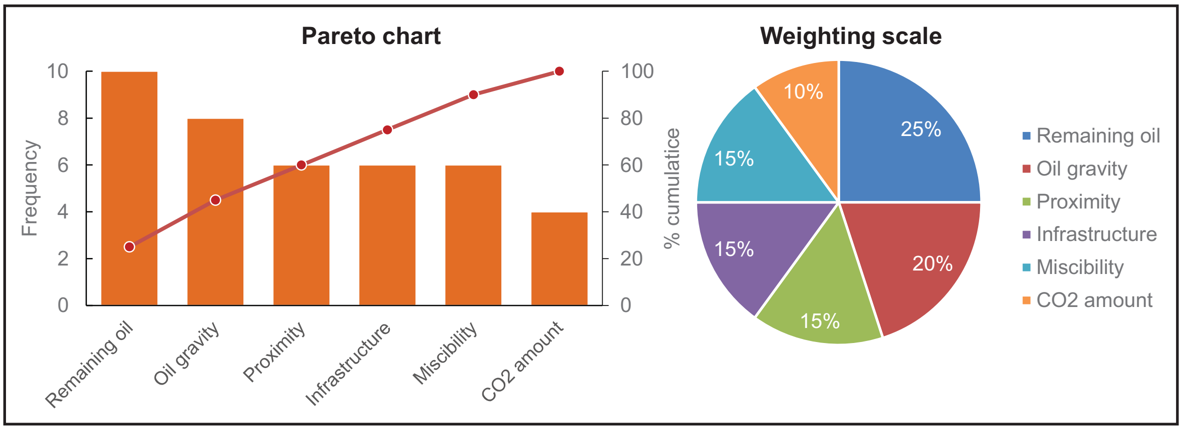


Figure 3
Pareto chart and weighting scale for each of classification parameter.

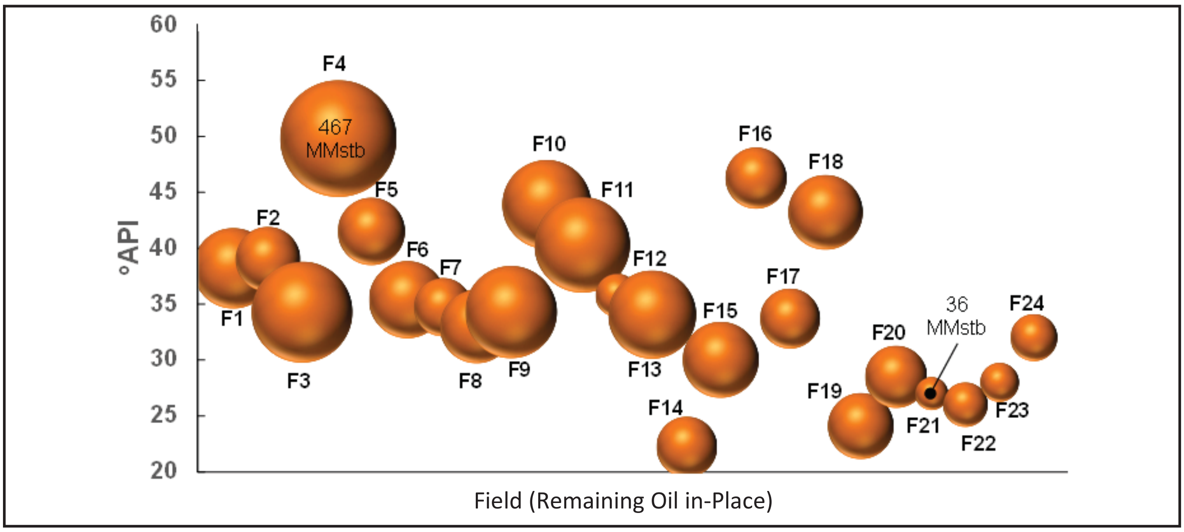


Figure 4
3D bubble map showing relationship between remaining oil in-place with °API gravity from the selected mature oil fields.

Table 3
$CO_2$ sources from selected industrial activities for $CO_2$-EOR

| **$CO_2$ Source** | **Method** | **$CO_2$ (Mt/year)** |
|---|---|---|
| Power plant | Data Survey 2018 | 135.911 |
| Petroleum refinery | Data Survey 2018 | 2.456 |
| Gas gathering station | Data Survey 2018 | 5.042 |
| Industry facilities | Data Survey 2018 | 22.053 |
| Gas flaring | Data Survey 2018 | 0.897 |
| From underground reservoirs | Data Survey 2018 | 3.268 |
| **TOTAL** | | 169.627 |

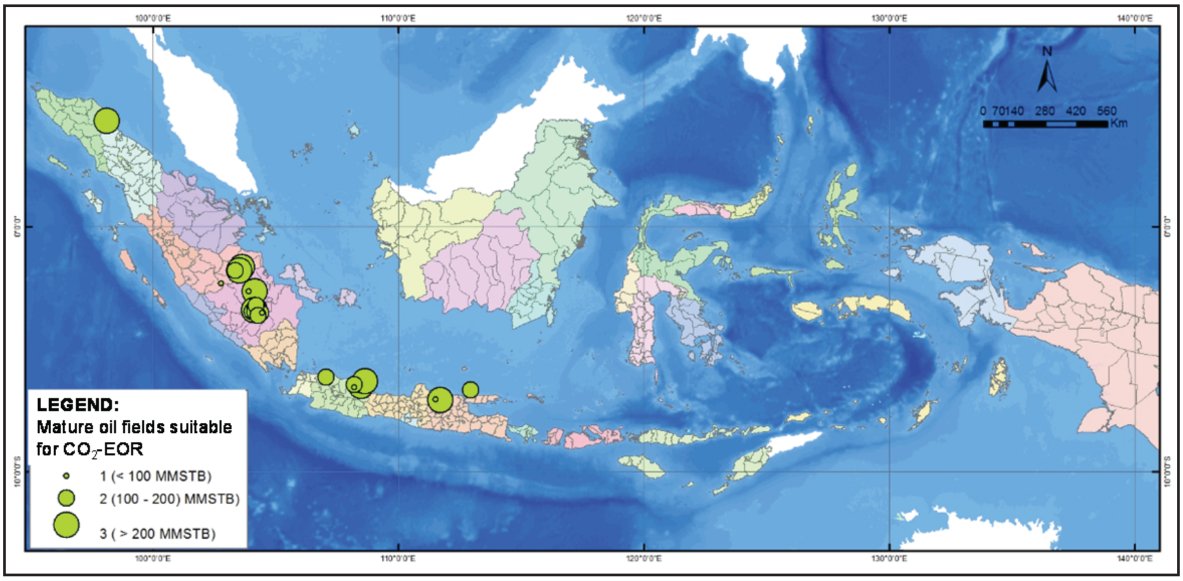


Figure 5
Location of the mature oil field candidates for $CO_2$-EOR.

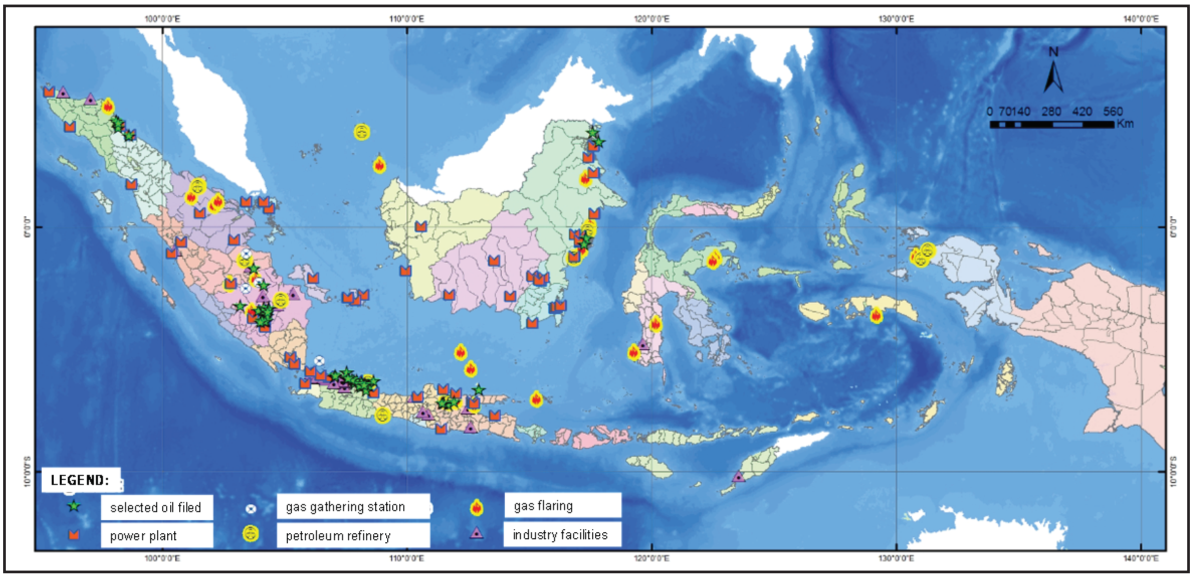


Figure 6
$CO_2$ source and sinks on GIS map.

## RESULTS AND DISCUSSION

There are 24 oil field candidates for $CO_2$-EOR with the total remaining oil in-place of 4.3 Billion barrel are selected. The range from 36 MMstb to over 467 MMstb of oil and the gravity value ranged from 26 to 50 °API. Of the selected mature oil fields, there of 21 fields would achieve miscible processes, 3 fields would immiscible. Minimum miscible pressure (MMP) calculation using Yellig-Metcalfe (1980) and Lee (1979) correlations which use reservoir temperature parameter are used to determine the miscibility condition in the oil fields. A 3-D bubble map shows relationship between remaining oil in-place with the gravity for 24 selected mature oil fields depicted in Figure 4. Most of the fields concentrated in South Sumatra, West Java, and East Java regions as shown on GIS map in Figure 5.

Totally 176 $CO_2$ sources are estimated and their emissions amount to around 170 Mt$CO_2$/year, with power, industry facilities, and others sharing 80%, 13%, and 7% respectively, as detailed in Table 3. The industries which give abundant amount of $CO_2$ emission are oil and gas, mining, cement, petrochemical, and also pulp and paper.

Arc-GIS has been established to pair each of selected oil fields with $CO_2$ sources within the radius of 100 km and 200 km from a selected oil field. All data needed for the source-sink matching process have been integrated into the Arc-GIS make easy to display, consume, and analyze geographically. An example of GIS map with $CO_2$ sources and sinks is given by Figure 6. It can be seen that within South Sumatra, West Java, and East Java regions are many large stationary sources of $CO_2$ that can be captured, therefore promise of CCUS $CO_2$-EOR cluster deployment.

The field ranking based on the classification parameter and the weighting method presented by Figure 7. The top five cluster highest scoring for CCUS $CO_2$-EOR implementation are F1, F2, F3, F4, and F5 oil fields. These results are consistent with the operator willingness at the present time in which the operator planned to apply $CO_2$-EOR in these fields. Highest scoring for those five oil fields due to the proximity to abundant $CO_2$ sources in addition their suitability for the application of $CO_2$-EOR, though those five fields are not the fields that have the highest oil remaining.

The F1 oil field which located in South Sumatra surrounded by several potential $CO_2$ sources in the 100 km and 200 km radius come from petrochemical, fertilizer, pulp and paper facilities, coal power generation, and oil refinery plant. $CO_2$ can also be supplied from gas processing plant that separated $CO_2$ from the oil and gas fields production. Within 100 km radius, there are 3 gas processing plants, 1 oil refinery plant, 1 gas power generation plant, 1 petrochemical and fertilizer facility, and 1 ceramic facility. For $CO_2$ sources in 200 km radius from the F6 field, there are additional potential $CO_2$ source from 1 coal power plant, 2 pulp and paper facilities, 1 gas refinery, and 2 gas processing plants. Figure 8 shows the candidate of CCUS $CO_2$-EOR for the F6 cluster.

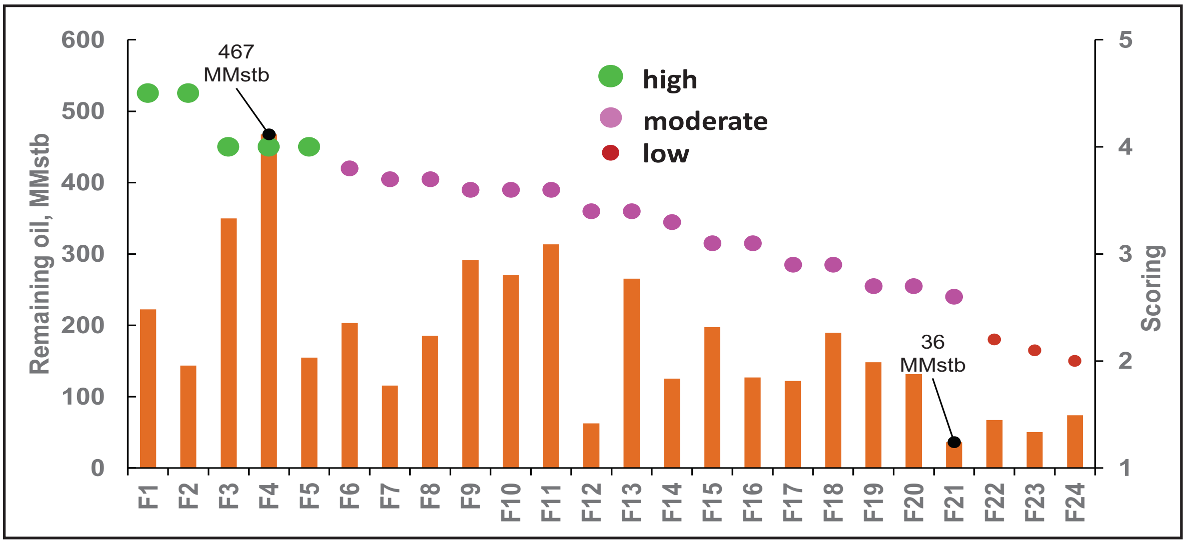


Figure 7
Ranking of candidates for CCUS $CO_2$-EOR cluster presented in high, moderate, and low priority.

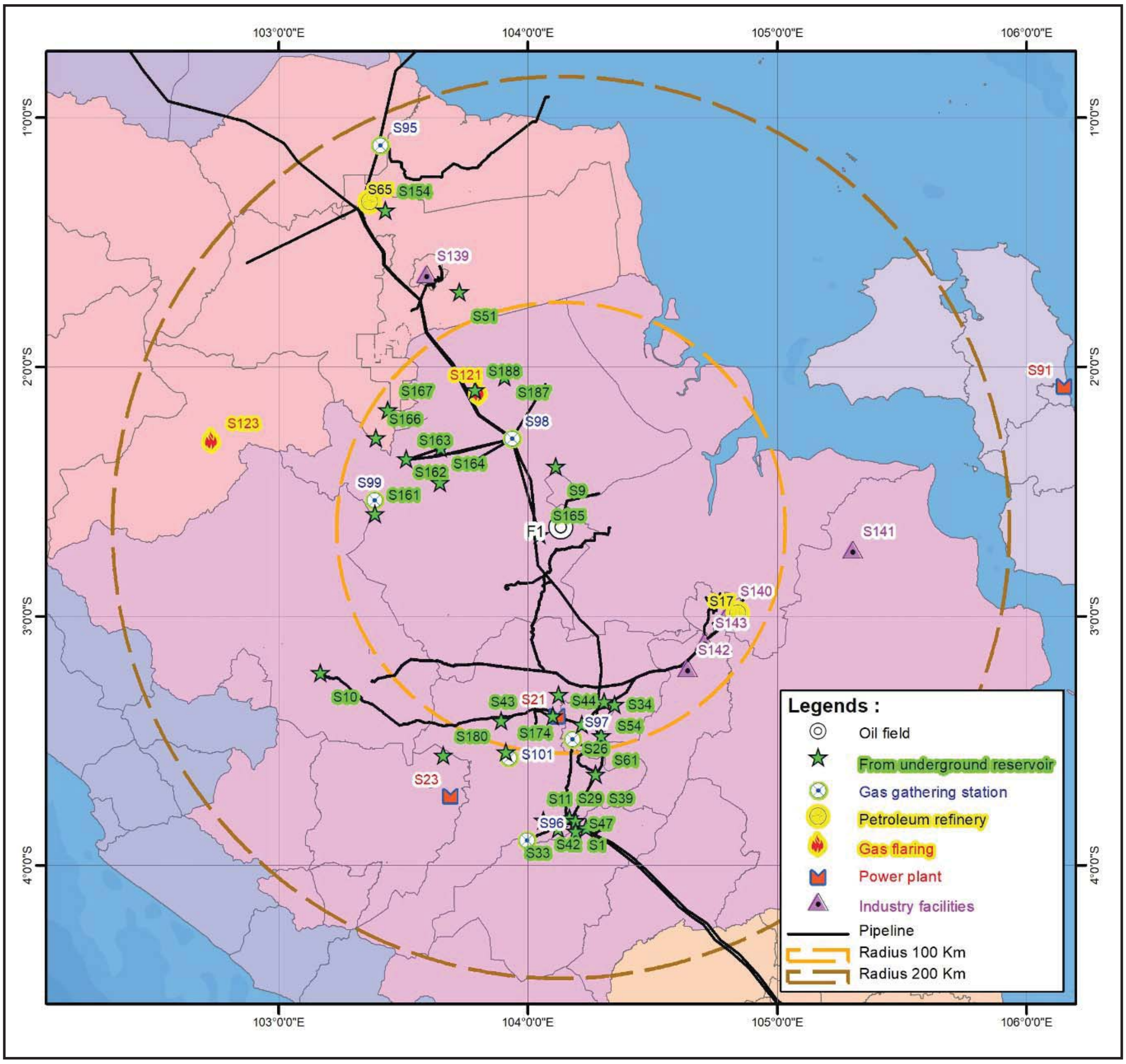


Figure 8
Candidate of F1 CCUS $CO_2$-EOR cluster.

The F2 oil field is located in East Java and one of the main focus for CCUS $CO_2$-EOR development in Indonesia. Through the source-sink matching analysis, found that there are several potential $CO_2$ sources available to be used for the future project. Within 100 km radius of F2 oil field, there are $CO_2$ sources from pulp and paper, cement, and petrochemical industries, coal power plant, flare, and oil refinery plant. Additional $CO_2$ sources come from gas fields which will be processed in the nearby gas processing plant with $CO_2$ separation unit. Extended to 200 km radius, there are coal power plants, and textile and manufacture facilities emitted abundant amount of $CO_2$. Figure 9 reveals the candidate of CCUS $CO_2$-EOR for the F24 cluster.

## CONCLUSIONS

A source-sink matching process based on geographical information systems (Arc-GIS) has been developed to facilitate data management, evaluation, modeling and generate information for CCUS $CO_2$-EOR field scale analysis. The top five cluster highest scoring for CCUS $CO_2$-EOR implementation are identified, which are F1, F2, F3, F4, and F5 oil fields. These results are consistent with the operator willingness at the present time in which the operator planned to apply $CO_2$-EOR in these fields. $CO_2$-EOR field priority ranks developed in this study could be used as the supporting assessment for developing future field scale of CCUS

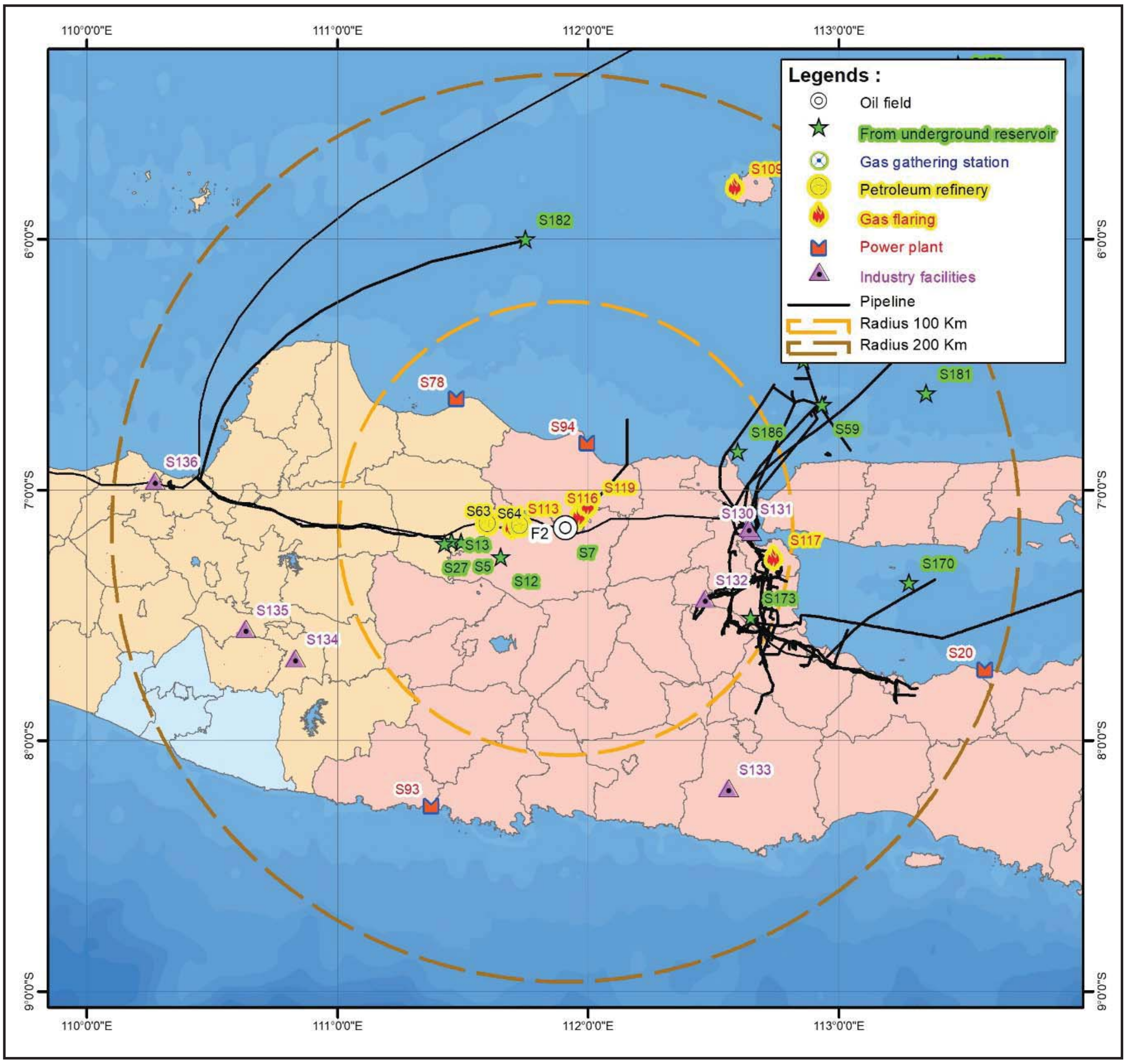


Figure 9
Candidate of F2 CCUS $CO_2$-EOR cluster.

$CO_2$-EOR project. The Arc-GIS map developed in this study should be interested to project developers, policymakers, government agencies, academicians, civil society and environmental non-governmental organization in order to enable them to assess the role of CCUS $CO_2$-EOR as a major carbon management strategy application in Indonesia.

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## GLOSSARY OF TERMS

| Symbol | Definition | Unit |
|---|---|---|
| API | American Petroleum Institute | |
| CCUS | Carbon Capture Utilization and Storage | |
| EOR | Enhanced Oil Recovery | |
| GHG | Green House Gas | |
| GIS | Geographic Information System | |

| Symbol | Definition | Unit |
|---|---|---|
| MMP | Minimum Miscible Pressure | |
| MMSTB | crude oil volume unit of million stock tank barrels | |
| OOIP | Original Oil in Place | |
| SNG | Synthetic Natural Gas | |

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