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Integration of Clustering System and Joint Venture Business Model for CCUS Deployment: A Case Study in South Sumatra Region

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Abstract

Carbon Capture, Utilization, and Storage (CCUS) have been a 'buzzword' for the past two years, especially in Indonesia, a developing country committed to achieving net-zero emissions. However, 43% of global CCUS projects were still terminated or put on hold, mainly driven by economic inability and public acceptance. Therefore, a suitable business model and clustering system must be proposed to make carbon sequestration projects economically attractive in Indonesia. Under the Analytical Hierarchy Process (AHP) assessment collaborating with the previous study conducted by Center of Excellence ITB and Lemigas, clustering systems can be deployed in three regions: South Sumatra, West Java, and East Kalimantan. The selected CO_2 sources consist of various industrial sectors surrounding the fields, aiming to facilitate the source's matching process to the possible sink. Thus, it is obtained that the Talang Jimar field (South Sumatra) becomes the highest priority and the most probable sink point with 0.584 $GtCO_2$ storage and an annual sink capacity of 0.0292 $GtCO_2$ for 20 years storage period. Integrating CCUS deployment in Talang Jimar with a clustering system and advanced capturing technology seriously adds commercial value to the project. A carbonate fuel cell is the proposed capturing technology for coal power plants, with expected CO_2 capture efficiency by 90% and reduced electricity cost by 33%. These developing technologies and clustering systems are forcing companies to find more efficient business models to compete in the carbon market. In this study, a joint venture scheme is applied to specify the CO_2 value chain in this project and to cover the capturing and transportation cost through the joint-stock cooperative system, under sharing percentage assumptions of 40% for the capturing company, 30% for storage, and 30% for transport.

Keywords:
joint venture, clustering, CCUS, South Sumatra, Talang Jimar

1. Introduction

As a developing country, Indonesia is expected to experience substantial population growth and economic growth, followed by increasing energy demand. In the next few decades, Indonesia will remain to use coal, oil, and gas as a big part of its energy mix (Figure 1). The increase in transportation and domestic gas demand increases the share of oil and gas demand in the energy mix. To meet the oil and gas demand, the Ministry of Energy and Mineral Resources (MEMR) has the vision to achieve the oil production target of 1 million barrels per day (BOPD) and gas of 12 billion standard cubic feet per day (BSCFD) by 2030. Meanwhile, oil production in Indonesia for the past decades has been declining, with most oil production coming from mature fields and few signs of new oil and gas discoveries in Indonesia. SKK Migas support the vision by planning to emphasize in digitalization process, strategic alliance, and Enhanced Oil Recovery (EOR). SKK Migas is aiming to perform CO_2 injection, chemical EOR, and steam-flood in several prioritized fields to execute.

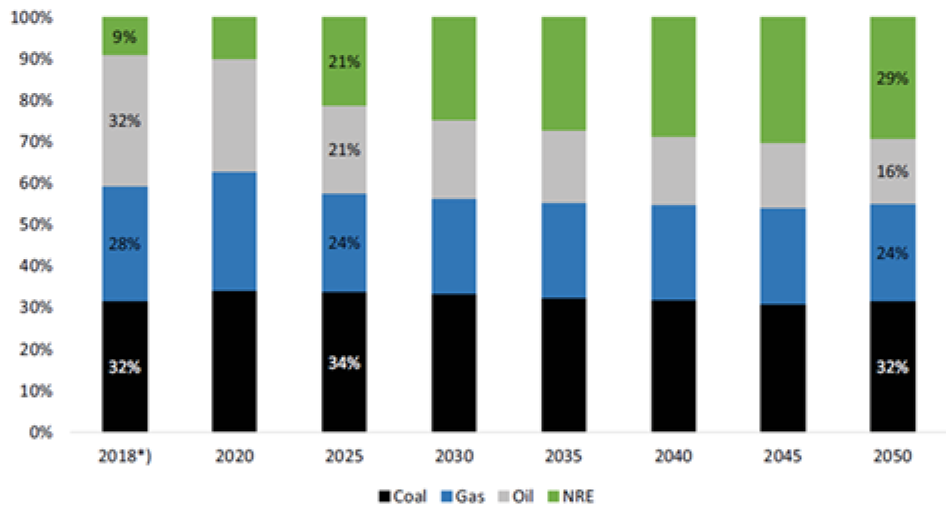
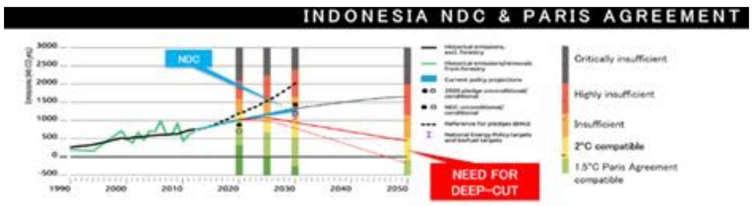


Figure 1. Indonesia's primary energy mix by BaU scenario (Dewan Energi Nasional, 2019).

The electricity demand in 2050 will grow about 6% to 7%, reaching 2,214.1 TWh (BaU). The Indonesian Government plans to rapidly expand the domestic use of coal for PLTU as the primary load of electricity generation in Indonesia, with a percentage of 45%. The impact of increased demand for electricity is the CO_2 emissions from the coal-fired power generation sector are projected to increase substantially. On the other hand, Indonesia has committed to pursuing efforts to reduce climate change temperatures below 2 °C and continued efforts to limit the temperature rise by 1.5 °C above pre-industrial levels in the Paris Agreement as Indonesia's Nationally Determined Contributions (NDC) pledged to reduce emissions by 26% (41% with international support) against the business-as-usual scenario by 2020 as shown in Figure 2. One of the ways to meet Indonesia's NDC in GHG emissions reduction and fulfill the oil and gas demand in 2050 is by implementing Carbon Capture Utilization Storage (CCUS) technology. CCUS can tackle emissions in coal-fired power plants, refineries, petrochemical, cement, iron, and steel industries to emit big sequestration capacity.



No	Sector	GHG Emission Level 2010*	GHG Emission Level 2030 (MTon CO_2e)			GHG Emission Reduction (MTon CO_2e)		GHG Emission Reduction % of Total BaU		Annual Average Growth BAU (2010-2030)	Average Growth 2000-2012*
		MTon CO_2e	BaU	CM1	CM2	CM1	CM2	CM1	CM2		
1	Energy*	453.2	1,669	1,355	1,271	314	398	11%	14%	6.7%	4.50%
2	Waste	88	296	285	270	11	26	0.38%	1%	6.3%	4.00%
3	IPPU	36	69.6	66.85	66.35	2.75	3.25	0.10%	0.11%	3.4%	0.10%
4	Agriculture	110.5	119.66	110.39	115.86	9	4	0.32%	0.13%	0.4%	1.30%
5	Forestry**	647	714	217	64	497	650	17.2%	23%	0.5%	2.70%
	TOTAL	**1,334**	**2,869**	**2,034**	**1,787**	**834**	**1,081**	**29%**	**38%**	3.9%	3.20%

* Including fugitive **Including peat fire

Notes: **CM1** = Counter Measure (*unconditional mitigation scenario*)
CM2 = Counter Measure (*conditional mitigation scenario*)

Figure 2. Indonesia's NDC (first nationally determined contribution Republic of Indonesia).

CCUS is considered the most important clean technology. However, most CCUS projects initiated in the past three decades have failed. Three direct reasons were identified behind the lagging projects. The first thing is related to the investment and public funding by state-owned enterprises. However, CCUS projects are usually characterized by a low or negative internal rate of return (IRR) which make it more difficult to attract commercial bank loans and fulfill the requirements of existing financing options such as equity and debt. Another reason for CCUS failure is the technical aspects of CO_2 storing and capturing. As can be seen in Figure 3, the high failure rate of projects drains the social resources allocated towards CCUS, deepens the doubts on the social feasibility and potential of the technology, hinders the business model innovations, and can ultimately lead to an unsustainable cycle of innovation.

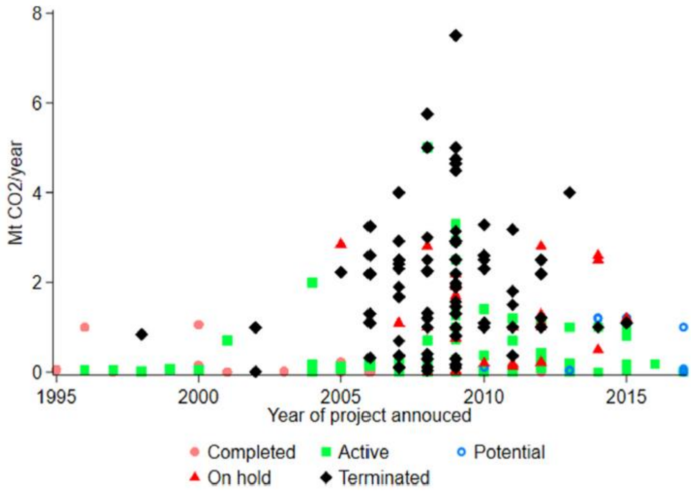


Figure 3. Project number, status, and announced year of CCUS project.

Indonesia has a lot of geological storage medium potential for CCUS development, such as depleted oil and gas reservoirs, deep saline aquifers, and unmineable coal seams. Geological storage is an important parameter to assess for the CCUS within national jurisdictions that generate contiguous geographic areas and several sedimentary basins for CCUS development in the country. Moreover, Indonesia has a lot of industries that especially emit carbon emissions which will be relatively more favorable for CCUS deployment. Hence, to integrate these industries and CCUS operators, a new business model needs to be proposed in order to make CCUS more economically attractive, resulting in a successful CCUS project.

2. Method

2.1 Framework

The methodology of CCUS deployment with business model analysis and economic study is based on assessment scale and resolution according to the Carbon Sequestration Leadership Forum CSLF report, analytical hierarchy process (AHP), Joint Venture business model, and PSC Cost Recovery scheme, as compiled in Figure 4.

The assessment scale of CCUS deployment is divided into country-scale assessment, basin-scale assessment, and site-scale assessment (Bachu et al., 2007; Carbon Sequestration Leadership Forum [CSLF], 2007). LEMIGAS has assessed in high-level country-scale assessment and basin-scale assessment of the most appropriate basins for CCUS deployment candidates. The McKinsey DSPA Framework is used for the rank weighting of basin selection criteria based on its urgency and importance in choosing the prospective basins of CCUS deployment, as shown in Figure 5.

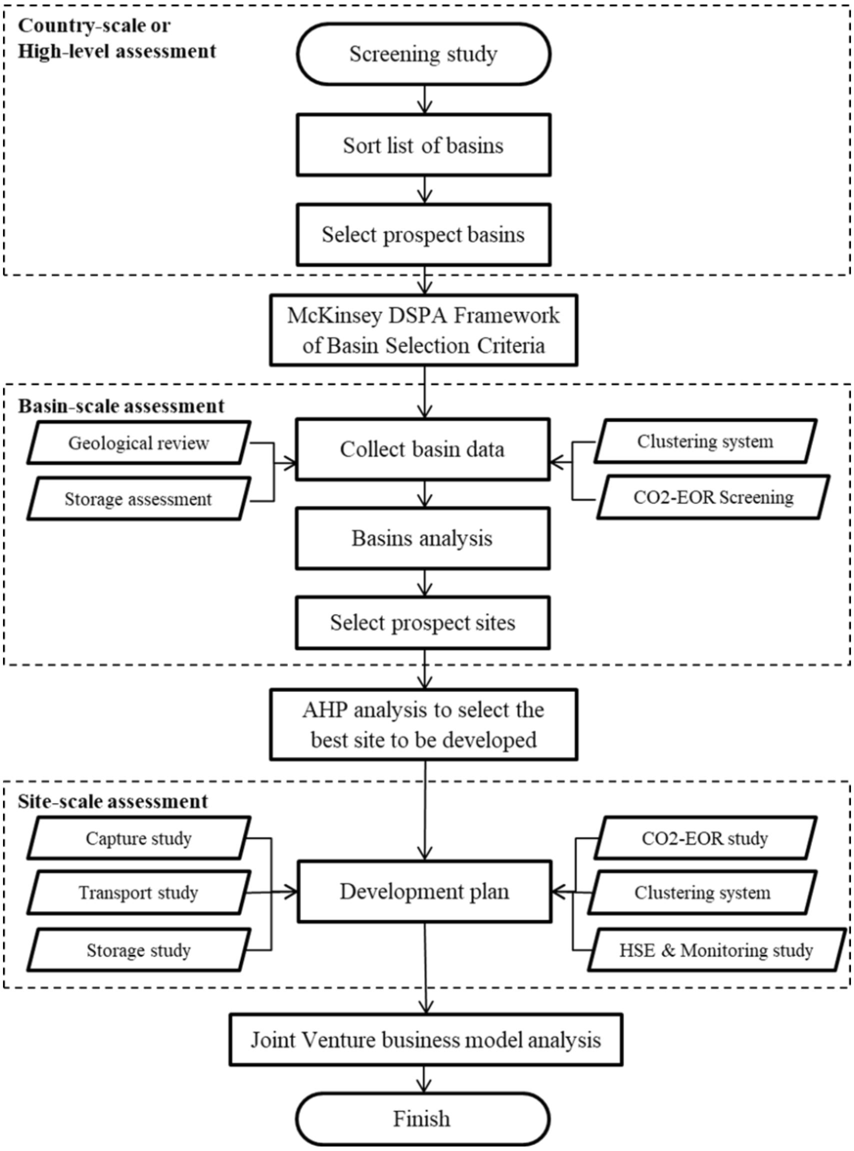


Figure 4. Assessment Workflow Project

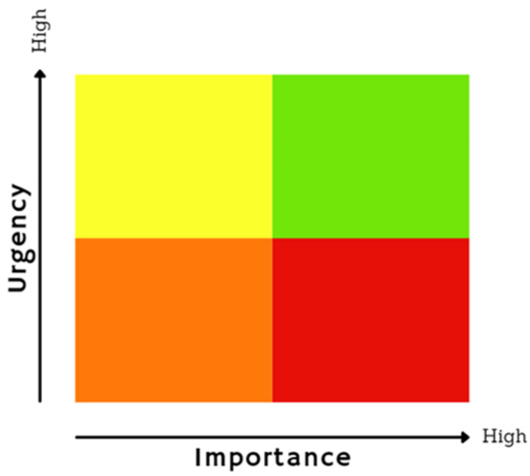


Figure 5. McKinsey DSPA framework of basin selection.

The three chosen prospected basins are analyzed based on the geological review, storage assessment, clustering system, and CO_2-EOR screening. Intending to select the prospective site to develop CCUS, Analytic Hierarchy Process (AHP) framework is used to measure the priority scale through pairwise comparisons of the judgments of experts. The selection process consists of 6 steps guided by Super Decision AHP Software. The validation process starts with experts' judgment until sensitivity analysis, as shown in Figure 6.

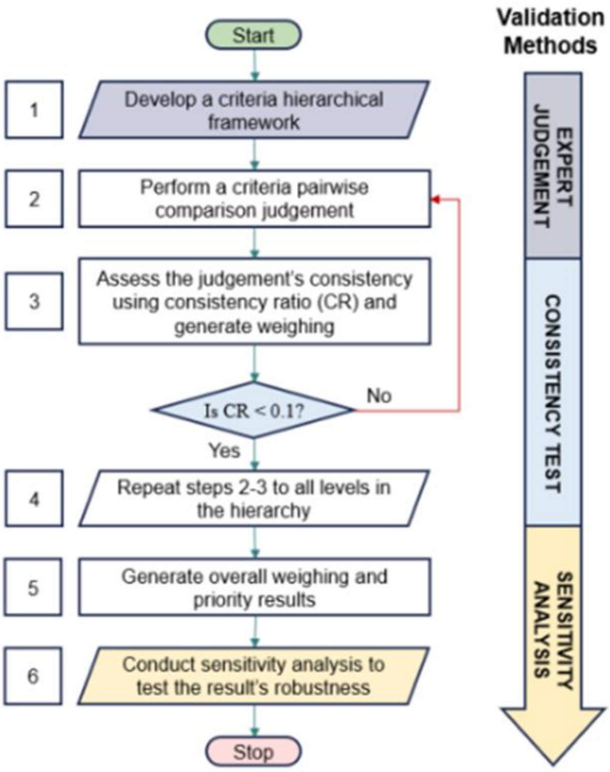


Figure 6. Analytical hierarchy process framework validation methods.

The selected site is assessed and developed the plan of development of capture, transport, storage, CO_2-EOR, clustering system, monitoring and Health, Safety, and Environment (HSE) studies. The CCUS field development then assesses the business model using the Joint Venture business model as the framework of how joint venture companies create, deliver, and capture value.

2.2 Analytical Hierarchy Process

Analytic Hierarchy Process (AHP) is a theory of measurement through pairwise comparisons of the judgments of experts to derive a priority scale. A scale of numbers is needed to make comparisons as it shows how important one factor is over another concerning the criterion being compared (Table 1). The synthesized priority scales are generated by multiplying the derived priority scales by the priority of their parent nodes and adding for all such nodes. Each block's external and internal parameters can be compared and calculated to choose the best basins or sites to be developed. In this study, experts' judgment was acquired from three Indonesian CCUS professionals.

In this study, the field development scenario selection uses AHP combined with sensitivity analysis and performed with the aid of Expert Choice AHP Software with the four-level hierarchical framework that consists of goal (level I), criteria (level II), sub-criteria (level III), and alternative (level IV). The criteria and sub-criteria (Table 2) were obtained from two approaches: expert judgment and literature review. To propose one out of three fields from three different basins, AHP was performed according to the workflow in Figure 7.

Table 1. Scale for pairwise.

Intensity of Importance	Definition	Explanation
1	Equal Importance	Two factors contribute equally to the objective.
3	Moderate Importance	One factor is slightly more important than the other one.
5	Strong Importance	One factor is more important than the other one. It's firmly favouring one over another.
7	Very Strong or Demonstrated Importance	One factor is more important than the other. Its dominance of the demonstrated in practice.
9	Extreme Importance	The evidence referred to one activity over another in the highest possible order of affirmation.
2, 4, 6, 8	The mediant of two adjacent	Used when a compromise is needed.

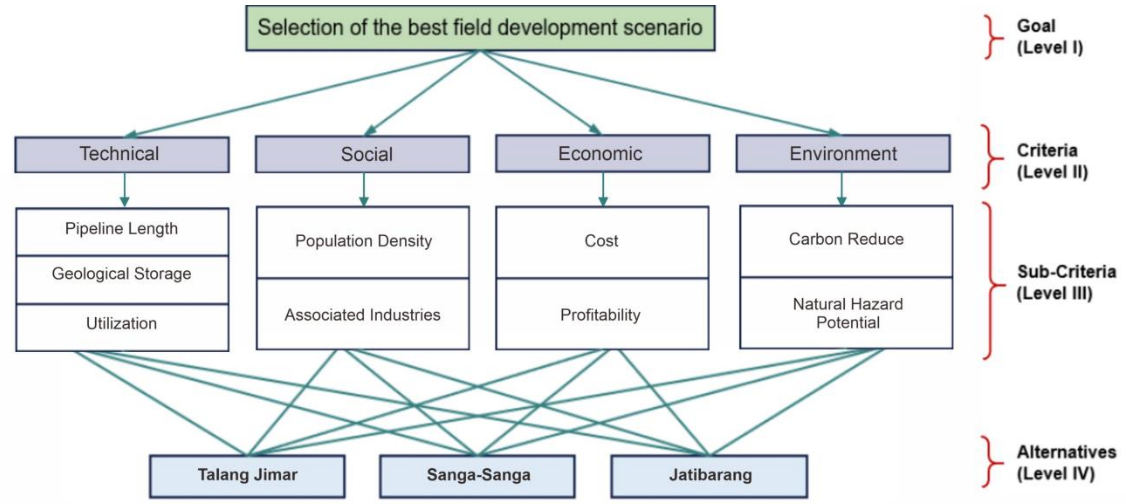


Figure 7. Relationships of the pairwise comparison.

Table 2. Description of each sub-criteria.

Criteria & Sub-Criteria	Description
Technical	
Pipeline Length	The pipeline distance needed to transport CO_2 from industrial sources to the selected sink
Geological Storage	The theoretical CO_2 mass that can be stored in the reservoir
Utilization	In terms of CO_2 EOR, the remaining in a place of a field and the incremental recovery due to CO_2 flooding
Social	
Population Density	Total population of a regency that the pipeline passes through
Associated Industry	The number of industries within the cluster that can be considered CO_2 sources.
Economic	
Cost	Estimated CAPEX and OPEX
Profitability	The ratio of revenue and the total investment
Environmental	
Natural Hazard	Natural hazards (for example, earthquakes and active faults) that may increase CO_2 leakage potential
Carbon reduced	The estimated value of CO_2 reduced compared to CO_2 emitted in the region

The weight value of each alternative represents final priority ranking results. The result shows that Talang Jimar Field is the highest priority with 54% weight, followed by Sanga-Sanga Field and Jatibarang Field. Talang Jimar Field has the most favorable parameter value on technical considering the storage, incremental recovery, and the shortest pipeline distance, which results in a favourable economic parameter (Figure 8).

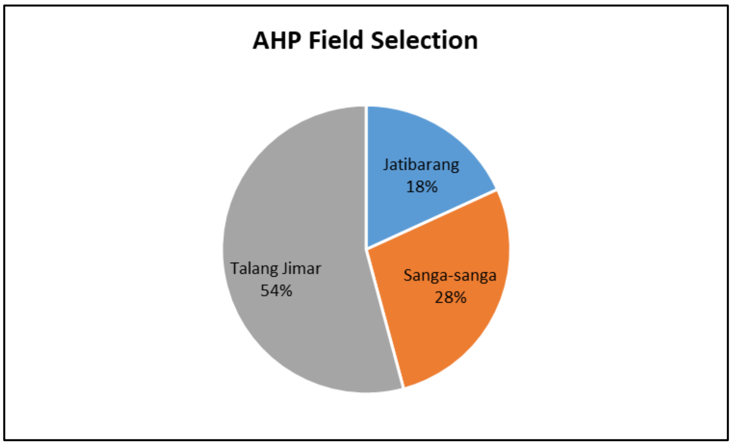


Figure 7. AHP result.

Based on the conducted sensitivity analysis, as shown in Figure 9, Talang Jimar Field still becomes the most probable field to be developed in technical, social, and economic criteria. However, Sanga-Sanga Field has significantly surpassed Talang Jimar Field in environmental parameters because East Kalimantan has the safest storage since it lacks tectonic activity, which possibly causes CO_2 leakage. If the environmental parameter is prioritized, it yields a large inconsistency (> 0.1). Thus, that scenario won't be used, and Talang Jimar Field can be considered the preferred alternative instead of Sanga-Sanga and Jatibarang Field.

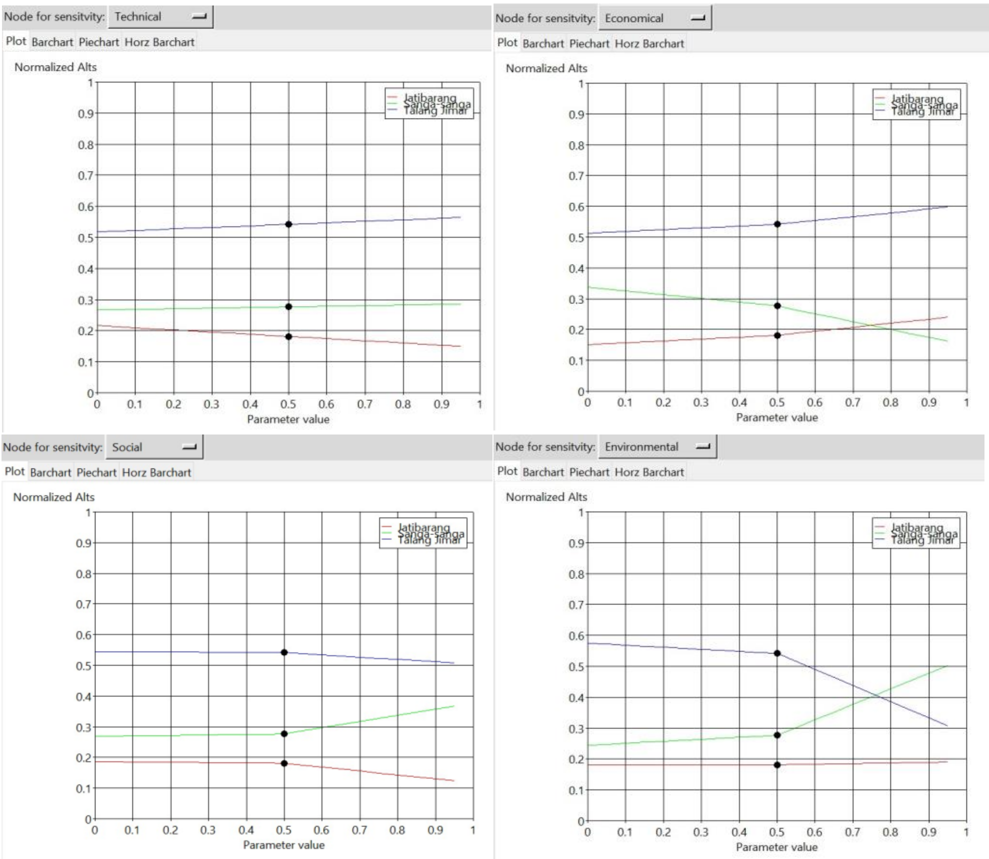


Figure 8. Sensitivity analysis.

3. Results and Discussions

3.1 CCUS Potential in South Sumatra

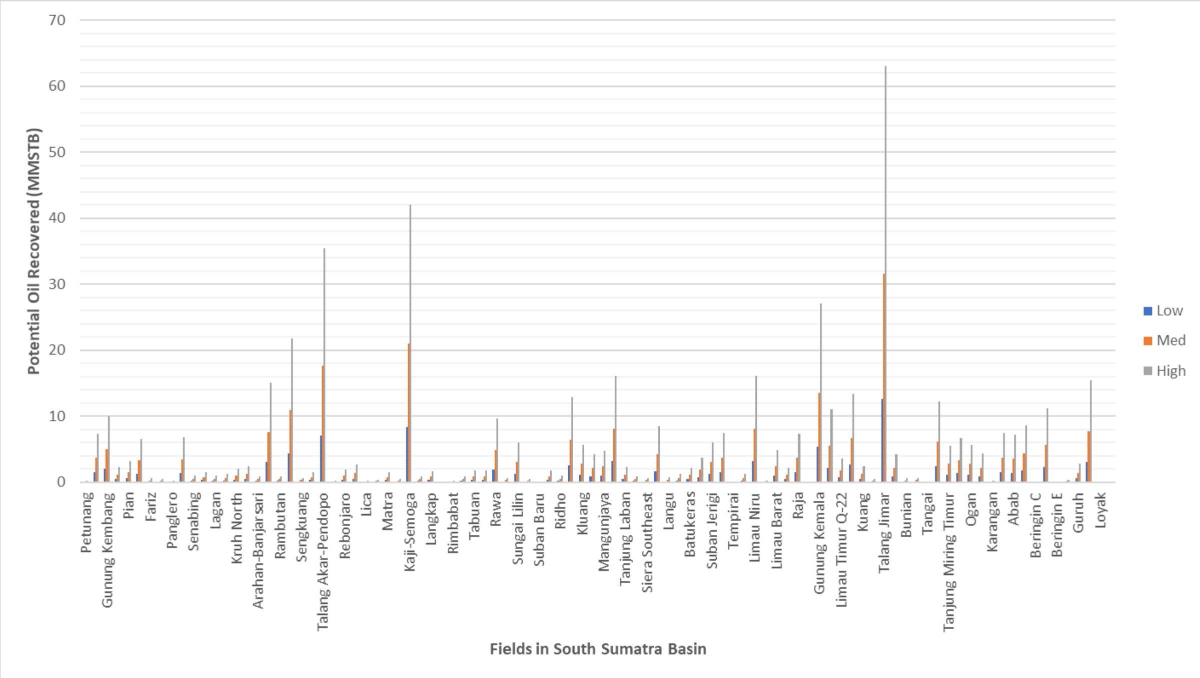


Figure 9. Field storage assessment of South Sumatra basin.

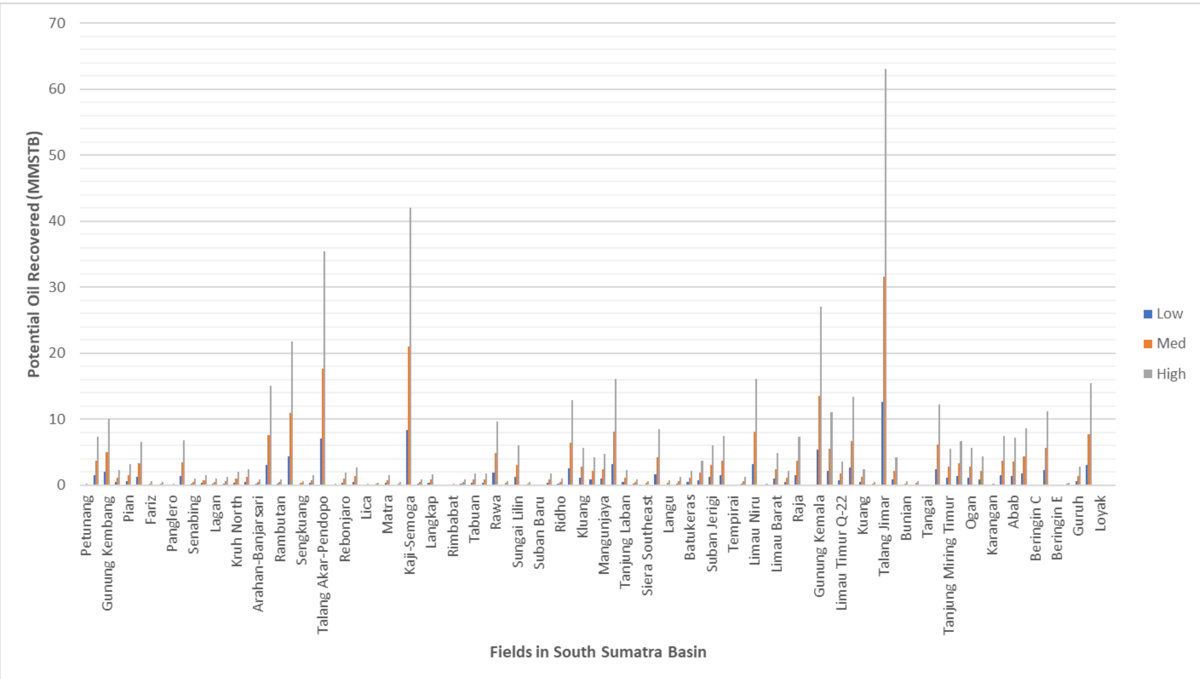


Figure 10. Potential oil recovered in South Sumatra basin.

Concerning Figure 10 and Figure 11, it is known that South Sumatra Basin has 96 fields with a total storage capacity of 3789.0019 BSCF. The Talang Jimar field has the highest CO_2 storage, reaching 95.912 BSCF or 0.584 $GtCO_2$. Based on the field screening, it is also known that Talang Jimar saves high remaining recoverable reserves at 63.1 MMSTB, higher than the other 95 fields in South Sumatra Basin. To make a detailed CO_2 EOR prior feasibility analysis, this literature reviews the fluid properties of the Talang Jimar field as followed by the parameter guidance from Taber & Martin (1983), manifested in the table below.

Table 3. Taber & Martin CO_2-EOR assessment parameter.

Parameter	Recommended	Talang Jimar Field
API Gravity	>27	28.3
Oil Viscosity (cP)	<10	N/A
Water salinity (ppm)	-	N/A
Oil Saturation (%PV)	>20	N/A
Depth (ft)	>2500	4388.12336
Temperature (°C)	>2500	105
Porosity (%)	NC	17%
Permeability (mD)	NC	200
Net Thickness (ft)	Relatively thin	21.97
Lithology	Sandstone, carbonate rocks	Sandstone

3.2 Clustering System

Determining specific CO_2 sources in industrial clustering systems and seal integrity for the selected storage are vital to prevent CO_2 leakage. There are two prime criteria for selecting an excellent CO_2 source from the different industries; the CO_2 emission rate and maximum distance from the wellsite sink are 300 km. In this project, there are five CO_2 sources from Pagardewa Field Development Project, Merbau Gas Gathering System, South Sumatra 8 Power Station, PT Semen Baturaja, and PT Pupuk Sriwijaya (Table 4).

Table 4. CO_2 emission of each source.

Sources	Locations	CO_2 Emission (MMT/yr)
Pagardewa FDP	Prabumulih, South Sumatra	2.23
Merbau GGS	Merbau, South Sumatra	0.028
SS-8 Power Station	Muara Enim, South Sumatra	11.57
PT Semen Baturaja	Palembang, South Sumatra	15
PT Pupuk Sriwijaya	Palembang, South Sumatra	1.2

Pagardewa Field Development Project is a current mega project for developing exploration projects in the Pagardewa area. In 2016, this field produced 44.4 MMSCFD of gas. The emission profile of each source is diverse. Carbon dioxide produced by South Sumatra 8 Power Station is 11.5 $MMTCO_2$/Year, mainly cast in fuel gas form. Meanwhile, PT Semen Baturaja induces 15 $MMTCO_2$/Year of CO_2, and PT Pupuk Sriwijaya produces 1.2 $MMTCO_2$/Year. The removal process in Merbau GGS then becomes the source of carbon dioxide (producing 363 tCO_2/d) with high carbon purity.

The industrial cluster in South Sumatra has a high potential to emit CO_2 (with a total of 160,195 MMT/Year), which can be utilized as CO_2 flooding. CO_2 transport with the onshore pipeline is more economically feasible and repeatedly used under the supercritical condition or above 31 °C of temperature and 73,84285 bar of pressure. In this report, the Merbau Gas Gathering Station is projected to become the cluster centroid (the gathering CO_2 point from each source). CO_2 collected will be transported to Talang Jimar after being purified and dehydrated, as it will be sunk to Talang Jimar Field as CO_2 EOR.

3.2.1 Transportation and Pipeline Specification

Following the sources distribution, this study reviews the CO_2 transportation roadmap and verifies the pipeline specification feasibility. The designation of CO_2 pipeline during fluid transport e refers to Canadian Standard Association (CSA) Z662 for a proper pipeline design recommendation in the CCUS Clustering system in each region. The inner diameter of the pipeline can be found through the multiplication of gas viscosity (μ), CO_2 density (ρ), and flow rate (Q) or can be written with the following equation:

$$D = 0.363 \; x \; Q^{0.45} x \; \rho^{0.13} x \; \mu^{0.025} \tag{1}$$

After knowing the diameter of the pipeline, the volumetric flow rate and pipeline thickness values are obtained through the following formula:

$$Q = \frac{m \; x \; Ru \; x \; T \; x \; Z}{144 \; x \; MW \; x \; P} \tag{2}$$

The diameter value is substituted to earn the thickness value of the pipeline through the formula below:

$$t = \frac{P \; x \; D}{2\{S \; x \; F \; x \; (E - P)\}} \tag{3}$$

Pipeline material pointing to API 5L X60, a typical high-grade pipe for oil and gas transmissions with a minimum yield strength (S) is 415 MPa (60,200 psi). API 5L X60 pipeline is a carbon steel material pipeline that is suitable for CO_2 transport in the CCUS project. The longitudinal joint factor (E) is 1.0, and the design factor is 0.72. CO_2 is assumed to have undergone a dehydrated process that leaves pure CO_2 only. Thus, several conditions regarding the P&T and CO_2 chemical properties are applied in the pipeline design specification as follows.

Table 5. Pipeline specification assumptions.

Temperature	48.89 °C
Pressure	96 bar
CO_2 Density	341.86 kg/m3
CO_2 Phase	Dry Supercritical
Universal Gas Constant (R)	35.114 ft lbf/lb °R
Molar Mass (MW)	44.01 g/mol
Compressibility (Z)	0.64
Viscosity	1.64×10^{-5} Pa.S

Talang Jimar field can store 95,912 BSCF/year with a period estimation of 20 years. Thus, the mass flow rate is at 926.35 kg/s or 2042.25 lb/s. By the formula, it is known that the volumetric flow rate (Q) is 3.786 CFS or 0.107 CMS.

$$Q = \frac{2042.25 \ x \ 35.114 \ x \ 48.9 \ x \ 0.65}{144 \ x \ 44.01 \ x \ 95} = 3.786 \ CFS \ or \ 0.107 \ CMS \tag{4}$$

The Q value is substituted to the diameter formula generating the inner diameter value at 21.5 cm or 8.46 in.

$$D = 0.363 \ x \ 0.107^{0.45} x \ 341.87^{0.13} \ x \ (1.64 \ x \ 10^{-5})^{0.025} = 21.5 \tag{5}$$

The diameter value was then substituted to the thickness formula, resulting in pipeline thickness at 0.14 in or 0.3537 cm.

$$t = \frac{9.5 \ x \ 0.215}{2((415 \ x \ 0.72 - 1) - 9.5)} = 0.3537 \tag{6}$$

The engineering pipeline design in Talang Jimar can be concluded as manifested below.

Table 6. Pipeline grade.

Grade	P [bar]	T [°C]	ID [in.]	OD[in.]	T [in.]	Q [CFS]
X-60	95	48.9	8.46	8.6	0.14	3.786

As the pipeline specification has been evaluated, the route is mapped through **Figure 7**, CO_2 emitted from each source will be transported through pipelines that trail to the right-of-way pipelines that send natural gas after being purified in the Merbau Gas Gathering Station. Following the route, CO_2 from SS-8 Power Station will be gathered and purified in Merbau Gas Gathering Station to produce CO_2 with low impurities before being transported to Talang Jimar through the CO_2 transport pipeline that trails with the existing RoW pipeline. CO_2 emitted from other sources is assumed to undergo purifying and dehydration practices in Talang Jimar.

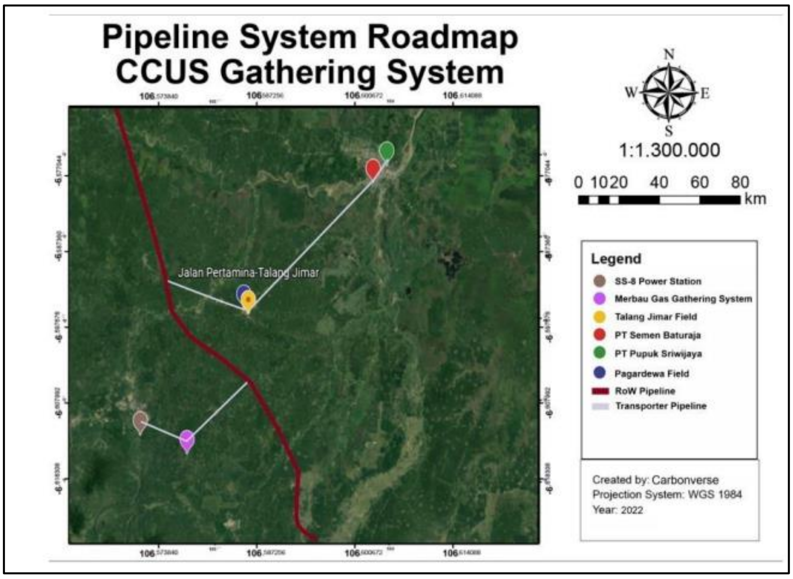


Figure 11. Pipeline system roadmap of CCUS in projected area.

3.3 Capturing System

Carbon capture is a technology to trap CO_2—before it enters the atmosphere—in concentrated streams such as coal-fired power plants, petrochemicals, cement, and refineries that can readily be transferred to a geological storage site. The current CO_2 capture technology application in large industrial plants can capture CO_2 efficiently up to 90% with cost vary. There are commonly four system classifications, namely post-combustion, pre-combustion, oxy-fuel combustion capture system, and capture system from industrial process streams.

Since clustering systems are able to compile captured CO_2 from each concentrated stream, it is important to understand the capture technologies of each stream and each system. Industrial processing streams are some concentrated streams that produce a large amount of CO_2 from hydrocarbon conversion processes such as process sweetening of natural gas processing plants, coal-fired power plants, ammonia, or fertilizer factories. These industries can capture CO_2 in three methods: post-combustion, pre-combustion, and oxy-fuel combustion capture. The cement plant is able to capture CO_2 with commonly two methods: post-combustion and oxy-fuel combustion.

Industries in the Talang Jimar CCUS clustering system project contain South Sumatra 8 Power Station, Merbau Gas Gathering Station, and Pagardewa Field Development Project, PT Semen Baturaja, PT Pupuk Sriwidjaya, and Pagardewa Field Development Project are able to use a post-combustion system. The post-combustion definition is the sources of CO_2 from separated flue gasses produced by the combustion of fossil fuels or kiln-off gas or ammonia. There are several steps to implement CO_2 capture: Selective Catalytic Reduction (SCR), Flue Gas Desulphurization (FGD), Monoethanolamine (MEA) process plant, CO_2 Compressors and dryers, and Low-pressure (LP) steam turbo-generator. SCR could reduce the level of NOx by reacting NO2 with ammonia in a catalyst bed at elevated temperatures to yield nitrogen and water vapor. FGD process reduces the SO2 content by two types of process: Wet FGD can remove SO2 effectively 80–98% by scrubbing flue gas using limestone as a reagent, and dry FGD remove 50-80% SO2 content by contacted flue gas with alkaline (most often lime) sorbent. Seawater scrubbing of flue gas can be proposed at a coastal location. Amine scrubber such as MEA or MDEA (methyldiethanolamine) is a proven solvents for CO_2 capturing from post-combustion. A CO_2 conditioning system (compressed with cooling and dehydration to 110 bars) is required to prepare and maintain the CO_2 into a liquid phase to efficiently transport the CO_2.

Current capture technology in coal-fired and natural gas-fired power plants succeeds in capturing 90% of CO_2, but this technology decreases the power output by 20-30%, increases electricity cost by 80%, and produces additional pollution of capture technology by 25% (lbs/MWh). To reduce the cost and CO_2 emissions, there is an innovative technology of utilizing advanced carbonate fuel cell technology (Figure 12). This technology works by increasing the amount of power plant electricity while concurrently reducing carbon dioxide emissions on fuel cells. Fuel cells act as carbon purification membranes that transfer CO_2 from a very dilute air stream to a concentrated fuel exhaust stream, allowing CO_2 to be easily and inexpensively recovered, cooled, and compressed. Fuel cell power generation receives the flue gas from power plant exhaust, and combining with natural gas to generate power, the carbon dioxide is concentrated in the exhaust stream of natural gas-fueled power turbines. South Sumatra has natural gas production that can be utilized as a fuel in carbonate fuel cell technology for better efficiency, fewer emissions, and more power.

This technology can increase the power output by 80% from the fuel cell generated from natural gas, the cost of electricity by only 33%, and pollutants decrease by 78% (lbs/MWh) with an efficiency of 90% CO_2 capture. The result is shown in Table 7.

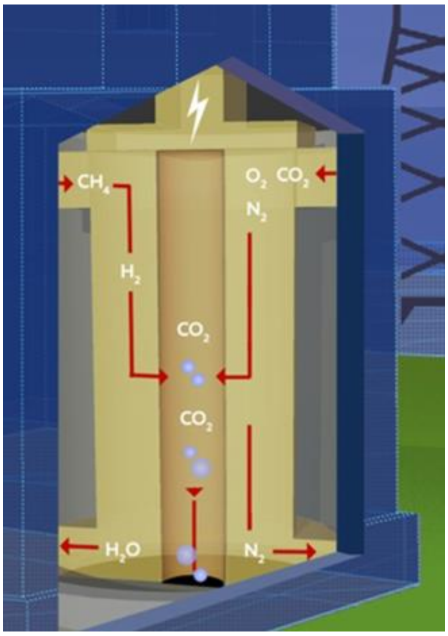


Figure 12. Carbonate fuel cell energy technology.

Table 7. CO_2 mass efficiently captured.

Streams	CO_2 Emission (MMT/yr)	CO_2 captured (90% Efficiency) (MMT/year)
South Sumatra 8 Power Station (600 Mwe)	11.570	10.400
Merbau Gas Gathering Station	0.028	0.025
Pagardewa FDP	2.230	2.000
PT Semen Baturaja	15.000	13.500
PT Pupuk Sriwidjaya	1.200	1.100

3.4 Utilization

Based on the previous simulation, Talang Jimar is prospective for CO_2 flooding regarding the fluid properties screening for CO_2-EOR. Comparably, this field has low pressure at 1647.9 psia. Two approaches are recommended to reduce the MMP value based on a previous review; CO_2-WAG and slug injection. Each approach will use pure CO_2 and CO_2 with methane impurities (9:1 ratio, 8:2 ratio, and 7:3 ratio). Water alternating gas (WAG) is aimed at controlling gas mobility and elevating sweep efficiency. In the preceding study regarding CO_2-WAG (Abdurrahman et al., 2019), the suggested ratio of CO_2/water is 1:2, generating an additional oil recovery factor of 35,94%. Besides, CO_2-WAG under the recommended ratio initiates the most significant residual oil saturation (SOR) decrease after 910 days. Under this ratio, the required CO_2 volume injected is also lower.

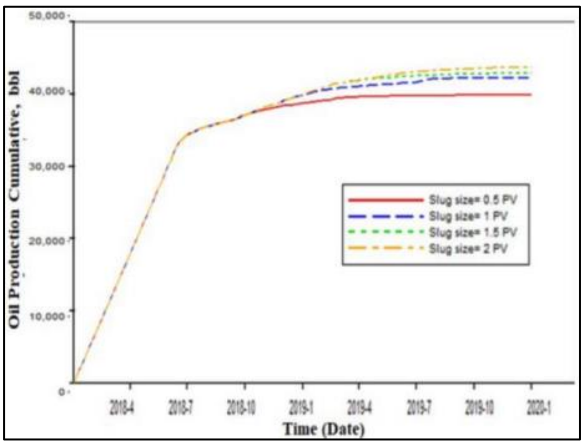


Figure 13. Slug size vs oil production cumulative (Abdurrahman et al., 2018).

In CO_2 slug injection, the slug size is a major component to consider in CO_2 injection. Commensurate with a study conducted by Hidayat et al. (2018), the most favorable slug size is 0.5 PV, as it increases cumulative oil production by 10–21%. The higher slug size (>1 PV) generates a higher oil production rate yet causes the additional oil production to appear less significant, as shown in Figure 13. Moreover, CO_2 injection with slug size >1 PV might originate a CO_2 breakthrough condition that causes the injected CO_2 to be released to the surface.

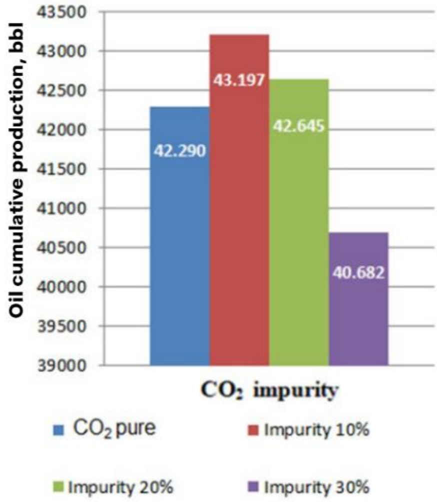


Figure 14. CO_2 impurities (CH_4) percentage vs cumulative oil production (Abdurrahman et al., 2018).

Several types of co-solvent might be added during the injection process, primarily CH_4. In the slug injection scenario, the ratio of CH_4 content in CO_2 affects cumulative oil production (**Figure 14**). The previous study evaluated that 10% CH_4 content might add cumulative oil production insignificantly. However, CH_4 causes the need for additional pressure for CO_2 injection to be miscible, as CH_4 has a lower density value than CO_2.

3.5 Economic and Business Model

In this study, we proposed a business model for the development of the CCUS case study project in the South Sumatera Region, Talang Jimar Field. Furthermore, the economic analysis uses the Product Sharing Contract (PSC) fiscal system.

3.5.1 Cost of CCUS Project

CCUS project is considered an advance and expensive project because it involves many stakeholders. The stakeholders can be from power generation, coal, chemical, oil and gas, transport, and other industries. Thus, the cost of a CCUS project is commonly divided into four main part, which is the capture cost, transportation cost, storage cost, and utilization cost.

- *Capture Cost*

  The capture cost consists of capital and operational cost. The capital cost includes the construction and investment cost of capturing technology along with compression equipment and pump technology. While the operational cost consists of the O&M cost, the incremental cost of the vapors and absorbents, and the loss of electricity output. (Yao, 2018). There are differences in cost between different technologies. Based on the study by David and Herzog (2000) it is said that the natural gas combine cycle (NGCC) is the highest capital cost and the highest energy requirements for the capture (0.354 kWh/kg of CO_2 processed), and the post-combustion decarbonization at Pulverized Coal plant has lower energy requirement around 0.317 kWh/kg of CO_2 processed, finally the Integrated coal Gasification Combined Cycle (IGCC) plant has the lowest energy requirement of (0.194 kWh/kg of CO_2 processed).

- *Transport Cost*

According to McCollum and Ogden (2006), the transportation capital cost should be considered several things, namely the length and diameter of the pipe, location factor, and terrain factor (Figure 15). The operational cost is the capital cost times the factor of O&M factor, which is case specific.

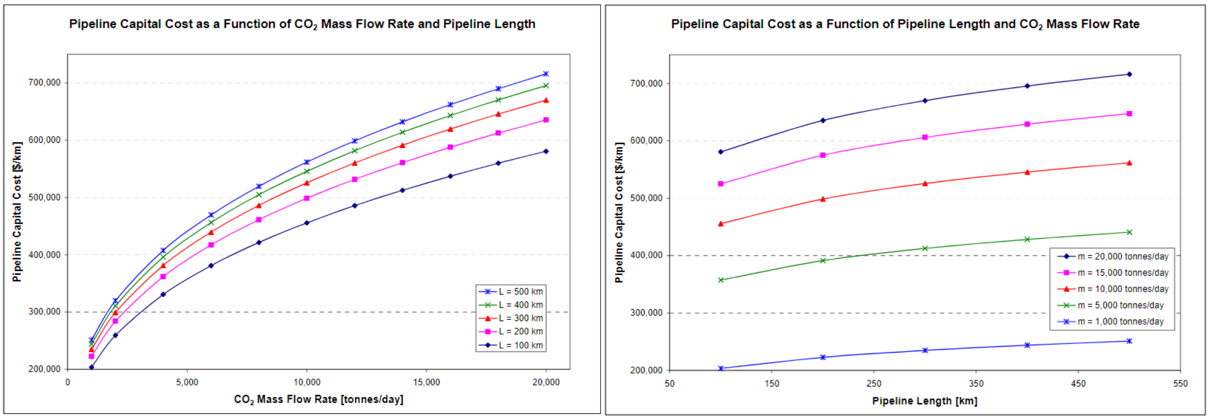


Figure 15. Pipeline capital cost as a function of CO_2 mass flow rate (left) and pipeline length (right) (McCollum and Ogden, 2006).

- *Storage Cost*

The storage of CO_2 is commonly in depleted oil reservoirs; thus, it does not need any additional drilling costs or other costs. However, in some cases, we still need to drill to avoid hazard-prone locations or any other potential problems. According to Yao et al. (2018), the capital cost of storage cost consists of the cost of site screening and evaluation, the cost of injecting equipment, and the drilling cost in certain places. Based on another study by McCollum and Ogden (2006), the parameter that still needs to be considered other than what has been stated is characteristic of the reservoir itself. The reservoir determines how many injecting well are required to store the CO_2. As the increase of wells numbers, the cost will also increase linearly (Figure 16 & Figure 17).

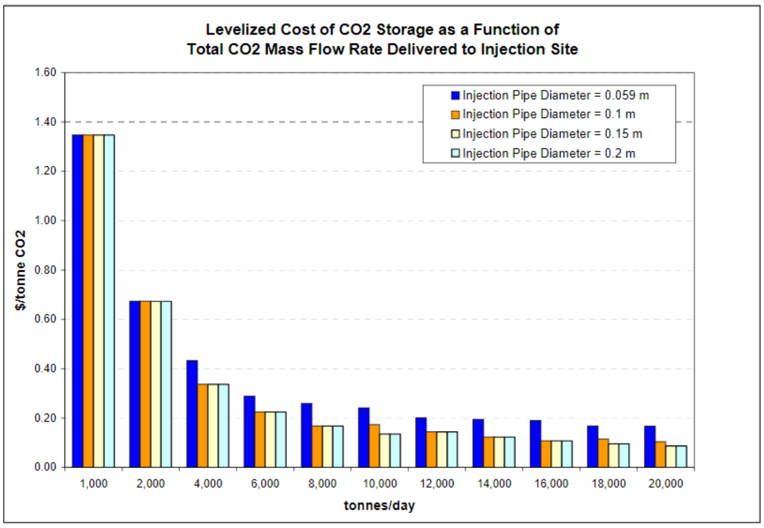


Figure 16. Levelized cost of CO_2 storage as a function of total CO_2 mass flow rate delivered to injection site (McCollum & Ogden, 2006).

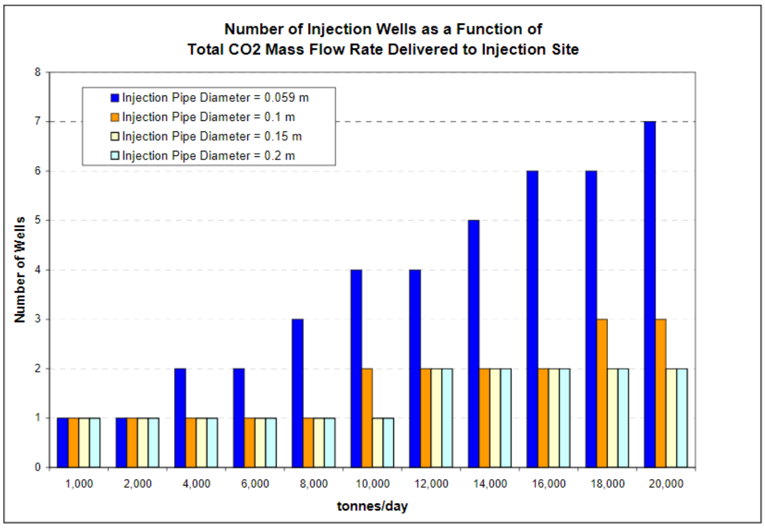


Figure 17. The number of injection wells is a function of the total CO_2 mass flow rate delivered to the injection site (McCollum & Ogden, 2006).

- *Utilization Cost*

  There are several utilization options for the CCUS project, but the most attractive and widely utilized was the EOR for the depleted oil/gas field. This cost of utilization is varied in each field.

Based on these costs, the CCUS project is really expensive, and if not handled carefully, the project would not be economically profitable both for the contractor and the government. Taking this thing into account, we recommend the contractor of the oil field form venture that could ease the cost of the project.

3.5.2 Joint Venture

The development of a clustering system needs a special requirement on the degree of integration of a typical company, extensive development of CCUS will never be realized without collaboration among sectors. Thus, a joint venture model is designed to develop this system. In this business model, a long-term purchase and sale agreement is introduced to the joint venture model.

In this paper, a joint venture is performed that consists of three main companies (Figure 18). Oil and gas contractors are responsible for the storage and utilization of CO_2, and other companies will help in the capturing technology and in the transportation facility. This is being done in order to reduce the cost of CCUS development while also expanding the project further. As in Figure 12, we can see that outside of the PSC cost recovery, the contractor is involved in a joint venture with two other companies in developing CCUS with a percentage of 30% for the contractor, 30% for the transportation facility company, and 40% for the capturing technology company. However, the applied percentage is adjustable, conforming to the contract negotiated between the contractor and the venture.

In the future, the source of revenue for this joint venture is not limited to the EOR of the oil/gas field. But it can also be from electricity generation that utilizes CO_2 and even carbon trading with a levelized scale. In this way, all the companies should have multiple sources of revenue that make this joint venture successful.

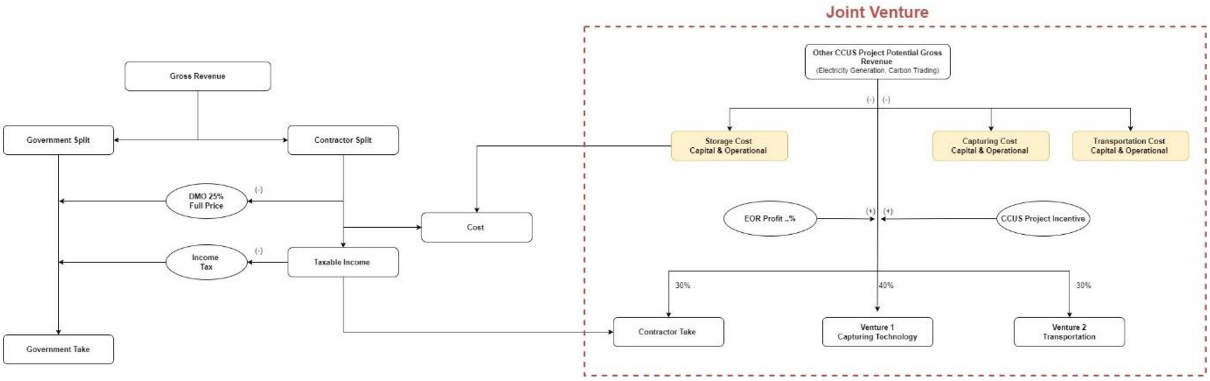


Figure 18. Joint venture scheme.

4. Conclusions

Based on the study, CCUS deployment in South Sumatra is a clustering system that utilizes CO_2-EOR and CO_2 storage as commercial strategies. Several considerations are applied, comprising theoretical field storage, possible associated industries, annual CO_2 emitted in the industry, and a number of depleted oil fields. Carbonate Fuel Cell is the chosen capturing technology that generates ~90% CO_2 capturing efficiency. CO_2 EOR in the Talang Jimar field can generate ~35.94% of the supplementary recovery factor. To maximize the profitability of the industry, we propose a joint venture model as one of the best ways to support the project.

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