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Solar Enhanced Oil Recovery as the Solution to Enhance Oil and Gas Production for Mature Fields in Indonesia

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Abstract
Indonesia has a target of reducing 29% of GHG emissions by 2030 (NDC, 2022), reaching net-zero emissions in 2060 (LTS-LCCR, 2021), and obtaining 1 million BOPD oil production and 12 BSCFD gas production in 2030. Oil and gas companies have particular challenges to achieve the target in line with paying attention to national energy security despite the oil reserve and production declining since 1995 because of the maturity of the fields. In such a case, the enormous amount of remaining oil in place left by the primary and secondary production stages has led to the EOR method as the best way to improve oil production. In Indonesia's mature fields with specific reservoir conditions, steamflooding is currently a highly effective EOR method to increase oil production by 20–300% and reduce viscosity by up to 98%. However, the production of steam in huge quantities conventionally would require vast amounts of fossil fuel resources. Hence, replacing fossil fuel-derived steam with solar-derived steam would solve the twin problems of energy scarcity and greenhouse gas emissions. Solar EOR is a viable alternative to gas-fired steam production for the oil industry by using the sun's energy to generate steam. For designing the long-term Solar EOR, Ayman Solar Concentrator (ASC) technology on low-cost solar thermal energy storage will generate high-temperature steam for 24 hours all day by enabling the system to achieve higher temperatures with less mirror surface. The evaluation of annual energy output from the solar project's design could save more than 8,672,400 MMBTU/year of natural gas and cut the environmental footprint up to 1200 metric tonnes per day of net CO_2 so that natural gas can be sold and allocated to various sectors. Furthermore, the economic analysis shows that solar EOR has the lowest operational. This technology's novelty is its low cost and ability to generate steam to supply it upon demand in Indonesia's ongoing steamflood project.

Keywords:
ASC, basalt, CSP, EOR, natural gas, oil, solar, steam

1. Introduction

Could Indonesia achieve a target of 1 million BOPD and 12 BSCFD by 2030 in conjunction with a net-zero emission target by 2060? A recent study shows that replacing fossil fuel-derived steam with solar-derived steam would solve the problems of energy scarcity and greenhouse gas emissions. The world is facing an increasing need to become more environmentally sustainable by seeking alternative and renewable energy sources beyond conventional fossil fuels. Oil and gas companies have particular challenges in achieving the target in line with paying attention to national energy security despite the oil reserve. Production has been declining since 1995 because of the maturity of the fields (SKK Migas, 2019). In such a case, the enormous amount of remaining oil in place left by the primary and secondary production stages has led to the EOR method as the best way to improve oil production. In Indonesia's mature fields with specific reservoir conditions, steamflooding is currently a very effective EOR method to increase oil production (Bae, 2017).

Steam injection generates steam from natural gas-fired boilers, and the steam is injected into the reservoir. However, the production of steam in huge quantities conventionally using natural gas boilers would require vast amounts of fossil fuel resources. For example, the fuel requirement for the steamflood project of Chevron in California ranges from 2.1 to 11.8 MMscfd (Dwidevy, 2017), and the natural gas consumption for the steamflood project of Silangkitang Field (SIL-1) Sarulla reach 511.72 MMBTU/day (Reyseliani et al., 2020). Everywhere in the world strives to innovate new ways of innovative technology in facing recent global change. In the energy transition roadmap towards zero emissions of Indonesia, in 2035–2060, Indonesia will target 55% of renewable energy dominated by solar power (Candra, 2022). Another direct benefit of using Solar Thermal EOR is that the company gets "green credits" in the form of tax reductions by replacing fossil fuel (natural gas) with clean energy sources (solar). And the most important thing is the company's public image as an "environmentally responsible" brand. This branding is prestigious, and big companies compete to project it to their customers nowadays.

Direct transition from fossil fuels to renewable clean energy will take time, but the need is growing more urgent. This paper discusses the Solar EOR (S-EOR), which will generate high-temperature steam for 24 hours a day by enabling the system to achieve higher temperatures with less mirror surface implementation (Al-Maaitah, 2020) in Indonesia, specifically Duri Steamflood Project.

2. Theory and Definitions

2.1 Solar Potential in Indonesia

During the last eight years (2015), Indonesia has installed solar technology with 159.43 MW (IRENA, 2020). Nonetheless, the government has begun to make efforts to produce new renewable energy, with a target of 23% of renewable energy in 2025. Especially the solar power plant target of 6.5 GW in 2025 and 45 GW in 2045. Indonesia is located in a tropical country that passes by the equator line. Every day, Indonesia receives an average solar radiation (DNI) of 892 kWh/m^2 (Gupta et al., 2017), with the best solar sunshine from 4 to 5 hours. A tropical country zone has good data for average solar radiation because there is no significant seasonal variation and variability in monthly solar insolation. Indonesia has the potential to utilize solar energy for all provinces up to 207 GW (Ministry of Energy and Natural Resources). Additionally, Indonesia is located in the equatorial zone, which provides for a rather even distribution of sun irradiation, which is shown by the amount of average global horizontal irradiation (GHI). The amount of Indonesia's GHI is 4.8 kWh/m^2 per day. It is greater than the daily average GHI in Germany (2.9 kWh/m^2), Japan (3.6 kWh/m^2), China (4.1 kWh/m^2), and Singapore (4.5 kWh/m^2), according to the Global Solar Atlas PV study (Solargis, 2020). Specifically, Riau province has the potential to utilize solar from 4.4 to 14.8 giga watt-peak (GWp). As a result, Riau province is sufficient as a location for constructing a Concentrator Solar Power Plant to generate steam in Indonesia's ongoing steamflood project.

2.2 Steamflood Characteristic

Heavy oil with a high viscosity value and a low API degree (specific ravity scale developed by the American Petroleum Institute) makes it challenging to produce conventionally. The reservoir management practices consider the various IOR/EOR (Improved Oil Recovery/Enhanced Oil Recovery) options much earlier in a field's productive life. Screening criteria are helpful for a cursory examination of many candidate reservoirs before expensive reservoir descriptions and economic evaluations are done. A cursory examination of the technical standards for steamflood is necessary (Table 1) to rule out the less likely candidates.

Table 1. General screening guide for steamflooding (Taber & Martin, 1997).

API	μ_0	So	K	d	h	Kh/μ_0
	cP	%	mD	ft	ft	mD-ft/cp
8 -- 25	< 100,000	>0	>200	<5000	>20	>50

2.3 Solar Technology and Surface Facilities

2.3.1 Ayman Solar Concentrator (ASC) (Al-Maaitah, 2020)

To generate hot steam that can reach the effective steam temperature for EOR, around 370 ℃, concentrated solar power (CSP) is needed. Currently, there are five known types of CSP, including parabolic through converter (PTC), heliostat tower, parabolic dish, linear fresnel concentrator, and Ayman solar concentrator (ASC). In this paper, the ASC technology will be used to develop the solar EOR in Indonesia.

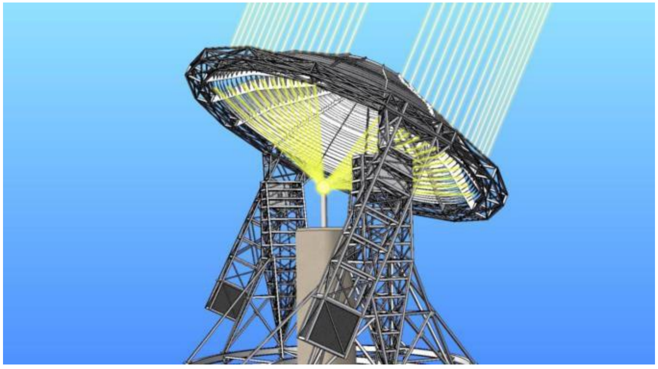

Figure 1. ASC illustration (Al-Maaitah, 2020).

Combining the Fresnel Concept for metallic lenses with an innovative tracking system, this technology could reach the optical efficiency of 91% incidence angle modifier (IAM). Fresnel Concept on the metallic lens that consists of a conical reflective ring allows ASC to collect and concentrate the solar radiation to the fixed focal point. Hence, ASC is capable of reaching the concentration ratio until 10,000 suns on the center of the focal point and temperature until 1000 ℃. The tracking system uses a dual tracking system to maintain the top aperture of the concentrator perpendicular to sunrays by altering the angle of the support arm (Elevation) and rotating the support structure (Azimuth), which can track the sun's location with 0.1° accuracy. (Al-Maaitah, 2022) Furthermore, this technology also provides an automatic system to self-clean up, has a low cost for operational and maintenance, and has a scalable system for various applications (Al-Maaitah, 2020).

Figure 2. The cross-section for metallic lens in ASC (Al-Maaitah, 2020).

2.3.2 Thermal Energy Storage Technologies

Storing the hot air from the ASC and maintaining the temperature is one of the biggest challenges. Therefore, innovative thermal energy storage (TES) is needed. For this paper, TES on the packed bed that composed of basalt or ceramic refractory materials is chosen. Basalt rock is chosen due to its high thermal capacity with a higher amount of stored energy in the system and the stability to maintain high temperatures up to 1000 ℃ and has a proper working temperature at 700 ℃. Basal rock has a low proportion of amorphous domes and makes the behavior close to fully crystallized material. The appearance of hematite in Basal Rock could stabilize the thermal conductivity at high temperatures. Basalt rock also has a low levelized cost of electricity (LCOE) and low-cost storage materials by using natural rocks for the materials. Basalt rocks cost around 8 euros/ton compared with molten salts, which cost 700 euros/ton. (Nahhas et al., 2019).

The concept of this innovative technology, according to the thermocline theory, is that hot air is ducted into a single tank of rocks to store energy, which is then released by switching the direction of the airflow. These benefits make the air-rock-packed bed, which is regarded as an emerging technology to increase overall system efficiency. Furthermore, the storage could store and maintain the temperature even if the solar beam is not available. This technology was completed on the pre-commercial and laboratory scale in 2016 in Jordan, and it is currently accelerating as well as testing the pilot scale at Masdar City, Abu Dhabi (Michael, 2020).

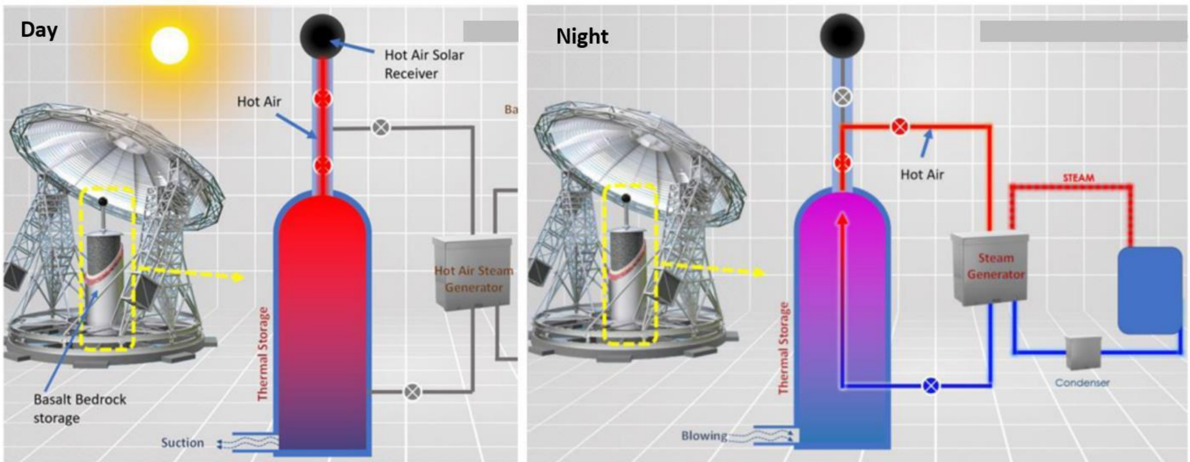

Figure 3. Thermal energy storage for ASC (Al-Maaitah, 2020).

3. Methodology

3.1 Workflow

This study investigates the feasibility of using Solar as the technology to support thermal from the workflow shown in Figure 4, the enhanced oil recovery (EOR) method. Literature reviews show how thermal-enhanced oil recovery is one of the best methods to maximize production in Indonesia's mature field with specific criteria. Then, analyze the key problem by using PESTLE analysis of the conventional thermal EOR that uses natural gas as the energy resource, without further considering the emission as the long-term effect of using natural gas boilers. Data collection and analysis also conducted about Indonesia's geographical characteristics show the potential for solar energy to meet its current energy needs. Also, observed Indonesia's field characteristics for thermal EOR, potential technology system of solar EOR, steam and energy demand of current thermal EOR project in Indonesia's mature fields, and cost analyses consisting of installation and operation of solar technology. Also analyses how solar energy reduces global warming. Data collection and analysis were made by several calculations to generate the solutions and conclusion. However, due to limited sources of data, some of the numbers in the calculation might be adjusted and assumed.

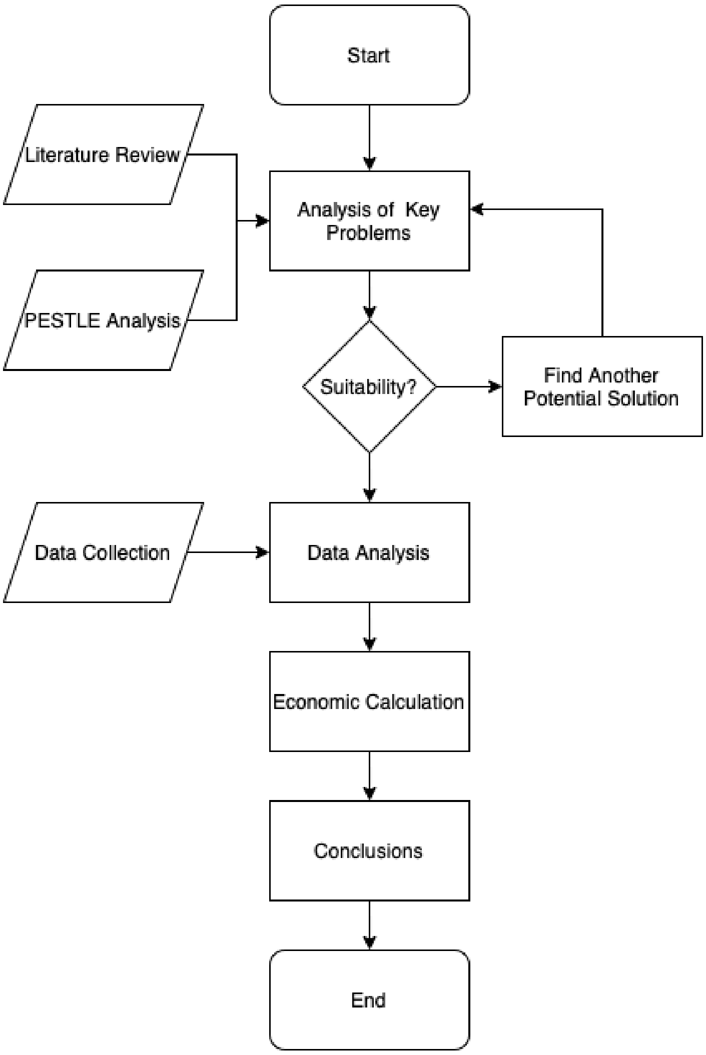

Figure 4. Workflow.

3.2 Analysis of Key Problems

Kolios et al. (2016) used PESTLE analysis (Table 2) to identify critical problems of fossil fuel use for the oil and gas industry in Indonesia. PESTLE analysis is used to analyze the problem using a helicopter view and deeper understanding, reduce the impact of potential threats to the company, and provide a technique to capitalize on opportunities (F.J., 1967). The elaboration can be seen below:

Table 2. PESTLE analysis.

Political	Political trends for fossil fuel in the oil and gas industry include: • Government policy and Indonesia's roadmap to the net-zero emission target by 2060 (Kementerian Koordinator Bidang Perekonomian Republik Indonesia, 2023). • Indonesia's target of reaching 1 million BOPD oil production and 12 BSCFD gas production in 2030 (Kementerian Energi dan Sumber Daya Mineral, 2022).
Economic	Economic trends for fossil fuel in the oil and gas industry include: • Investment in clean energy technology is significantly exceeding spending on fossil fuels as the global energy crisis-related affordability and security concerns increase demand for more environmentally friendly solutions (IEA, 2023).

Social	Social trends for fossil fuel in the oil and gas industry include: • The oil and gas industry is facing increasing demands to clarify the implications of energy transitions for their operations and business models. (World Energy Outlook, 2020). • The COVID-19 situation has caused a significant short-term decline in global energy consumption, which at one time reached a 30 percent decline. Hence, pandemic-related public stimulus plans should result in a significant increase in investment in green technologies. (McKinsey, 2021). • Therefore, a new breakthrough is needed that can be used to meet the increasing demand in the oil and gas industry but considering the use of new renewable energy.
Technological	Technological trends for fossil fuel in the oil and gas industry include: • Inquiries exist regarding technological advancements and public understanding of industrial process automation. On the other hand, the oil and gas industry still regularly uses conventional natural gas-fired boilers. As a result, the oil and gas business needs technologies that employ automated and integrated systems to increase the efficacy and efficiency of labor.
Legal	Legal trends for fossil fuel in the oil and gas industry include: • Law Number 16 of 2016, dated 24 October 2016, concerning the Ratification of The Paris Agreement to The United Nations Framework Convention on Climate Change. (UNFCC, 2016). • Sustainable Development Goals (SDG) Number 7: "ensuring access to affordable, reliable, sustainable, and modern energy for all". (United Nations, 2015).
Environmental	Environmental trends for fossil fuel in the oil and gas industry include: • Emissions from fossil fuels are the dominant cause of global warming. In 2018, 89% of global CO_2 emissions came from fossil fuels and industry (IPCC, 2018). • Greenhouse gas (GHG) emissions can continue to increase from 259.1 million tons of CO_2 in 2021 to 334.6 million of CO_2 in 2030. (IEA, 2022). • Global carbon dioxide emissions from fossil fuels and cement have increased by 1% in 2022, new estimates suggest, hitting a new record high of 36.6 tonnes of CO_2. (Global Carbon Project, 2022).

4. Result and Discussion

4.1 Ongoing Steamflood Project in Indonesia Field Data Overview

The ongoing steamflood project in Indonesia, which is being observed, is Duri Field, a giant heavy oil developed in thirteen areas (about 930 km^2), in four patterns (inverted 5, 7, 9 spots and irregular). The average daily production during 2022 was 52,000 BOPD, with peak production in 1992, approximately 290,000 BOPD. Total cumulative production is around 3 BBO. Indonesia's ongoing steamflood project (Table 3) fits into the general screening for steamflood characteristics by Taber & Martin, 1997. More than 10,500 wells have been drilled, consisting of around 3,000 injectors, 6,700 producers, and 800 observation wells (Winderasta et al., 2021).

Table 3. Indonesia ongoing steam flood project in Indonesia.

API	μ_0	So	K	d	h	Kh/μ_0
	cP	%	mD	ft	ft	mD-ft/cp
17 -- 23	300	40 -- 80	500 -- 5000	250 -- 800	80 -- 200	133 – 3300

Besides the field characteristic suitable with steamflood EOR, the Duri Steamflood Project has already been successful in enhancing the ultimate recovery to 55 %, yielding an additional 2.5 x 10^9 barrels of oil over the primary recovery technique (Subiyantoro, 2010). However, the project conventionally uses a boiler to generate the steam, and the boiler uses natural gas as an energy resource to heat the water. Using the data reference from Duri Field, the steam injection needed is 360,000 BSPD/BCWED to operate the steamflood project, and by knowing the energy needed to generate 1 barrel of steam, the boiler needs 118,000 MMBTU/day of natural gas (Pertamina, 2022).

Furthermore, looking at the geography of Indonesia, Indonesia has sufficient technical potential for solar energy to meet its current and future energy needs. Also, Indonesia is known for its abundance of sunny days, with direct normal irradiance (Table 4) that Indonesia receives. As a result, Solar EOR technology is sufficient as a method to replace conventional boilers in line with boosting oil production.

Table 4. Steam characteristics in Indonesia.

Solar EOR plant in ongoing steam flood project Indonesia (Gupta et al., 2017).		
Direct Normal Irradiance (DNI)	892	$\frac{kWh}{\frac{m^2}{yr}}$
Steam Temperature	237	Celsius
Steam Pressure	475	Psi
Steam Quality	70	%
Steam Injection Needed	360,000	BSPD/BCWED
Energy for generate 1 BSPD	330,000	BTU/BCWED

4.2 Implementation of Solar EOR Technology

The implementation of Solar EOR Technology in Indonesia is attached to the workflow (Figure 5). ASC technology contains heat transfer fluid (HTF) called Liquid Sodium. Liquid sodium is chosen because this fluid has a low melting point (97.7 °C) and high boiling point (873 °C) that allow a larger range of operational temperatures (Boerema et al., 2012). The HTF will get heated from the direct sunlight and start to enter thermal storage on the basalt-packed bed during the day (Figure 3). ASC started to capture and concentrate the solar beam to the focal point, and the Liquid Sodium on the basalt-packed bed was heated up until the temperature was 1000 °C. For achieving the target of the production, the large scale of the project is needed by using more than one ASC. Therefore, a central storage is needed to gather up the hot steam from each basalt-packed bed storage. Then, the heat transfer fluid (liquid sodium) entered the steam generator to generate steam from the water supply wells that have been treated by a Softening Heat Recovery. After the hot steam is generated, a separator is used to separate the steam and water. The treated steam is then injected into the steam flood well, while the water is injected into the Water Softening Heat Recovery to be inputted to the generator, and the cycle is repeated.

The hot air from ASC reached the temperature of 1000 °C. Meanwhile, the thermal energy storage from each basalt bed packed on ASC could maintain the steam temperature up to 700 °C (Nahas et al., 2019). After that, the hot steam is transferred into the central thermal storage. The central storage that is being used is electric-thermal energy storage (ETES). It employs a packed bed of low-cost crushed volcanic rock to store thermal energy at a maximum storage temperature of 500–700 °C and flexible power-to-heat. The storage unit receives air at a relatively constant input temperature when charging. The heater's power regulates the temperature up to 700 °C during the scrutinized measuring campaign. As the thermocline zone approaches the cold end of the storage unit, the air leaves the storage at a cooler temperature, which rises as the charging operation closes. (Figure 7) shows these measures lead to a constant steam generator power over the first 23 h of discharge.

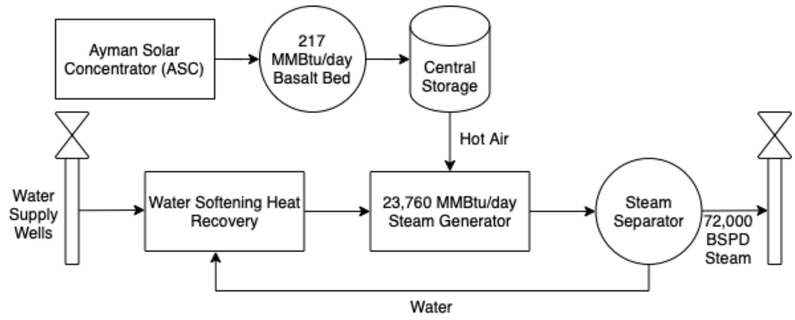

Figure 5. Surface facility for ASC.

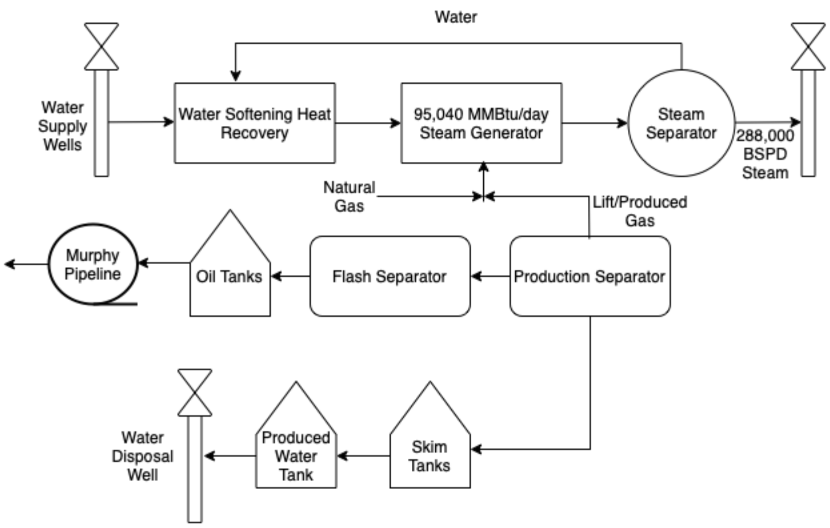

Figure 6. Surface facility for Boiler.

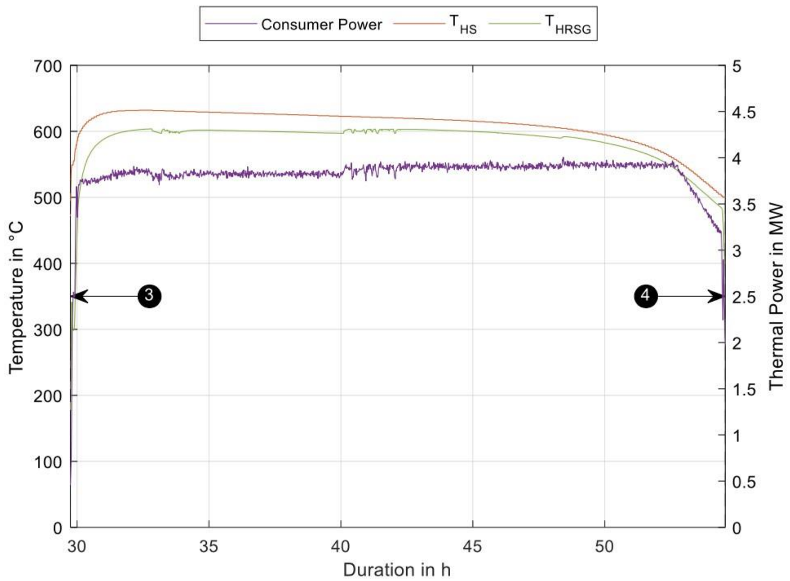

Figure 7. Duration discharging ETES (Jan-Rudolf-Eggers, 2022).

For designing the long-term solar technology in Indonesia, we proposed to build a hybrid solar EOR. The optimum share of these two objective functions can be reached with 20% steam generated with solar and 80% steam generated with natural gas boilers. To replace the natural gas, the evaluation of annual energy output from the solar project's design is needed. The evaluation is performed by Direct Normal Incident (DNI) solar radiation in kWh divided by year. The energy output correlates with some parameters: **1)** Total area of solar concentrator, m^2, **2)** Average efficiency of the collectors, dimensionless (η), **3)** DNI is the total annual direct-beam sunshine received at the location, kWh/m^2.

Thus, formula for heat obtained by using solar concentrated technology calculation is:

$$Qt = DNIt \,.\, A \,.\, \eta \tag{1}$$

Where DNIt = total annual direct-beam sunshine received at the location (kWh/m^2); A= Total area of solar concentrator (m^2); η= Average efficiency of the collectors (dimensionless).

As the offer to use Solar Thermal EOR in Indonesia, this paper evaluates how much the total annual steam could be produced from CSP plant technology. With reference to Indonesia's ongoing steamflooding project, the project needs 360,000-barrel steam per day to be injected as Thermal EOR (one barrel of steam needs 330,000 BTU). Based on reservoir description and field data analysis, the DNI of Indonesia's targeted place was 892 kWh/m^2 (Gupta et al., 2017); the efficiency of optical solar technology could reach up to 91% in practice by using Ayman Solar Concentrated Technology (Boretti & AlMaaitah, 2021). ASC technology can be easily deployed with a mirror area of 78.5 m^2 (Boretti & Al-Maaitah, 2021), so the heat obtained by using one piece of solar ASC technology is calculated to be 57,348 kWh. The heat from the parabolic dish of ASC technology will be streamed into steam generator. The evaluation of the efficiency of the steam generator is 90%, so heat that could be converted to generate steam and replace the boiler is 57,348.02 kWh. So, by building one piece of ASC Solar technology, the project could generate 592.96 barrels of steam per day. This paper proposes to design 122 sets of ASC technology to fulfill 20% of steam requirements per day in Indonesia's mature fields. By designing 122 sets of ASC technology, the solar project could save 8,672,400 MMBTU/year of natural gas from being consumed.

4.3 Economic Calculation

The market potential of solar thermal EOR was the field with steam-based EOR projects. By this paper, solar thermal EOR could be possible to apply the technology in Indonesia's field with significant ongoing steam-based EOR projects. Some methods to validate it are by reviewing the economic side of solar thermal EOR. By generating the modeling approach of solar thermal EOR, the company could reduce costs and have low operational costs by saving the cost of natural gas and natural gas-based boilers. To calculate the economic analysis, the production shared contract (PSC) gross split principle is used as the main guide.

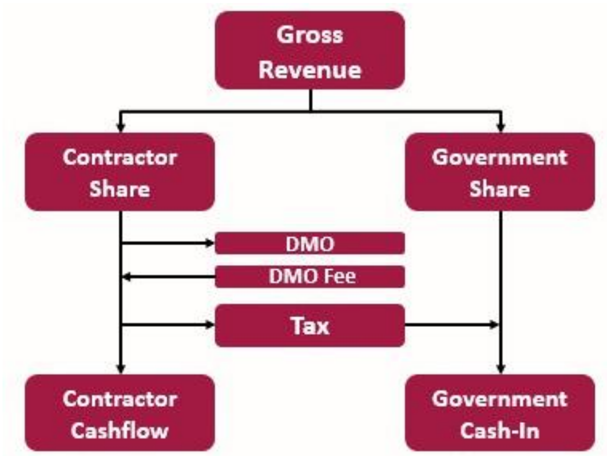

Figure 8. PSC gross split scheme.

The PSC Gross Split is a production-shared contract in the upstream oil and gas business activities based on the principle of gross production shared without any mechanism of operating cost return. The scheme of the PSC Gross Split is depicted in (Figure 8) The PSC Gross Split was chosen because the previous PSC Recovery agreement of this field already expired in 2021 (Julyus, 2018). The contractor should use new regulations (PSC Gross Split) to propose field development optimization (OPL) to build solar technology as the future development.

The internal rate of return (IRR) is a metric used in financial analysis to estimate the profitability of potential investments. IRR is a discount rate that makes the NPV of all cash flows equal to zero in a discounted cash flow analysis (Fernando, 2022). The equation to obtain IRR is as below:

$$0 = NPV = \sum_{t=1}^{T} \frac{C_t}{(1 + IRR)^t} - C_0 \tag{2}$$

Where, C_t = Net cash inflow during the period t; C_0 = Total initial investment costs; IRR = The internal rate of return; t = The number of time periods.

The NPV calculation for Ayman Solar Concentrator (ASC) technology is eight years (with a target of Indonesia in 2030), an internal rate of return regularly used in the oil and gas industry is 10% (PV10), and a total investment cost of approximately USD 425 (with ASC needed for 20% of steam injected in Duri).

Levelized cost of energy (LCOE) is a measurement used to assess and compare alternative methods of energy production. The LCOE can be calculated by first taking the net present value of the total cost of building and operating the power-generating asset. This number is then divided by the total electricity generation over its lifetime (CFI Team, 2022):

$$LCOE\left(\frac{USD}{MMBTU}\right) = \frac{NPV of\ Total\ Cost\ Over\ Lifetime}{NPV\ of\ Electrical\ Energy\ Produced\ Over\ Lifetime} \tag{3}$$

$$LCOE = \frac{\sum \frac{(I_t + M_t + F_t)}{(1+r)^t}}{\sum \frac{E_t}{(1+r)^t}} \tag{4}$$

Where, I_t = The initial cost of investment expenditures (I); M_t = Maintenance and operations expenditures; F_t= Fuel expenditures; E_t = The sum of all electricity generated; r = The discount rate of the project. The payback period is the amount of time it will take to recoup the initial cost of an investment or to reach its breakeven point. The payout time is the year before that year has a positive cumulative.

This Ayman Solar Concentrator (ASC) technology on low-cost storage of solar thermal energy can generate high-temperature steam 24/7 to be utilized in Enhanced Oil Recovery (EOR). Indonesia's steamflooding project, specifically the Duri Steamflood Project, needs 118,800 MMBTU/day of steam (Pertamina, 2022). The optimum share of these two objective functions can be reached with 20% steam generated with solar and 80% steam generated with natural gas boilers. Priority was given to maximizing the IRR and considering the possibilities to build the CSP solar plant.

The reference data quoted from Ayman Solar Technology (Al-Maaitah, 2020) stated that the efficiency of the incident angle modifier (IAM) is constant at 91% at any time of the day. This technology is also feasible for no less than 100MWth, and the system has scalable capacities starting from a few kWth to MWth. Hence, the ASC could be built by adjusting the DNI in the targeted area. According to co-founder and Managing Director Ayman Adnan Al-Maaitah, the initial investment for one piece of ASC plant in Abu Dhabi, UAE, in 2017 is projected to be around USD 3.5 million (Ahmed, 2021). By energy calculation, to support 20% steam injection, this paper proposes to build 122 ASC technology, costly USD 420 million with a total area of 0.01 km^2. The project could generate up to 72,000 BSPD solar steam to be injected as EOR requirements and replace natural gas as an energy resource. With the implementation of solar technology, the company could save natural gas up to 8,672,400 MMBTU/year.

For the OPEX calculation, this paper compares the operational cost of a solar power plant using Parabolic Through Technology, costly USD 0.035/kWh (International Renewable Energy Agency, 2012), so the operational and maintenance cost for ASC technology calculated to be 70% from PTC technology. The breakdown of operational and capital investment costs of the power plant is shown in Table 5.

Table 5. ASC cost schematic.

Capital and Operational Cost		
Heat obtained for steam	57.348.018	kWh
	195679 466.1	BTU
Heat to produces 1 BSPD steam	330.000	BTU
ASC needed	1.214.230.623	pcs
Heat needed to generate 20% steam from solar per day	6.963.372	kWh/day
	2.541.630.765	kWh/year
Operational cost PTC	$0.035	USD/kWh
Operational cost ASC	$0.02	USD/kWh
	$62,269,953.75	USD/year
CAPEX of ASC	$424,980,717.91	USD
Operational cost steamflood Indonesia’s project	$2,574,000,000	USD

By using solar as a method to generate steam, the field with Natural Gas production could economize the natural gas or sell their gas for domestic use or export outside. The calculation cases are using solar technology by saving on natural gas purchases. The calculation shows IRR or metric that is used in the financial analysis to estimate the potential investment profit for implementation of solar ASC technology for this case, calculated to be 18% using Table 5 with a payback period of 7 years, and the NPV calculation obtains USD 295,978,489. It was assumed that using solar technology parallel with saving natural gas would be much more profitable, which would be significantly attractive for the investor.

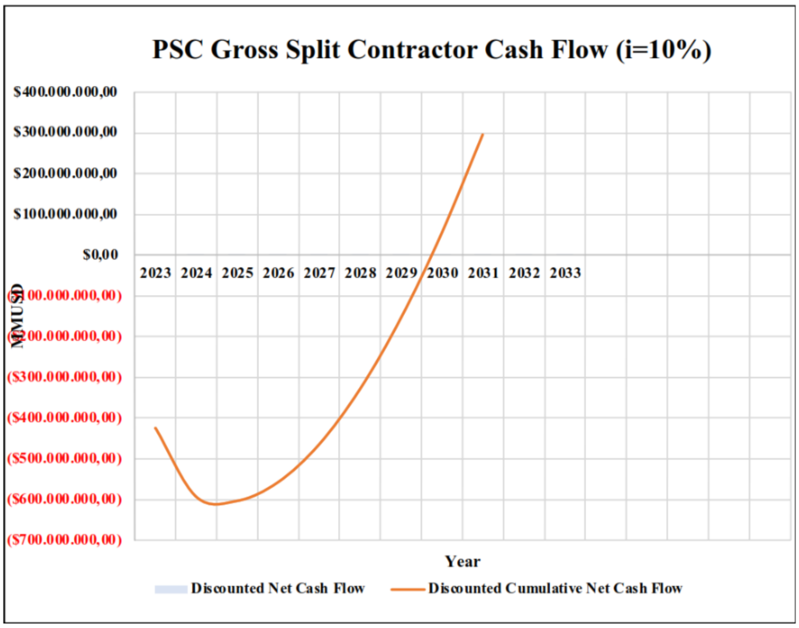

Figure 9. PSC gross split.

The decision maker selects the most economical steam source to fill the moisture needed. The macroeconomic assumption is used to calculate whether it is the most economical way to install Solar Thermal EOR. The premise, such as the discount rate (assumed 10%), projecting lifetime of the solar plant over 30–40 years, and energy generated from the CSP model calculated before (57348,018 kWh for one-piece solar ASC). The solar steam LCOE was estimated to be USD 0.62/MMBTU cheaper than natural gas (USD 2,567/MMBTU). As the price of natural gas is the main factor of Thermal EOR, retrenching natural gas consumption would benefit the company.

4.4 Solar EOR Environmental Effect

Indonesia's ongoing steamflood project, specifically in Duri, uses up to 43,362,000 MMBTU/year to generate steam for thermal EOR uses by flaring up the natural gases (Pertamina, 2022). Using Ayman Solar Concentrator (ASC) can save up to 8,362,970 Mcf/year, so it can save CO_2 emission of 1,262 metric tons CO_2/day and up to 460,800 metric tons CO_2/year. Integrating solar EOR will displace more significant gas consumption without affecting oil output.

Table 6. CO_2 emission in Indonesia's ongoing steamflood.

Indonesia's Ongoing Steam Flood Project		
Natural gas needed to generate steam	43.362.000	MMBTU/year
Natural gas saved by using solar	8.362.970	Mcf/Year
Natural gas used	34.999.030	Mcf/Year
CO2 emission save by using solar	460.800	metric tons CO2/ year
	1.262	metric tons CO2/day

5. Conclusion

1. Indonesia has sufficient technical potential for solar energy up to 207 GW, specifically a 4.4 to 14.8 giga-watt peak in Riau Province. Indonesia is located in a tropical country and known for its abundance of sunny days, with a high direct normal irradiance of 892 kWh/m^2.
2. Ayman Solar Concentrator (ASC) Technology uses a concave metallic lens combined with a dual tracking system to generate the steam injected for the EOR process with an optical efficiency of 91%. ASC uses the basalt-packed bed for the Thermal Energy system to maintain the temperature for 24/7 up to 700 °C.
3. Reviewing all the references and assumptions, this paper projects to build solar thermal on an area +- 0.0095 km^2, with the hybrid scheme (20% steam generated with solar and 80% steam generated with natural gas). The total amount of energy from solar project design (Qt) is calculated to be 63,720 kWh, so solar technology could save 8,672,400 MMBTU/year of natural gas from being consumed.
4. Retrenching natural gas consumption would benefit the company by steering clear of the possibilities of cost fluctuation. In this case, using solar technology is saving on natural gas purchases. It was assumed that using solar technology parallel with saving natural gas would be much more profitable with an NPV of USD 295,978,489 with an IRR of 18% and a payback time of 7 years, which would be significantly attractive for the investor.
5. Implementation of ASC technology could save the emission CO_2 around 1,262 metrictons CO_2/day and up to 460,800 metric tons CO_2/year. Integrating solar EOR will displace more significant gas consumption and reduce emissions without affecting oil output.

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Appendix

Detailed economic calculation performance of economic review of solar thermal EOR technology depends on several parameters. Table 7 shows the breakdown data of the operational cost of solar power plant converted to Indonesia's case based on Williams (2014) reference data to calculate operational calculation.

Table 7. Operational cost ASC technology.

Parameter		Assumption	
Operational power plant Indonesia's case			
Labor cost	28%	$17,124,237	USD
Electricity	4%	$2,241,718	USD
Backup fuel	1%	$622,700	USD
Water	3%	$1,868,099	USD
Service contract	7%	$4,047,547	USD
Materials and maintenance	21%	$13,076,690	USD
Insurance	38%	$23,662,582	USD
TOTAL		$62,643,573	USD

Table 8 shows the breakdown data of the total operational cost of Indonesia's ongoing steam flood project based on (Julyus, 2018).

Table 8. Operational steamflood and solar power plant.

Parameter	Assumption	
Operational cost power plant Indonesia's case	$62,643,573	USD
Steamflood operational cost	$994,439,000	USD
TOTAL	**$1,057,082,573**	**USD**

Table 9 shows the breakdown of several data for energy calculation referenced from Indonesia's ongoing steamflood project.

Table 9. Data input to calculate the amount of energy from one piece of ASC technology.

ASC Mechanism		
Efficiency dish	0.91	%
AREA	78.5	m^2
DNI	892	Kwh/m^2
(Heat Obtained)	63,720.02	Maximal heat that could obtained from 1 piece ASC
Efficiency steam geneators/strilling engines	0.9	
Heat obtained for strilling/steam generators	57,348.018	Kwh
	195,679,466.1	BTU
Heat to produces 1 BSPD steam	330,000	BTU
Steam generates	592.9680792	BSPD

Table 10 shows the breakdown of the Ayman Solar Concentrated parameter for energy calculation referenced from Indonesia's ongoing steamflood project (Al-Maaitah, 2020).

Table 10. Data input for calculating energy and the ability of ASC technology.

ASC		
Efficiency dish	0.91	%
AREA	78.5	m^2
DNI	892	kWh/m^2
(Heat Obtained)	63720.02	Maximal heat that could obtained from 1 piece ASC
Efficiency steam generators /strilling engines	0.9	
Heat obtained for strilling/steam generators	57348.018	kWh
	195679466.1	BTU
Heat to produces 1 BSPD steam	330000	BTU
Steam generates (1 ASC)	592.9680792	BSPD
Steam injected in Steamflood Project	360000	BSPD
20% of steam injected in Duri	72000	BSPD
ASC needed	121.4230623	pcs
Price for 1 ASC	$3,500,000.0	USD

Table 11 shows the data resource for energy generated steam by ASC for economic calculation.

Table 11. Data resource for economic calculation.

Parameter	**Assumption**	
Energy generete	2,541,630,765	kWh/year
	2,541,630,77	MWh/year
CAPEX	424,980,718	USD
OPEX	1,057,082,573	USD
% Steam Covered in Duri	20%	
Steam Injected in Duri	43,362,000	MMBTU/year
Annual Steam Covered by S-EOR in Duri	8,672,400	MMBTU/year
Steam Injected by Natural Gas Boiler	34,689,600	MMBTU/year
Oil Rate	52,000	BOPD
Natural Gas Price	$2,567	USD/MMBTU
Oil Brent Price	$78,810	USD/bbl

To evaluate the economic side of Solar Thermal EOR, there is a proposed case in this paper by using solar technology to minimize natural gas uses. Table 12 shows the breakdown calculation of NPV and IRR for results.

Table 12. Breakdown data to calculate IRR, NPV, and payback time.

Time (year)		**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Oil rate	BOPD		53,000	63,600	69,960	76,956	84,652	93,117	102,428	112,671
Oil production	BOPY		19,345,000	23,214,000	25,535,400	28,088,940	30,897,834	33,987,617	37,386,379	41,125,017
Cummulative production	BOE		19,345,000	42,559,000	68,094,400	96,183,340	127,081,174	161,068,791	198,455,171	239,580,188
Brent's oil price	USD/BBL		78.81	78.81	78.81	78.81	78.81	78.81	78.81	78.81
Oil revenue	USD		1,524,579,450.00	1,829,495,340.00	2,012,444,874.00	2,213,689,361.40	2,435,058,297.54	2,678,564,127.29	2,946,420,540.02	3,241,062,594.03
Split for contractor			960,485,053.50	1,134,287,110.80	1,247,715,821.88	1,372,487,404.07	1,509,736,144.47	1,660,709,758.92	1,826,780,734.81	2,009,458,808.30
Natural gas uses	Mmbtu/year		34,689,600.00	34,689,600.00	34,689,600.00	34,689,600.00	34,689,600.00	34,689,600.00	34,689,600.00	34,689,600.00
Natural gas cost	USD		$89,048,203	$89,048,203	$89,048,203	$89,048,203	$89,048,203	$89,048,203	$89,048,203	$89,048,203
Operational cost	USD		$1,057,082,573	$1,057,082,573	$1,057,082,573	$1,057,082,573	$1,057,082,573	$1,057,082,573	$1,057,082,573	$1,057,082,573
Investment (CAPEX)	USD	$424,980,718								
Revenue after cost	USD	-$424,980,718	-$185,645,723	-$11,843,666	$101,585,045	$226,356,627	$363,605,368	$514,578,982	$680,649,958	$863,328,032
Tax		$0	$0	$0	$40,634,018	$90,542,651	$145,442,147	$205,831,593	$272,259,983	$345,331,213
Contractor cash flow	USD	-$424,980,718	-$185,645,723	-$11,843,666	$60,951,027	$135,813,976	$218,163,221	$308,747,389	$408,389,975	$517,996,819
Discount net cash flow	USD	-$424,980,718	-$168,768,839	-$9,788,154	$45,793,409	$92,762,773	$135,462,196	$174,279,852	$209,568,631	$241,649,339

Cumulative	USD	-$424,980,718	-$593,749,557	-$603,537,711	-$557,744,302	-$464,981,529	-$329,519,333	-$155,239,481	$54,329,150	$295,978,489
Pay out time	Year	-	-	-	-	-	-	-	7	-

As the calculation showed before, Table 13 shows the comparison of NPV and IRR.

Table 12. NPV and IRR result.

Net Present Value	$295,978,489
Internal Rate of Return	18%