Techno-Economic Evaluation of Suralaya CFPP Unit 1 Coal Gasification for Gas Supply Cilegon CCPP

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Abstract. The Indonesian government's energy transition policy includes phasing out Coal-Fired Power Plants (CFPPs), such as Suralaya CFPP Unit 1, and addressing natural gas limitations in Combined Cycle Power Plants (CCPPs) like Cilegon CCPP. This study introduces a novel approach as the first to integrate syngas production using Mitsubishi Heavy Industries (MHI) entrained-flow gasifier fueled by coal from a retiring CFPP to support CCPP operations. The innovation lies in repurposing decommissioned CFPP assets, reducing dependence on natural gas while leveraging advanced gasification technology to maintain power generation efficiency. The MHI gasifier achieves 99,9% carbon conversion with CGE 77,2 % and produces syngas with an LHV of 4,575 MJ/kg, enabling a combined cycle output of 306 MW with 50,36% efficiency. This process also reduces air consumption by 25%, from 2.188.000 kg/h to 1.650.000 kg/h, contributing to environmental sustainability. Economic analysis estimates construction costs at Rp41,3 trillion for the gasification plant and Rp1,02 trillion for a 15 km gas pipeline from Suralaya to Cilegon. This study pioneers a pathway for integrating gasification technology into Indonesia's energy infrastructure, demonstrating a practical and sustainable strategy to transition from coal dependence to cleaner energy systems while maximizing efficiency and minimizing environmental impact.

Keywords: IGCC, Suralaya CFPP unit 1, Cilegon CCPP, Gas Supply.

1 Introduction

PT PLN (Persero), Indonesia's state-owned electricity company, plays a key role in supporting the government's efforts to meet the Paris Agreement and achieve Net Zero Emissions (NZE) by 2060. The Ministry of Energy and Mineral Resources (ESDM) has set national energy and electricity plans to ensure energy security while protecting the environment [1]. PLN aims to reduce carbon emissions by transitioning from fossil fuels to greener energy sources, with a target of 75% renewable energy and 25% natural gas by 2040 [2]. Indonesia has significant geothermal potential, but only 7,5% is currently utilized [2]. To meet

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the NZE target, PLN is transitioning the plants, reducing coal-fired power plants (CFPPs), and promoting technologies like biomass co-firing, green hydrogen, and Integrated Gasification Combined Cycle (IGCC) [2].

Suralaya CFPP Unit 1 and Cilegon CCPP are crucial for this transition. Suralaya CFPP Unit 1, which is 30 years old, is nearing the end of its life, while Cilegon CCPP faces fuel shortages. This study explores how repurposing Suralaya CFPP Unit 1 to produce syngas using IGCC technology could address Cilegon's fuel limitations and help meet PLN's decarbonization goals. The syngas would be transferred to Cilegon CCPP, ensuring continued power supply and supporting the country's energy transition.

2 MHI Entrained Flow Gasifier

An entrained-flow gasifier combines fuel (coal, biomass, or liquid fuels) with a gasifying agent (oxygen, air, or steam) at high speeds in a reactor. This process occurs at temperatures between 1200°C and 1500°C, converting the fuel into syngas, primarily composed of carbon monoxide (CO), hydrogen (H_2), and small amounts of methane (CH_4). The ash is removed as non-leachable slag, which can be repurposed for applications like CO_2 capture. Advantages of entrained-flow gasifiers include high processing capacity and near-total carbon conversion, though high-ash fuels can reduce efficiency. Blending with higher-quality coals or petcoke can improve performance [3][4][5][6]. The MHI gasifier consists of two sections: the combustor, where coal is burned with air to produce CO, CO_2, and water vapor, and the reductor, where additional coal undergoes gasification at a lower temperature. The syngas is cooled to improve efficiency, and char is recycled to the combustor to enhance carbon conversion [7][8].

Figure 1 and Figure 2 show the process of the MHI-manufactured entrained-flow gasifier. The reactor is divided into two main sections: the Combustor and the Reductor. In the combustor, coal is mixed with air and burned, producing carbon monoxide (CO), carbon dioxide (CO_2), and water vapor. The temperature in the combustor is sufficiently high to melt the coal ash. The gases generated in the combustor are directed to the reductor, where additional coal is added without extra air. In this stage, the heat from the combustor drives the endothermic gasification reactions at a lower temperature. Cyclones downstream of the syngas cooler capture and recycle the char to the combustor, enhancing overall carbon conversion efficiency [7][8].

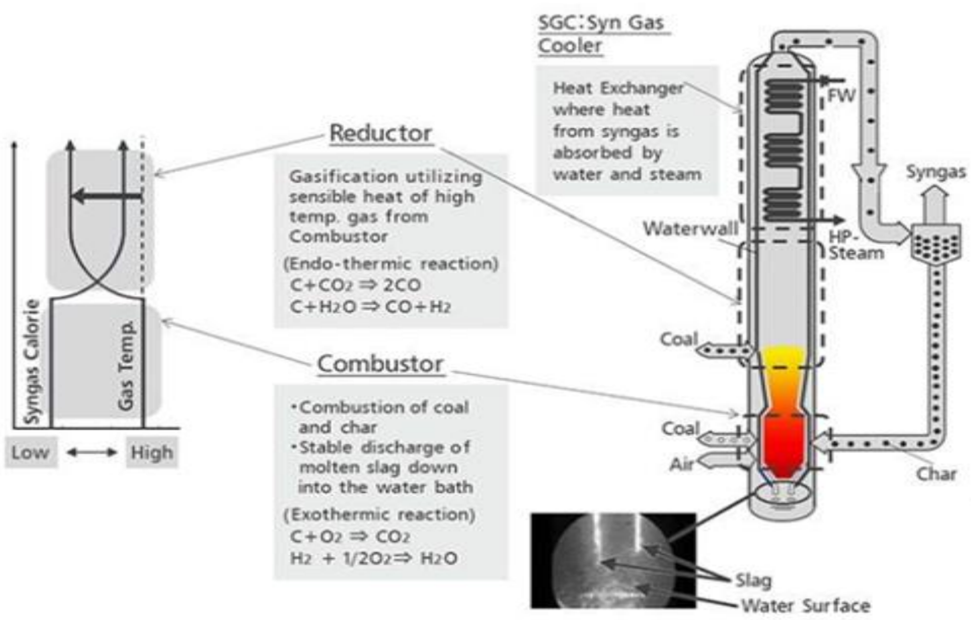

Figure 1 Design of MHI entrained-flow (air-blown) gasifier [8]

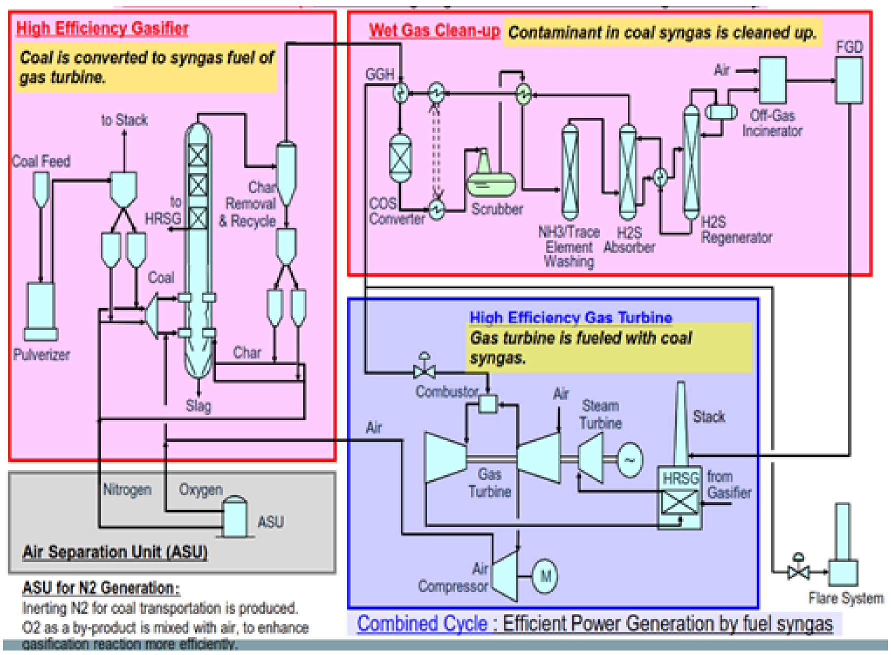

Figure 2 MHI detail layout of air-blown gasifier [8]

3 Projected Engineering Result And Analysis

In conventional coal-fired power plants, using coal with a low ash melting point can lead to issues like slagging and fouling. However, in an Integrated Gasification Combined Cycle (IGCC) system, the gasifier is designed to melt and remove the ash, making it ideal for coals with low ash melting points. This feature enables the use of lower-rank coals and petroleum coke (PetCoke), which are usually unsuitable for traditional power generation systems [8].

Table 1 Actual Coal Consumption Suralaya CFPP Unit 1 [9]

Parameter (Ar)	Units	**Measuring Result (Gasifier Inlet)**
Inherent Moisture	%Wt	-
Total Moisture	%Wt	28,858
Ash Content	%Wt	3,875
Volatile Matter	%Wt	34,389
Fixed Carbon	%Wt	31,447
Calorific Value	Kcal/Kg	4.632,4
Grindability	%	61,8
Total Sulfur	%Wt	0,1628
Carbon	%Wt	47,992
Hydrogen	%Wt	3,6948
Oxygen	%Wt	13,816
Nitrogen	%Wt	1,6702

3.1 MHI Gasifier Evaluation

The dry-feed method is preferred in the air-blown gasifier because it results in lower latent heat loss from water compared to the slurry feed method. When combined with the 2-stage, 2-chamber entrained bed technique, the Mitsubishi air-blown coal gasifier can reduce oxygen consumption by 15-25% compared to other air-blown gasifiers. This contributes to the reduction in air-production unit power consumption, thereby enhancing cold-gas efficiency [7].

3.2 Succes Story and Projected Output to Cilegon CCPP

At the Nakoso IGCC Power GK (Japan), after successfully operating for 2.000 consecutive hours in September 2008, verification tests were conducted, including coal type change tests, operational optimization, and thermal efficiency checks. By June 2010, the facility had passed the long-term durability test, reaching the target of 5.000 cumulative hours of operation in a year [8].

Cilegon CCPP features two M701F gas turbines, also manufactured by MHI, similar to the 250 MW gas turbines used in the Nakoso IGCC Power GK (Japan), which were commercialized in 2006 for natural gas. Based on the results presented in Table 2, it is concluded that implementing an IGCC system between Suralaya CFPP Unit 1 and Cilegon CCPP is quitely feasible. Detailed modeling will be discussed in Section 3.3.

Table 2 Commercial Output of MHI Gasifier [7][8][10][18]

Parameter	Unit	**Result**
Coal throughput (bituminous/sub-bituminous)	ton/h	146-166
Operation Pressure	MPa	2,8-4,0 (changeable)
Gasifying Agent		Air
Amount of Syngas	ton/h	270-380
GCV of Syngas	Kcal/Nm^3	2500 (dry)
SGC Outlet		13 MPa 430º C 130-190 t/d
CO	%vol	30,5
H_2	%vol	10,5
CH_4	%vol	0,7
CO_2	%vol	2,8
N_2	%vol	55,5
Cold Gas Efficiency	%	77,2
Gas Turbine	model	M701F (1 unit)
Net Plant Efficiency	%	48 (LHV 1 on 1, net)
Carbon Conversion	%	99,9

3.3 IGCC Modelling Suralaya CFPP Unit 1 and Cilegon CCPP

The air-blown IGCC with CGCU system, as shown in Figure 2, uses a small ASU to produce oxygen for gasification, achieving 25% oxygen content in the gasifying air. The gasifier, operating at 1200°C, cooled syngas to 900°C before passing through cyclones to collect and recycle char and ash. The syngas is further cooled to 237°C, then pre-heated to 250°C using a gas-gas heat exchanger or closed water loop [19].

Syngas is scrubbed to remove ash and contaminants, with H_2S converted in a hydrolysis reactor and removed by an MDEA process. The cleaned syngas is heated before fueling the gas turbine combustion at Cilegon CCPP. Syngas is transferred through a pipeline with compressor at above 40 kg/cm² pressure, and its production is modeled in Aspen HYSYS based on MHI gasifier data[19].

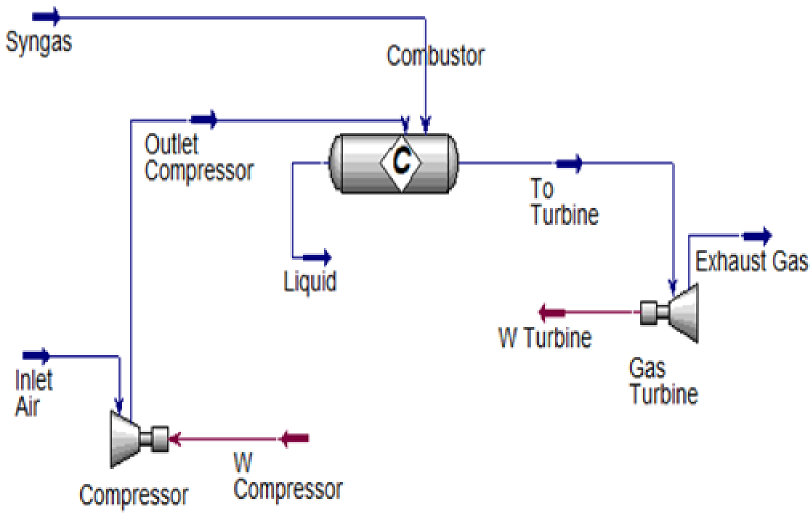

Figure 3 Syngas production from Suralaya CFPP Unit 1 to Cilegon CCPP

The simulation data (Figure 3, Table 1) shows syngas composition as 30,5%vol CO, 10,5%vol H_2, 0,7%vol CH_4, 2,8%vol CO_2, and 55,5%vol N_2 with an LHV of 4,575 MJ/kg. No water saturation is needed to maintain acceptable NOx emissions [20]. The air-cooled combustion turbine operates with a 1.103°C turbine inlet temperature (TIT), requiring 1,65 million kg/h of air for syngas combustion, less than the 2,19 million kg/h for natural gas combustion.

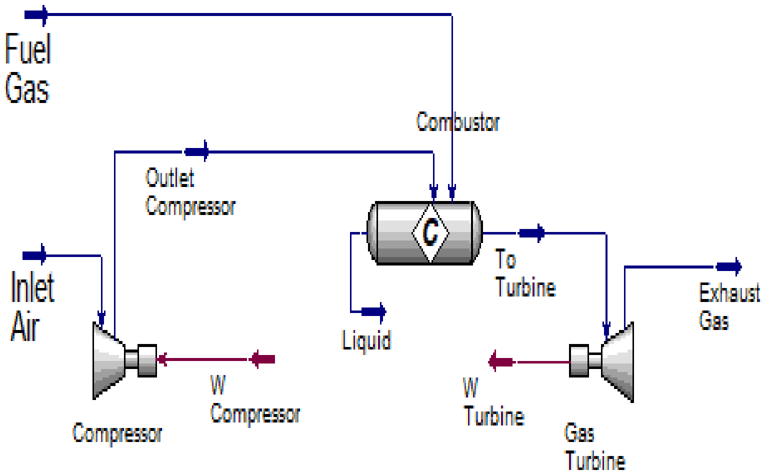

Figure 4 Existing Conventional Natural Gas Cilegon CCPP

Table 3 Syngas-Engineering Result Cilegon CCPP

Name	Inlet Air	Syngas	Exhaust Gas
Pressure [kPa]	101,3	1.582	103,3
Temperature [C]	30	200	441,7
Mass Flow [kg/h]	1.650.000	369.600	2.019.593
Mass Lower Heating Value [kJ/kg]	0	4.575	9,3
Std Ideal Liq Vol Flow [m^3/h]	1.921,1	502,5	2.433
Vapor / Phase Fraction	1	1	1
Molar Enthalpy [kJ/kgmole]	137,9	-40.094	-20.694,3

Table 4 Natural Gas-Engineering Result Cilegon CCPP

Name	Inlet Air	Fuel Gas	Exhaust Gas
Pressure [kPa]	101,3	1.580	103,3
Temperature [C]	30	200	612
Mass Flow [kg/h]	2.188.000	54.400	2.242.391,2
Mass Lower Heating Value [kJ/kg]	0	43.390	28,82
Std Ideal Liq Vol Flow [m^3/h]	2.529,3	154,9	2.765,3
Vapor / Phase Fraction	1	1	1
Molar Enthalpy [kJ/kgmole]	137,9	-85.459	-13.646,2

The coal analysis from Suralaya CFPP Unit 1 (Table 1) shows that 1 kg of coal produces 4,575 MJ of syngas after entering the gasifier, then fueling Cilegon CCPP with 77,2% cold gas efficiency. To generate 236.901 kW of power, 369.600 kg/h of syngas is needed, consuming 2.710,4 tons of coal daily. In comparison, conventional Suralaya CFPP Unit 1 uses 151,75 tons/h of coal for 194.050 kW, while IGCC requires 112,934 tons/h of coal for 236.901 kW (GT) and 70.000 kW (ST), achieving a Net Plant Efficiency of 50,36%.

Table 5 Cilegon CCPP Performance Using Syngas

Name	Aspen Hysis	Design MHI
Power GT [kW]	236.901	236.900
Power ST [kW]	70.000	Follower GT
Efficiency Combined Cycle 1 on 1 using syngas (LHV) [%] with ST Efficiency 28%	50,36	48,00
NOx [PPM]	9,106	8

Table 6 Cilegon CCPP Performance Using Natural Gas

Name	Aspen Hysis	Design MHI
Power GT [kW]	236.702,9	236.900
Power ST [kW]	134.050	Follower GT
Efficiency Combined Cycle 1 on 1 using natural gas (LHV) [%] with ST Efficiency 35%	56,54	56,59
NOx [PPM]	25,03	25

The CO_2 emissions from IGCC are about 59,54% lower, with 215.549,7 kg/h emitted, compared to 362.000 kg/h from the coal – fired conventional power plant [9]. This reduction is achieved despite similar NOx conversion rates, with NOx emissions [21] from syngas at 9,106 PPM for IGCC, compared to 25,03 PPM for the conventional CCPP using natural gas.

Table 7 Cilegon CCPP Emission Using Syngas

Name	Amount Emission
Total Mass Flow [kg/h]	2.019.593,02
CO_2 [kg/h]	215.549,7
Volume Flow NO [m^3/h]	33,5
Volume Flow NO_2 [m^3/h]	2,6
Oxygen [kg/h]	242.228,7
Nitrogen [kg/h]	1.525.292,62
H_2O [kg/h]	30.276,71
Actual Gas Flow [m^3/h]	3.959.399,8
NOx [PPM]	9,106

Table 8 Cilegon CCPP Emission Using Natural Gas

Name	Amount Emission
Total Mass Flow [kg/h]	2.242.391,2
CO_2 [kg/h]	138.379,7
Volume Flow NO [m^3/h]	139,2
Volume Flow NO_2 [m^3/h]	1,3
Oxygen [kg/h]	318.185,1
Nitrogen [kg/h]	1.673.582,2
H_2O [kg/h]	99.664,9
Actual Gas Flow [m^3/h]	5.613.695,1
NOx [PPM]	25,03

4 Cost Budgetting & Analysis

Economical approaches for this research according to the 2 options, first Cilegon CCPP is relocated to Suralaya CFPP Unit 1 area and build gasification plant on there and become IGCC completely and the second one is build Suralaya CFPP Unit 1 area ant the syngas product transferred to Cilegon CCPP by 15 Km onshore gas pipeline transmission. Practically, second option is simpler and cheaper because build gasification plant assuming Suralaya CFPP Unit 1 and Cilegon CCPP still in commercial status. Also, The construction plant is more faster compare relocated Cilegon CCPP to Suralaya CFPP Unit 1 area. So, assumption of economical approaches chose second option that build new gasification plant on Suralaya CFPP Unit 1 area (new land area assuming owned by PLN) and build 15 Km along onshore gas pipeline transmission from Suralaya CFPP Unit 1 to Cilegon CCPP.

4.1 Cost Budgetting Estimation of Gasification Plant

Investment cost estimates for the plant designs were generated using reference equipment costs, with scaling exponents applied to adjust these costs based on simulation results. The cost data is updated regularly using literature, vendor quotations, industry expert input, and in-house engineering judgments. The cost formula used is:

$$C = C_0 * \left(\frac{S}{S_0}\right)^k, \quad (1)$$

where So is the scale of reference equipment, S is the simulation result scale, and C the cost of equipment at the size suggested by simulation results. Costs were updated to 2024 rupiahs using the Chemical Engineering Plant Cost Index (CEPCI) [11]. The installation cost is 30% of the equipment cost, covering various aspects like instrumentation, electrical connections, and site preparation. Indirect costs are 22% of the equipment cost, including engineering, startup costs, and royalties. The annual operating and maintenance costs are 4% of the total plant cost, covering personnel, maintenance, insurance, and catalysts/chemicals [12].

For the Hirono and Nakoso IGCC units, a combined financing agreement in September 2016 raised US$ 2.755,05 million (approximately Rp 36,6 trillion). The funds were provided by multiple financial institutions, with the cost split 50:50 between the two units [13].

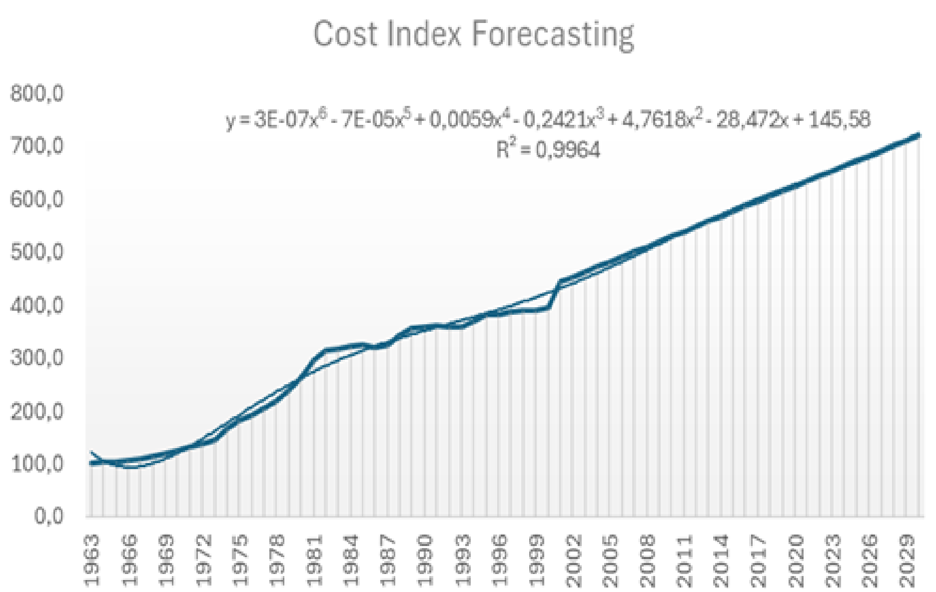

Figure 5 Cost Index Forcasting by CEPCI [11]

By using cost in 2016, formulating equation (1) for estimating cost in 2024. By mixing cost index forecasting in Figure 5 above with k = 0,9964, estimation cost investment of developing air-blown gasifier MHI between Suralaya CFPP Unit 1 and Cilegon CCPP around Rp 41.339.084.795.673,10.

4.2 Cost Budgetting Estimation of Gas Pipeline 15 Km

Investment cost estimates are based on the success stories of oil and gas enterprises in Indonesia, particularly PT. Pertamina (Persero). The transportation cost of natural gas depends on the infrastructure type, capacity, investment amount, and repayment scheme. Generally, the lower the capacity, the higher the transportation cost, which can be described by the following second-order polynomial equation:

$$c = e + f v + g v^2 \tag{2}$$

Where C is the transportation cost (USD/MMBTU) for an infrastructure, v is the total volume (MMSCFD) of natural gas that flows through the infrastructure. The constants e, f, and g (unitless) are derived from regression results based on the specific infrastructure. Pipeline investment estimates were obtained from current projects by PT. Perusahaan Gas Negara, Tbk (PGN) [14]. The costs are US$ 35.000 per km-inch for onshore pipelines and US$ 50.000 per km-inch for offshore pipelines. Additionally, the estimated cost for a compressor is US$ 2.300 per horsepower. To calculate e, f, and g, regression analysis was employed, and the LNG plant and receiving terminal investment estimates were calculated using the exponential method [15]. The base investment for an LNG plant with a 3.34 mtpa capacity is US$ 756 million, and the tanker harbor costs US$ 200 million. The regasification/receiving terminal with a 3,75 mtpa capacity costs US$ 360 million [16].

Figure 6 Gas Pipeline along Suralaya CFPP unit 1 dan Cilegon CCPP by Google Map

LNG tanker transportation cost is calculated by using Henry Lee formula [17] :

$$c_{tanker} = 7 \times 10^{-5} \times L + 0.102 \qquad (3)$$

Where C_{tanker} is the transportation cost (USD/MMBTU) and L is a round trip distance (Kilometer).

So, According to experience project by PT. Pertamina (Persero) group specifically PT. Pertamina Gas Negara Tbk (PGN), estimating cost onshore gas pipeline (diameter 8 inch, same with tie in pipeline gas existing in Cilegon CCPP) with distance 15 Km, (no need compressor cost to because increasing pressure up to 40 kg/cm^2 already included in gasification cost investment) Rp 1.019.084.850.000,00.

5 Conclusion

Suralaya CFPP Unit 1 and Cilegon CCPP have the potential to be integrated into an IGCC power plant in the future. Both power plants, manufactured by Mitsubishi Heavy Industries, have been modeled into an IGCC plant using the MHI Air-Blown Gasifier, a technology already commercially implemented in Nakoso and Hirono Power Plants in Japan. The simulation data (Figure 3, Table 1) shows syngas composition as 30,5%vol CO, 10,5%vol H_2, 0,7%vol CH_4, 2,8%vol CO_2, and 55,5%vol N_2 with an LHV of 4,575 MJ/kg. No water saturation is needed to maintain acceptable NOx emissions [20]. The air-cooled combustion turbine operates with a 1.103°C turbine inlet temperature (TIT), requiring 1,65 million kg/h of air for syngas combustion, less than the 2,19 million kg/h for natural gas combustion. The coal analysis from Suralaya CFPP Unit 1 (Table 1) shows that 1 kg of coal produces 4,575 MJ of syngas after entering the gasifier, then fueling Cilegon CCPP with 77,2% cold gas efficiency. To generate 236.901 kW of power, 369.600 kg/h of syngas is needed, consuming 2.710,4 tons of coal daily. In comparison, conventional Suralaya CFPP Unit 1 uses 151,75 tons/h of coal for 194.050 kW, while IGCC requires 112,934 tons/h of coal for 236.901 kW (GT) and 70.000 kW (ST), achieving a Net Plant Efficiency of 50,36%.

From an economic perspective, there are two main costs: building the gasification plant to produce syngas and constructing the 15 km onshore gas pipeline transmission from Suralaya CFPP Unit 1 to Cilegon CCPP. The estimated cost to build the gasification plant is Rp 41.339.084.795.673,10, and the estimated cost to build the pipeline transmission is Rp 1.019.084.850.000.

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