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Design of Effective Liquefaction Unit in LNG Plant Process based on Economic Study

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Abstract. Liquified Natural Gas (LNG) is natural gas that is used as a safe, clean and efficient energy source. LNG itself is liquefied and has been processed to remove impurities and heavy fraction hydrocarbons which are then condensed into liquid at atmospheric pressure with a temperature of -160 ºC. In Indonesia, LNG has good prospects for development, both in terms of raw material potential and its market. So, it is very appropriate if an LNG plant is established in Indonesia with the aim of meeting domestic LNG needs and opening up new jobs to reduce unemployment in Indonesia. LNG is made through several stages of the process, namely the Absorption, Dehydration, Fractionation and Liquefaction processes. The factory will be established in Muara Enim, Lahan Regency, South Sumatra Province. From economic calculations, it is obtained that the return on investment is 3.08 years after the factory is established. The rate of return on capital is 38.1%, and the BEP is 37.6%. Based on the economic analysis, the LNG plant from Natural Gas is feasible to be established.

Keywords: liquified natural gas, Muara Enim, condensed, investment, economics

1. Introduction

Liquefied Natural Gas, or also known as LNG, is natural gas that is liquefied and has been processed to remove impurities and heavy hydrocarbon fractions which are then condensed into a liquid at atmospheric pressure with a temperature reaching -160 ºC. Liquefied Natural Gas that comes from nature is different from liquefied petroleum gas that comes from petroleum. LNG properties include clear, odorless, and colorless liquids. Liquefied natural gas is non-corrosive and non-flammable. LNG values that need to be considered for quality include molecular weight, density, calorific value, boiling point, and flammability such as flash point and fire point. However, the selling point itself is the colorific value or the amount of heat in calories per gram [1]. In the manufacture of LNG there are several series of processes that need to be carried out [2]. Before being processed, gas consisting of hydrocarbon gases such as methane, ethane, propane, butane, long hydrocarbon chains in small amounts and other impurity gases such as CO_2 and H_2S and water vapor need to be processed and cleaned first before being further processed. Initial processing of sales gas is very necessary to obtain natural gas specifications according to the desired criteria.

The number of impurities contained in sales gas has a very large influence on the selection of the process to be used for processing. The selection of the process for processing feed gas into LNG needs to be adjusted to the composition of the feed gas from the selected source and the desired product specifications [3]. The processes required for processing feed gas into LNG include preparation of raw materials in the Acid Gas Removal Unit and Dehydration Unit, then continued with the product manufacturing process, namely in the Fractionation Unit and Refrigeration & Liquefaction Unit.

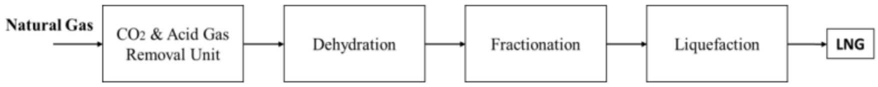

Fig. 1. LNG Manufacturing Process Block Diagram

The APCI/ C3 MR mixed propane liquefaction process is the most common natural gas liquefaction process used in the world. Almost 80% of LNG plants built in the world use this liquefaction process. The APCI liquefaction process has high thermodynamic efficiency. The characteristic of this process is that it uses a Main Heat Exchanger. This process uses propane as a pre-cooler for natural gas and a mixed refrigerant/multi-component refrigerant as a secondary coolant and natural gas liquefaction. The MCR consists of nitrogen, methane, ethane, and propane. [4,5]. cooling system is needed in the NGL recovery process and liquefaction so that there is a correlation or integration of the two process configurations. The integration concept is applied by Elliot et al. [6] to produce a significant reduction in overall capital costs and increase product capacity.

Research on increasing the efficiency of the process based on integrated groups classification of NGL and LNG. The integrated process for this product is known as Ghorbani et al. which includes no nitrogen. The process is used by C3-MR for cooling, and the results are sufficient specific energy to recovery of more than 90% [7]. Three integrated processes applying cascade refrigeration cycles were applied by Mehrpooya et al. where mixed fluid refrigeration (MFC), DMR and C3-MR. This configuration provides low-cost ethane recovery and low specific power consumption with previous studies [8]. This scheme uses a mixed refrigeration cycle for liquefaction and shows good efficiency and NGL recovery examined by Vatani et al. which can be applied to large-scale LNG plants [9]. The integrated process uses SMR and combined distillation by Khan et al. [10] where this scheme showed remarkable improvement in compression power compared to previous models. Wang and Xu reported that integrated NGL recovery with LNG regasification process shows great potential for energy saving and product production [11]. Efficient performance can be achieved by integrating liquid recovery with the liquefaction process introduced by Hudson et al. [12]. According to the abovementioned previous studies for the integrated LNG recovery and liquefaction schemes, some of them have tended to only focus on improving process efficiency. For large-scale plants, plant efficiency may be one of the most important factors compared to the total capital investment when considering long-term operation. From the calculation study, it is used to find out the right design operation in liquefied stage to have good performance so that the transfer process can be maximized. The performance of the deethanizer column and boiler that will be studied is the heat exchanger in the LNG industry, which plays a role in lowering LNG so that it can be optimized.

2. Methods

CO_2 and H_2S are the main impurities in natural gas that can inhibit a series of LNG Production processes in the industry, in addition to these 2 materials, the presence of water or H2O can also inhibit a series of Production processes, especially in the purification and liquefaction processes, therefore this process begins with separation with a vertical separator which aims to separate sludge and water that is still in the feed gas, in addition to lightening the load on the absorption process in the column. Feed Gas will exit the Feed Tank (F-101) exiting with a pressure of 54.76 bar and a temperature of 45.13 ºC, the pressure will be reduced (K-111) to 50 bar with a temperature of 43 ºC entering the absorber column (D-110) as the inlet of the absorption column, the absorption process is carried out by reacting MDEA solvent (50%) and Piperazine Promoter (5%) with CO2 and H2S. The solvent chosen is MDEA because the absorption process is quite good against impurities and can be regenerated. Feed Gas will enter from the bottom in direct contact with MDEA and PZ from above with a pressure of 50 bar and a temperature of 35 ºC counter currently MDEA will react with H2S and CO2 with the following reaction mechanism:

MDEA with H2S

$$RR'R''N + H2S \leftrightarrow HS- + RR'R''N+$$

MDEA with CO2

$$RR'R''N + CO2 + H2O \leftrightarrow RR'R''NH+ + HCO3-$$

Upstream Column Absorber (D-110) is used as a Feed Gas dehydration process that has absorbed CO2 and H2S with CO2 content <1% mol and H2S <1 ppm. CO_2 and H_2S will be carried downstream (D-110) with MDEA which will be regenerated for reuse. The Regeneration process is carried out in the Stripping Column (D-120) with the help of heat from the reboiler of 142°C to prevent the MDEA solution from evaporating with CO_2.

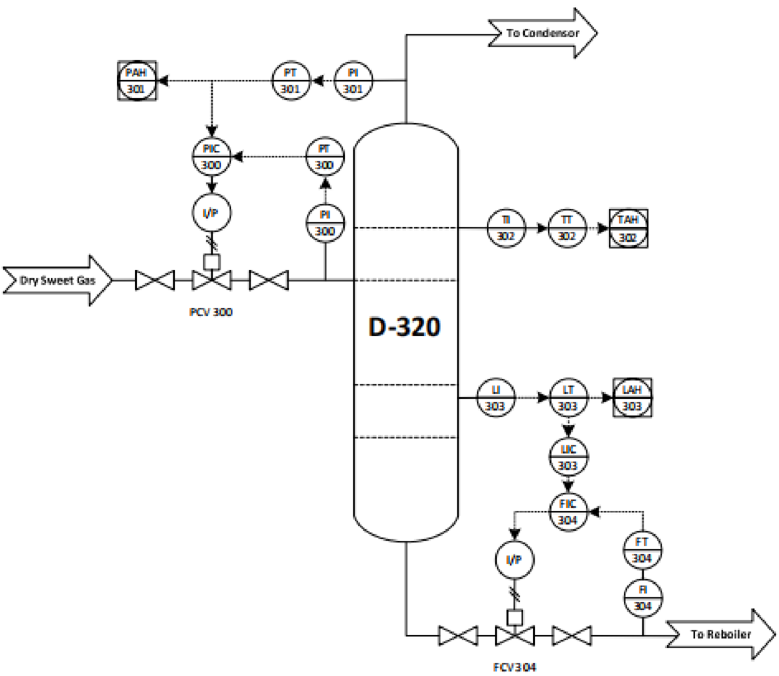

Fig. 2. Process Flow Diagram.

Sweet Gas that has gone through the CO_2 and Acid Gas Removal processes will enter the dehydration process (D-210) to reduce the H_2O content that is still included in the system. This process is carried out by absorption with the help of TEG as an absorbent because TEG has a high absorption capacity for water. Sweet Gas with a pressure of 50 bars and a temperature of 37 ºC enters the column (D-210). Sweet Gas will enter from the bottom directly in contact with TEG from above with a pressure of 50 bar and a temperature of 35ºC in countercurrent. Upstream Column (D-210) will be cooled in the propane cooler box (E-310) before entering the Deethanizer (D-320). Downstream Dehydration Unit (D-210) Rich TEG and H2O will be re-generated for reuse. The regeneration process is carried out in the Stripping Column (D-220) with the help of heat from the reboiler of 250°C to prevent H2O from being included in the TEG solution which will be reused to absorb water in D-210. Lean TEG that has been regenerated in D-220 will be Makeup with H_2O in M-214 and cooled in E-211 with an outlet temperature of 52.5°C and a pressure of 50.3 bar and reused in the dehydration column D-210. Dry Sweet Gas that has been separated from CO_2, H_2S in the Acid Gas Removal unit (D-110) and H_2O content in the Dehydration Column (D-210) before being fractionated, the Dry Sweet Gas is cooled in the propane cooler box (E-310) and propane cooler (E-312) to facilitate the separation process and energy efficiency.

Dry Sweet Gas from D-210 will enter E-310 with a temperature of 26.83°C and a pressure of 49.4 bar. The Cooling Process in the Propane Cooler Box (E-310) experiences a temperature decrease to -31°C with a pressure of 45 bar. This refrigeration cycle starts from the G-311 Propane Compressor multi stage so that the pressure becomes 36 bar followed by an increase in temperature to 167.4°C then cooled with a propane cooler (E-312) to a temperature of 83.8°C and a pressure of 35.6 bar which is then expanded in the JT Valve (K-313) and experiences a pressure change to 1 bar and a temperature of -43°C which will then be used as a coolant in the propane cooler box (E-310).

Table 1. Specification of Design

Parameter	Value
Distillate pressure	3510 kPa
Bottom pressure	4100 kPa
Distillate temperature	-56.80° C
Bottom Temperature	91.53°C
Column Design	
Tray space	0.55 m
Ideal stage amount	13 stages
Column pressure drop	590 kPa
Top Surface tension	0.0083 N/m
Bottom Surface tension	0.007 N/m
Top Product (D)	4212.167 kmol/h
Vapor Rate (V)	12838.147 kmol/h
Bottom product (B)	201.645 kmol/h
Vapor Flow Below Feed (V’)	12838.147 kmol/h
Liquid Flow Below Feed (L’)	13039.792 kmol/h
Top pV	37.64 kg/m^3
pL	432.499 kg/m^3
BM	23.45 kg/kmol
Bottom pV	80.32 kg/m^3
pL	395 kg/m^3
BM	52.39 kg/kmol
Top Lw	39.99 kg/s
Top Vw	44.82 kg/s
Bottom Lw	189.77 kg/s
Bottom Vw	186.84 kg/s

Dry Sweet Gas that has been cooled from E-310 experiences a temperature change to -31°C and a pressure of 45 bar, its pressure will be reduced with the help of the K-321 Deethanizer inlet Valve to 41 bar with a temperature of -35.1°C. Then the Dry Sweet Gas will be fractionated in the D-320 Deethanizer Column to separate C1, C2 and C3 +. Upstream D-320 in the form of fractions C1 and C2 will enter the liquefaction unit and downstream D-320 namely C3 +. will enter the C3 + Storage Tank F-301. After going through the fractionation process in the Deethanizer Column D-320, C1 and C2 with a temperature of -71.6°C and a pressure of 35 bar are reduced in pressure to 5 bar, so that the temperature decreases to -107.2°C with the help of the Mixed Refrigerant inlet Valve K-411. then C1 and C2 enter the Mixed Refrigerant Cooler Box E-410 to a temperature of -166 C and experience a phase change to LNG. after the LNG is reduced in pressure to 1 bar with the help of the LNG Product Valve K-415 valve to be stored in the LNG Storage Tank F-401.

Table 1. Common process specification

Specification of Deethanizer Column		
Code	D-320	
Function	Separated C2- and C3+	
Type	Sieve Tray	
Pass	Single Pass	
Capacity	190	kg/s
Materials	SA-167 Grade 3 Type 304	High alloy steel
Equal	4	pieces
Column Specification		
ID	551.1814	in
Shell thickness	3	in
Top thickness cover	1/5	in
Bottom thickness	1/5	in
Shell high	259.84	in
Top cover high	94.163	in
Bottom cover high	4.041	in
Plate Specifications		
Weir length	413.38	in
Downcomer width	6.889	in
Hole diameter	1.968	in
Weir high	1.968	in
Tray spacing	21.653	in
Plate thick	0.118	in
Hole specifications		
Hole area	14022.8	in
Hole size	1.968	in

The cooling process in the Mixed Refrigerant Cooler Box E-410 starts from Outlet E-410 with a temperature of -119°C and a pressure of 4.7 bar entering the E-412 Mixed Refrigerant Exchanger to be heated and change phase to gas, so that the temperature becomes -48°C with a pressure of 4.6 bar. Then the gas enters the Mixed Refrigerant Compressor G-413 to increase its pressure to 4.9 bars and experience a temperature increase to -36.3°C. Next, the mixed refrigerant is cooled in the Mixed Refrigerant Exchanger E-412 until the temperature becomes -62.7°C and the pressure is 4.5 bar, after which the MR is cooled again with the MR Cooler E-414 to a temperature of -176°C which is then ready to be reused as a cooler in the Mixed Refrigerant Cooler Box E-410.

3. Results and Discussion

Utilities in an industry have a very important role to be considered, because a series of production processes cannot run optimally if the utility aspect does not meet the requirements, therefore facilitating the production process to run optimally. Utilities in the Liquefied Natural Gas factory or also known as LNG with a capacity of 2,000,000 tons / year are divided into several categories, namely 1. Steam Supply Unit 2. Water Supply Unit 3. Electricity Supply Unit. The steam supply unit is designed to meet the steam needs in the LNG Production process, the amount of steam needed in the process is calculated according to the use of each tool. Based on the calculation of the heat balance, the steam needs for the Production process are as follows

Table 3. Equal needs Steam/hours

P (bar)	Instrument	Code	Rate Steam/ kg/h
4.3	Reboiler Amine Regeneration	E-125	7912.933
41	Reboiler TEG Generation	E-325	599.243
	Total		8512.176

It is estimated that leakage due to heat transfer is 10% of the total steam used while the safety factor is also 10% of the total steam so that the amount of steam quantity must be produced by each boiler of 120% of the steam requirement. So:

Boiler Requirements = 120% x Steam Requirements (kg/hour) = 10214.6112 kg/h

The boiler used is a Fire Tube with an efficiency of 80%, because the operating pressure is 4 bars with a temperature of 150 ºC with a latent heat of 2546.5 kJ / Kg. In addition, there is a boiler used to heat the column flow D-220 (TEG Regeneration Column) because it requires a pressure of 2 bars and a temperature of 260 ºC with a latent heat of 2794.9 kJ / kg with the tool code E-221 and a steam rate of 209,997 kg / hour.

Boiler Capacity

Boiler 1

Boiler Requirement	= Rate Steam x λ
	= 10214.6112 x 2546.5
	= 26011507.42 kJ / hour
	= 24654152.06 Btu / hour
BHP	= 9689.44 HP
Boiler heat transfer area	10ft^2/HP
A	=10x BHP
	= 10 x 9689.44 HP

	=96894.4 ft^2/HP
Water blowdown	=3%
Steam rate	= rate steam x (100 + blow down water)
	= 10214.611 x 103%
	= 10521.0495 kg/h
Boiler used hard coal (high calories)	
Heating value	= 13000 btu/lb.
Efficiency	= 80%
Fuel mass	=Qboiler/ (Hv x Eff)
	=24654152.06/ (13000 x 80%)
	= 25806.77 kg/day

Boiler 2

Boiler Requirement	= Rate Steam x λ
	= 209.997 x 2794.9
	= 586920.6153 kJ / hour
	= 556293.4 Btu / hour
BHP	= 218.63 HP
Boiler heat transfer area	10ft^2/HP
A	=10x BHP
	= 10 x 218.63 HP
	=2186.31 ft^2/HP
Water blowdown	=3%
Steam rate	= rate steam x (100 + blow down water)
	= 209.997 x 103%
	= 216.29691 kg/h
Boiler used hard coal (high calories)	
Heating value	= 13000 btu/lb.
Efficiency	= 80%
Fuel mass	=Q boiler/ (Hv x Eff)
	=556293.4/ (13000 x 80%)
	= 582.301 kg/day

The indicator of the length or shortness of the maintenance time is seen from the value of the dirt factor. The cause of the dirt factor is the presence of dirt which can be in the form of mud carried along with the flowing fluid, polymers, and deposits (corrosion crust) [14]. The fluid flow rate is a parameter that affects the value of the dirt factor for both hot and cold fluids where increasing the fluid flow rate can reduce the value of the dirt factor. Thus, the heat exchange process can take place perfectly [15].

Table 4. Specification of Boiler

Specification of Boiler	
Capacity Boiler 1	24654152.06 btu/h
Capacity Boiler 2	556293.4 btu/h
BHP boiler 1	9689.4
BHP boiler 2	218.6
Heat transfer area boiler 1	96894.46 ft^2
Heat transfer area boiler 2	2186.315 ft^2
Fuel boiler 1	25806.77 kg/day
Fuel boiler 2	582.310 kg/day
Water needs boiler 1	10521.049 kg/h
Water needs boiler 2	216.2969 kg/h

Type boiler 1 & 2	High calories coal

The selection of the process in the design of the LNG plant is carried out to obtain good quality products through the most effective and efficient process both in terms of Capex, OPEX and reliability from the process and equipment itself. The selection of the process is also based on the specifications of the Feed to be processed. Sanitation Water 1) Employee Needs For sanitation purposes, 11.7 x 998 (water density) kg/m^3= 488,333 kg/hour. 2) Laboratory, for water, the laboratory requirement is estimated to be 20% of the employee's water requirement, then 97.7 kg/hour ≈ 4.8 m^3/day; 3) Firefighting, for firefighting and water reserves, 40% excess water is required from the total sanitation requirement, then 820.40 kg/hour ≈ 40.32 m^3/day. So, the total water requirement for sanitation is: 1406.40 kg/hour ≈ 56.86 m3

Water cooling needs

Table 5. Equal needs water cooling

No	Instrument	Code	Rate water/ kg/h
1	Rich MDEA Cooler	E-115	36733.72
2	Amine Regeneration Condenser	E-126	3099398.2
3	Propane Cycle cooler	E-312	4817278.78
Total			7953410.715
			219954.04 m^3/day
Total (sanitary, water cooler, process, boiler)			227492.65 m^3/day

Electricity needs

Table 6. Equal needs electricity

No	Instrument	Amount	Power/ kW
Production Process			
1	L-114 A/B Pump Rich Amine	1	67.066
2	L-324 Deethanizer Reflux Pump	1	45.841
3	L-213 A/B Glycol pump	1	2.622
Amount			115.53
Utility electricity			
1	River water pump	1	83.47
2	Cooler water pump	3	250.41
3	Coagulant water pump	1	41.73
4	Sediment pump	1	41.73
5	Filtration pump	1	41.73
6	Storage pump	1	41.73
7	Ion Exchanger pump	1	41.73
Amount			542.53
Lux electricity			414.8

etc	22.5
Grand Total	1095.36

The availability of electricity and water in industry is one of the factors that is used as a benchmark for the feasibility of industry. The electricity needed for the LNG production process is obtained from the MT Sumatera Selatan -8 PLTU with an electric voltage of 150/20 kV and an electric capacity of 180 MVA. Where with this capacity it has met the needs of the LNG industry in operation. The availability of water that will later be used in the industry for the need for sanitation water, process water, cooling water and water for boiler feed is obtained from the Lema tang River which is also close to the planned location for the construction.

Availability of Land and Labor is the main aspect in designing an industry, if land and labor are not available, then the production process cannot run. Based on data released by the Central Statistics Agency in 2023, the area of Muara Enim is 7,384 km^2. This factory will be established with a total area of 240622.52 m2 or 0.24 km^2. So, the land area is not a problem when compared to the total land availability in Muara Enim. Based on data released by the Central Statistics Agency in 2023, the unemployment rate in Muara Enim Regency is 4.12% of the total population or 19,000 people with a working age of 15-64 years. With this unemployment rate, the source of labor can be met and can open new jobs as a form of increasing the level of the Indonesian economy, especially in South Sumatra.

This transportation aspect is needed to support production activities, both receiving raw materials and shipping products. The ideal factory location should have complete transportation facilities, both land, air and sea. Currently, Muara Enim does not have its own airport facilities, but the location from Muara Enim to Palembang as the capital of South Sumatra province is 189 km or equivalent to 3 hours of land travel. Where Palembang has complete facilities, both ports and airports. So that the transportation aspect does not become an obstacle to the development of the LNG industry in Muara Enim. Climate aspects in Indonesia are generally the same as other regions in Indonesia, based on BMKG (2023) rainfall in Muara Enim Regency is included in the medium - high category with a rainfall value of 201 - 401 mm. However, this does not make it a problem for this LNG plant to be established in Muara Enim Regency, South Sumatra.

Economic Analysis in establishing an LNG Plant from Natural Gas with a capacity of 2,000,000 Tons / Year can be reviewed by conducting an analysis of IRR (Internal Rate of Return) NPV (Net Present Value), POT (Pay Out Time and BEP (Break Event Point) and so on. These analyses are carried out to determine the impact that will arise from the economic side on the establishment of an LNG plant with a capacity of 2,000,000 Tons / Year in Muara Enim Regency, South Sumatra.

Basis for Economic Calculation

1. Production Capacity: 2,280,815 Tons / Year
2. Company Capital:

a. Own Capital = 60% Total Capital Investment
b. Loan Capital = 40% Total Capital Investment

3. Factory Lifespan = 10 Years
4. Production Capacity:

a. Year 1: 60%
b. Year 2: 80%
c. Year 3: 100%

5. Income Tax: 30%
6. Total Income:

a. Variable Cost
b. Semi Variable Cost
c. Fixed Cost

7. Loan repayment is made for 10 years with bank interest of 8% per year.

Fixed capital investment

No	Kind	Code	Cost
1	Total Direct Cost (instrument, installation, piping, electricity fix)	DC	Rp. 3,087,651,402,771
2	Indirect Cost	IC	Rp. 19,174,105,389,110
3	Fixed Capital Investment	FCI	Rp. 22,261,756,791,882
4	Work Capital Investment	WCI	Rp. 2,473,528,532,431
5	Invest PT	MP	Rp. 24,735,285,324,313
6	Direct Production Cost	DPC	Rp. 4,135,176,143,904
7	Fixed Cost	FC	Rp. 4,343,516,103,949
8	Plant Overhead Cost	POC	Rp. 1,574,576,135,432
9	General Expense	GE	Rp. 3,536,508,080,262
10	Variable Cost	VC	Rp. 623,049,141,126
11	Semi Variable Cost	SVC	Rp. 8,623,211,218,473

IRR (Internal Rate of Return) is a method used for Calculates a certain interest rate where reception will cover the whole the amount of capital expenditure. The calculation is done by doing a trial value i (interest rate) with Total capital investment is Rp 24,735,285,324,313

Year	Cash Flow (Rp)	Discounted Cash Flow		Present Value (Rp)
		i=	38.1%	
1	6,983,824,732,290	72.4%		5,057,256,809,334
2	9,258,511,042,535	52.4%		4,854,947,089,086
3	11,533,197,352,780	38%		4,379,401,391,773
4	11,592,234,245,557	27.5%		3,187,526,859,200
5	11,651,271,138,334	19.9%		2,319,966,370,991
6	11,710,308,031,111	14.4%		1,688,489,545,145
7	11,769,344,923,889	10.4%		1,228,864,572,456
8	11,828,381,816,666	7.6%		894,331,945,779
9	11,887,418,709,443	5.5%		650,852,601,968
10	11,946,455,602,220	4%		473,648,138,582
Total Present Value				**24,735,285,324,313**
Total Capital Investment (TCI)				**24,735,285,324,313**

BEP (Break Event Point) is a term used to find out the amount of capacity where the total production cost is equal to the sales result. To calculate the BEP value, the values of fixed cost, variable cost, semi variable cost, and selling cost are needed.

4. Conclusion

Based on the Demand and Increase in LNG Consumption in the world, then to maximize the potential and gas reserves in Indonesia, the LNG Plant from Natural Gas will be established with a capacity of 2.23 MTPA. Reviewed from the feasibility and raw material aspects, the LNG Plant from Natural Gas will be established in Muara Enim, South Sumatra Regency. Based on the Results of the Economic Calculations that have been carried out, then a) Total Capital Investment (TCI) = Rp 24,735,285,324,313; b) Working Capital Investment (WCI) = Rp2,473,528,532,43; c) Fixed Capital Investment (FCI) = Rp 22,261,756,791,882; d) Total Production Cost (TPC) = Rp 4,135,176,143,904; e) Pay Out Time (POT) =

3.08 Years; f) Rate of Return on Investment (IRR) = 38.1%; g) Break Event Point = 37.6%; From the data above, it can be concluded that the LNG plant from Natural Gas with a capacity of 2.23 MTPA is feasible to be established.

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