PROPOSED DESIGN OF 600 MW COAL – FIRED POWER PLANT LOCATED AT BRGY. BALANGA, LEMERY, BATANGAS

MERCADO, BRYAN V.

PANOPIO, VINCE LEMUEL B.

RIVERA, LEMUEL ARNEL A.

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EXECUTIVE SUMMARY

The design of the proposed project 600 MW Coal – Fired Power Plant owned by MRP Power Generation Corporation consists of two steam turbines which both provide a 300MW capacity. The plant capacity was based on the increasing power demand of the Philippines particularly in the Luzon grid. The power plant will be located in Brgy. Balanga, Lemery, Batangas. The location is in a vacant lot distanced from commercial establishments such as resorts, but is strategically located along the shore line of Balayan Bay. Balayan Bay will serve as the water source for plant operations

Three design options were analyzed and logically calculated in terms of technical parameters, environmental parameters, and economic parameters. Several factors were considered in the installment of the power plant to ensure that the operation of the power plant will be successful in the specified timeframe. Each of the design underwent different categories of analysis regarding the plant efficiency and economic considerations. Each design underwent analysis regarding with the efficiency and economic viability. The best efficiency is suitable in order to help deal with the increasing electrical demand of the province. The economic viability was considered to determine if the venture will be profitable for the company and if it can be a suitable source of income for workers.

Among the three design options, the most beneficial one was selected. Design option 2 was selected as it gave the best efficiency of 31.9% without sacrificing economic viability.

Proper equipment was selected with regards to the safe operating conditions of the plant as well as the economic considerations. Engineering codes and standards, environmental effects, health and safety issues, political factors, and ethical factors were considered for the design.

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CHAPTER I

INTRODUCTION

Electricity is a major contributor to developing countries. In modern technology, it serves as the fuel that utilizes technological advances and without it most of the technologies that the people use every day would not function as intended.

According to an article written by Ver, A. A. (2018), entitled Policy Framework for the Electric Power Industry in the Philippines' NIC-hood: Quo Vadis? For the Inquirer Journal, in the next ten years, new power plants will need to generate at least 82.10 percent of the installed capacity.

In an April 30, 2019 interview of MERALCO president Rogelio Singson, he stated that "DOE is right in saying that we need 600 MW every year,". Meralco issued at least eight red alerts for the month of April (meaning energy demand exceeds the power supply) causing its subsidiaries to rotate brownouts.

Power shortages were caused primarily by unplanned power plant outages. Most power shortages happen in Luzon, which consumes up to 70% of the country's demand for electricity.

Business World's senior researcher, Amoguis M.T, reported the following results on June 17, 2019: there are at least 126 power plants working within the Luzon grid, according to DOE. However, studies from the Energy Regulatory Commission (ERC) concluded that 72% of those power plants are at least 16 years or older in operation and contribute to the power deficiency of the Luzon grid.

In line with the articles reported, it was determined that building a new power plant in the Luzon grid will be both beneficial and profitable. This study proposes a 600 MW coal-fired power plant.

The subject of the Report

This project study focused mainly on the design of a 600 MW Coal-Fired Power Plant located at Brgy. Balanga, Lemery, Batangas. This research includes the basic foundations and fundamental factors concerning the place of the plant as well as the design of the plant layout taking into account the Codes and Standards for Engineering, Environmental and Economic Effects, Manufacturability, Sustainability, Health and Safety Issues, Ethical Considerations, etc. The research also involves critical operational condition-based criteria. The current plant profiles are evaluated in order to establish the plant layout and place as the reference data. The research will include the financial assessment for the design project cost overview, cost calculation and complete cost calculation of the power plant. The study's observation, conclusion, and recommendation will also be available.

Capitalization

Sufficient financing is considered for the installation and operation of the plant. Securing the plant's financing may come from the plant's operator or owner, and public funding. Fifty percent of the funding provided will come from the owner or operator of the plant, thirty percent of the total cost will be retained through public financing and the remaining twenty percent will come from bank loans.

Ownership

The owner of the proposed coal-fired power plant as per the completion of the project will be the MPR Power Generation Corporation. This company is a coal-fired power plant and will use sub-bituminous coal as the primary fuel. The organization in the company will be the one who has the power and authority to decide where the suggested coal-fireded energy plant will be located. All facility equipment, utilities, and infrastructure belong to the said company.

Organizational Set-up with Technical Organization

This is the MPR Power Generation Corporation technical organization

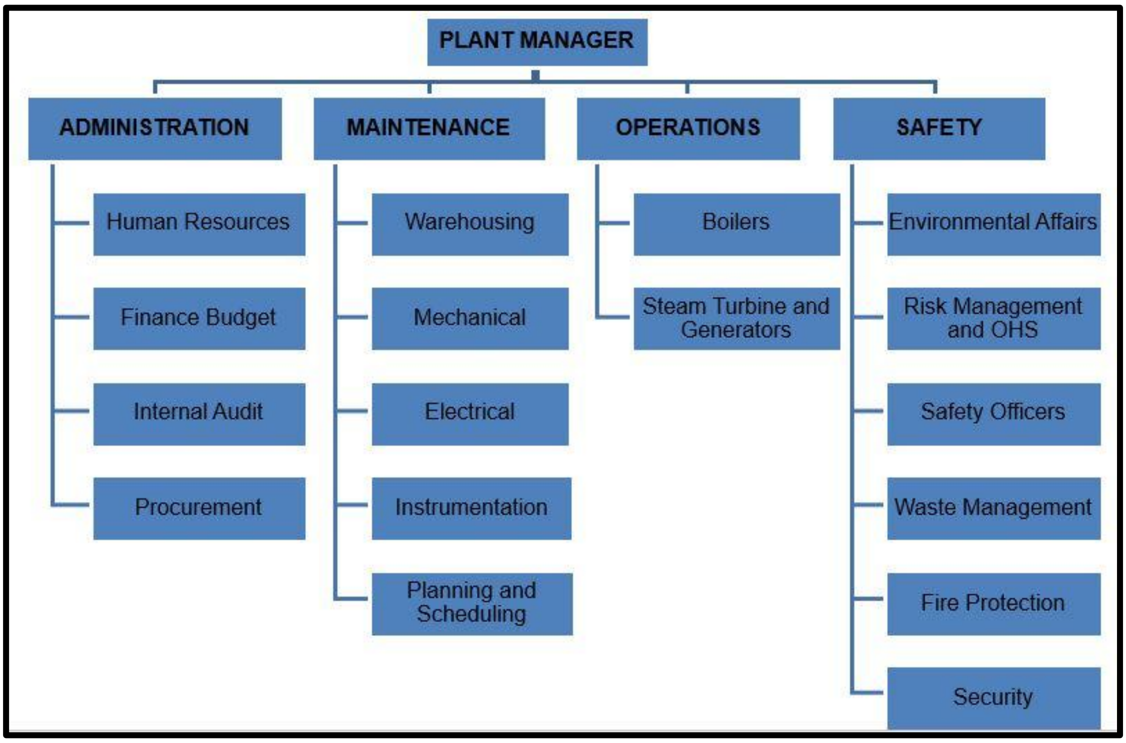

Figure 1. Organizational Chart

This figure shows the flow of power from the skilled worker up to the professional worker. It shows how every worker relates to each other, who has a higher position.

Location Map

For the location of the power plant, three municipalities in Batangas were considered: Mabini, Lemery, and Nasugbu. The available areas were all located near bodies of water needed to provide water for the plant operations. The location in Nasugbu however, seemed to conflict with the neighboring commercial resorts as it would affect their business. This narrows the options to Lemery and Mabini. For both options, the topography of the land area of Mabini is less beneficial as the landscape is craggy. Additional labor will be required to flatten the landscape. Therefore it was concluded that the location in Lemery is the most applicable option among the three. The location in Lemery can also be easily reached by road via a national highway. Several parameters were also considered to compare the three possible locations. The location must be determined first before arriving at a final conclusion. The parameters are given by:

Table 1

Comparison of Parameters of the Three Locations

Parameters	Location 1 (Mabini)	Location 2 (Lemery)	Location 3 (Nasugbu)
Surrounding bodies of water	Present	Present	Present
Vast open area	Present	Present	Present
Nearness to the grid	Near	Near	Near
ambient air temperature	27.75^{o}C	27^{o}C	29^{o}C
Disturbances	Forestation and Excavation	Forestation	Many Resorts
Topography	Elevated by 100m	Flat	Flat
Factors that are being protected	Seaside and the sea	Seaside and the sea	Seaside and sea
Cost of Land Area	PHP1800.00	PHP1500.00	PHP1650.00
Access to transportation	Easy	Easy	Easy

Table 1 shows the different parameters used to determine the plant location. All of the locations are vast open areas suitable for the construction of large facilities. The locations are strategically located near bodies of water. The location in Mabini is located along the coast of Batangas Bay, the location in Lemery is located along Balayan Bay, and the Nasugbu location is along the shore of Nasugbu Bay.

The researchers decided to install the plant in Brgy. Balanga, Lemery Batangas due to its strategic location with regards to the nearness to the grid, availability of water, cost of land, and fuel transport via sea. The vicinity will be less affected compared to the other locations. The chosen location will provide electricity to the different municipalities in the province of Batangas.

The construction of the power plant will not only benefit the corporation but will also provide career opportunities for the community. The power plant will help in the economic development and industrialization of Brgy. Balanga, Lemery.

Lemery is a 1st class urban municipality in the province of Batangas with an ambient temperature of 27%. The municipality is located in the west-central part of Batangas between the distribution utilities BATELEC I and BATELEC II. Lemery has a land area of 110 square kilometers constituting 3.5% of the land area in Batangas. According to the 2015 census, Lemery has a population of 93,157 people.

Brgy Balanga is located along the coast near the municipality of Calaca. Brgy Balanga's Philippines Standard Geographic Code is 041012006. The population of the Brgy. In 2014 constitutes 1.1% of the total population of Lemery with 1050 people. The specific location of the power plant is at 13°5" North and 120°52'16.1" East of the Philippines.

Below is the proposed plant location located at Brgy. Balanga, Lemery, Batangas.

Figure 2. Proposed Location of the Coal-Fired Power Plant (Google Map, 2019)

Figure 2 shows the location of the proposed plant site. The proposed coal-fired power plant is to be constructed in Brgy. Balanga, Lemery, Batangas with a land area of 0.325 square kilometers.

Figure 3. Plant location showing the target municipalities to be supplied by the coal-fired power plant (Google Map, 2019)

Figure 3 shows that the proposed power plant will provide energy primarily for the province of Batangas with the help of the distribution units of BATELEC I BATELEC II, First Bay Power Corporation (FBPC) and Ibaan Electric Engineering Corporation (IEEC). BATELEC distributes electricity in the municipalities of Nasugbu, Lian, Calatagan, Tuy, Balayan, Calaca, Lemery, Agoncillo, San Nicolas, Sta. Teresita, and San Luis. BATELEC II distributes electricity to the municipalities of Laurel, Talisay, Tanauan, Malvar, Balete, Lipa, Cuenca, San Jose, Alitagtag, Mabini, Tingloy, Padre Garcia, Rosario, Taysan, Lobo, and San Juan. Additional power produced can be exported to other provinces connected to the Luzon grid such as MERALCO which supplies the greater Manila area. Reports have shown that the country is faced with problems regarding energy demand especially the Luzon grid.

Load Projection

The following data necessary for the load projection were gathered from the Department of Energy (DOE) distribution utility profile particularly the distribution utilities operating in Batangas Province: BATELEC I, BATELEC II, FBPC, and IEEC. The Manila Electric Company (MERALCO) was also added to the load projection. The data were gathered to determine the forecast of the electrical consumption of the target locations.

Table 2

Projected load in MW from 2019-2044

Year	BATELEC I	BATELEC II	FBPC	IEEC	MERALCO	TOTAL
2019	69.93958701	165.59	9.44	4.75	7372.97	7622.7
2020	72.7511584	172.41	9.37	4.90	7608.91	7868.3
2021	75.67575497	179.52	9.30	5.06	7852.39	8121.9
2022	78.71792032	186.91	9.23	5.22	8103.67	8383.7
2023	81.88238072	194.61	9.16	5.39	8362.98	8654
2024	85.17405242	202.63	9.09	5.56	8630.60	8933.1
2025	88.59804933	210.98	9.02	5.74	8906.78	9221.1
2026	92.15969092	219.67	8.95	5.92	9191.80	9518.5
2027	95.86451049	228.72	8.89	6.11	9485.93	9825.5
2028	99.71826381	238.14	8.82	6.31	9789.48	10142
2029	103.726938	247.96	8.75	6.51	10102.75	10470

Source: Department of Energy

The data gathered from DOE showed the projected load from 2015-2029 for BATELEC I, BATELEC II, IEEC, and MERALCO. At 2019 the total projected load is equal to 7622.7MW and after 10 years the projected load will increase to 10470MW. The power demand has an average growth rate of 9.64% starting from 245.65 MW to 327 MW averaging 309.21 MW for 10 years.

Assuming no other power plants will provide the additional demand, the proposed 600 MW power plant will reach its capacity within the next 2 years of operation upon the finishing of construction within the next 10 years.

CHAPTER II
REPORT PROPER

This chapter is composed of the report proper and design calculations considered in the proposed 600 MW Coal-Fired Power Plant.

Theoretical Consideration

A steam power plant is used to generate electricity by the use of steam turbine. The major components of this power plant are boiler, steam turbine, condenser and water feed pump.

Coal is shipped to the port area where it will be conveyed in the coal yard for storage prior to being transported to the main power generating units. The first process of this power plant is where the pulverized coal is fed into the boiler and it is burnt in the furnace. The flue gasses and ash formed during combustion will be treated accordingly. The water present in the boiler drum changes to high pressure steam. From the boiler the high-pressure steam passed to the super heater where it is again heated up to its dryness. This super-heated steam strikes the turbine blades with a high speed and the turbine starts rotating at high speed. A generator is attached to the rotor of the turbine and as the turbine rotates it also rotates with the speed of the turbine. The generator converts the mechanical energy of the turbine into electrical energy. The electrical energy will be amplified by a transformer and will then be transferred to the switch yard. After striking on the turbine the steam leaves the turbine and enters into the condenser. The steam gets condensed with the help of cold water from the cooling tower. The condensed water with the feed water enters into the economizer. In the economizer the feed water gets heated up before entering into the boiler. This heating of water increases the efficiency of the boiler. The exhaust gases from the furnace pass through the super heater, economizer and air pre-heater. The heat of this exhaust gases is utilized in the heating of steam in the super heater, feed water in the economizer and air in the air pre-heater. After burning of the coal into the furnace, it is transported to ash handling plant and finally to the ash storage. The electricity produced by the generator are then stored at transformers before distributing it to the consumers.

Scope of the Design of a 600 MW Coal Fired Power Plant

The main objective of this project is to design a coal-fired power plant having a plant capacity of 600 MW located at Brgy. Balanga, Lemery, Batangas. Specifically, this study aims to:

1. Present and evaluate the design and development of the projected 600 MW coal fired power plant taking into account of the following considerations:

    1.1. Energy Balance

    1.2. Overall Efficiency

    1.3. Work Output

2. Provide technical design specifications for the different components of the coal fired power plant, presenting the proper data for the plant calculations, schematic diagrams, process flow diagrams, plant lay-out, and particular type of plant components considering the required engineering codes, standards and appropriate specifications to be utilized as a part of the advancement of the proposed coal-fired power plant.

3. Evaluate the economic viability of the three proposed design options as well as the comparison of equipment through calculations of economic indicators:

    3.1. Payback period

    3.2. Rate of Return/Rate of Investment

4. Evaluate the proposed design considering the environmental impact and elaborating the socio-economic benefits and outcomes of the project,

5. Establish a detailed project construction execution plan of the selected best design.

Design Calculation

1. Design Options

Design Option 1

The schematic and T-S diagram of design option 1 is shown as follows.

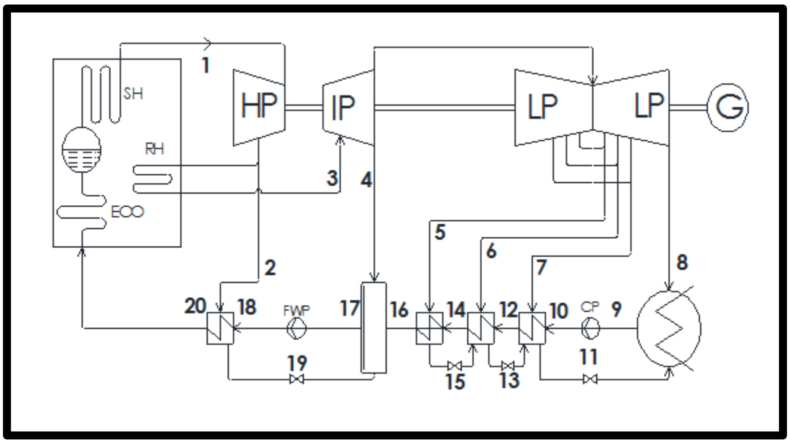

Figure 4. Schematic Diagram of Design Option 1

Design option 1 operates with a reheat regenerative rankine cycle. The system consists of 5 regenerative processes with 1 open feed water heater and 4 closed feed water heater, and reheating. The design option obtained a thermal efficiency of 30.6%

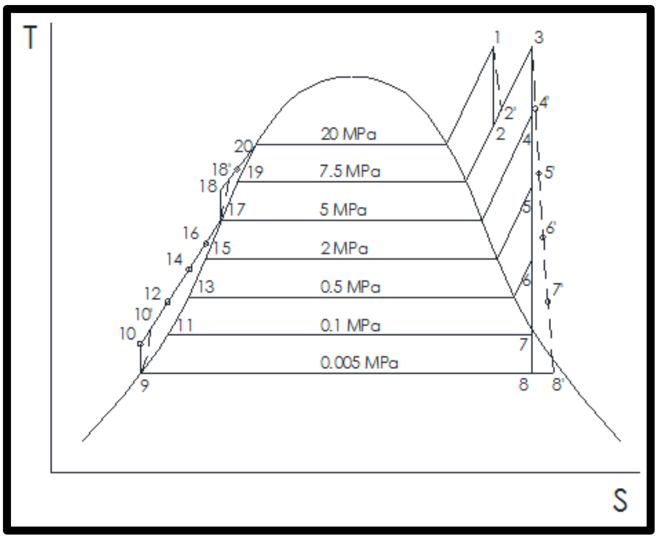

Figure 5. T – S Diagram of Design Option 1 Cycle

The figure above shows the thermodynamic relationship with in the design. The cycle consists of 20 state points with 7 operating pressures.

Design Option 2

The schematic and T-S diagram of design option 1 is shown as follows.

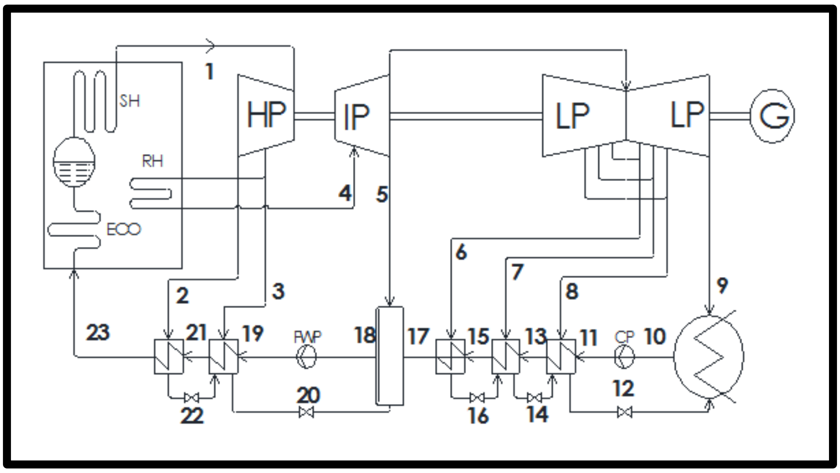

Figure 6. Schematic Diagram of Design Option 2

The system consists of 6 regenerative processes with 1 open feed water heater and 5 closed feed water heater , and reheating. The design option obtained a thermal efficiency of 31.9%.

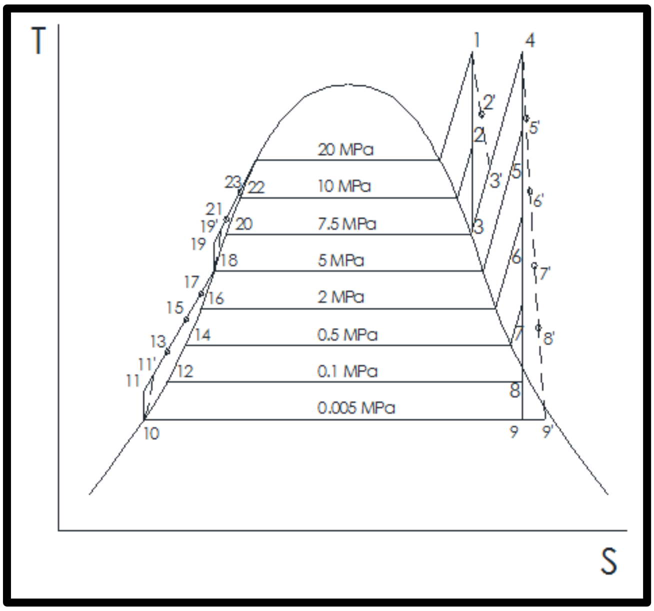

Figure 7. T – S Diagram of Design Option 2 Cycle

The figure above shows the thermodynamic relationship with in the design. The cycle consists of 23 state points with 8 operating pressures.

Design Option 3

The schematic and T-S diagram of design option 1 is shown as follows.

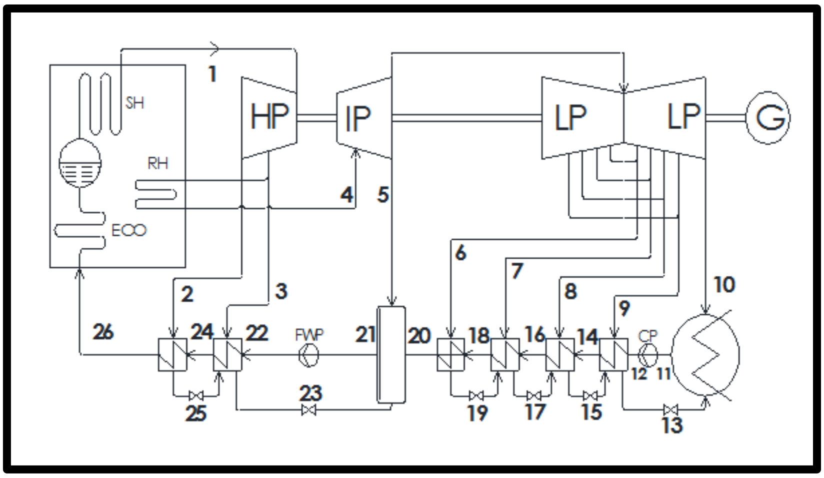

Figure 8. Schematic Diagram of Design Option 2

The system consists of 6 regenerative processes with 1 open feed water heater and 5 closed feed water heater , and reheating. The design option obtained a thermal efficiency of 31.6%.

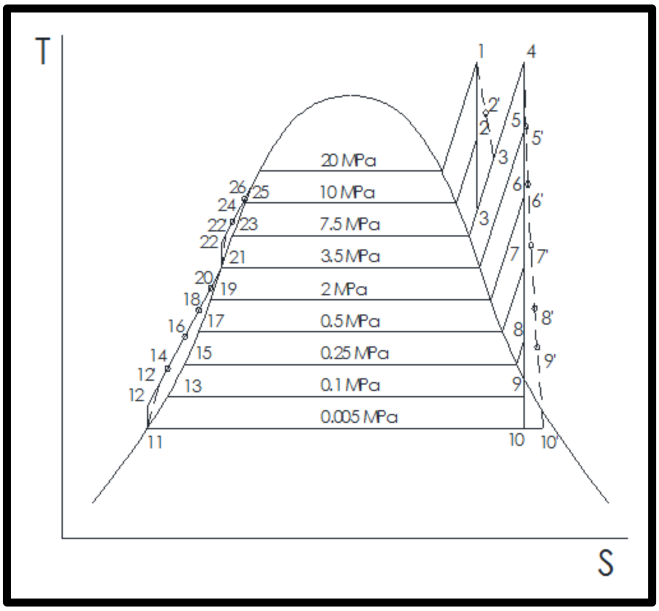

Figure 9. Schematic Diagram of Design Option 3

The figure above shows the thermodynamic relationship with in the design. The cycle consists of 26 state points with 9 operating pressures.

2. Design Data

The design data includes the ambient conditions in the proposed location in Brgy. Balanga, Lemery, Batangas and the steam cycle operating conditions used in the calculation of technical parameters of the design options.

Table 3

Ambient Condition in Brgy, Balanga, Lemery, Batangas

Ambient Condition		
Pressure	mbar	1014
Humidity	%	61
Temperature		
Design Temperature	^{o}C	27
Max. Temperature	^{o}C	34
Min. Temperature	^{o}C	22

The data from table 3 shows the ambient weather conditions for Brgy. Balanga, Lemery, Batangas. The atmospheric pressure is 101.4 mbar. The air has a relative humidity of 61%. The chosen design temperature is 27 ^{o}C as the historic maximum and minimum temperatures are 34 ^{o}C and 22 ^{o}C respectively.

Table 4

Steam Cycle Operating Conditions

Parameter	Design 1	Design 2	Design 3	Value
High Pressure Turbine				
Pressure	20	20	20	Mpa
1st Extraction Pressure	-	10	10	Mpa
Temperature (inlet)	540	540	540	^{0}C
Intermediate Pressure Turbine				
Pressure / Reheat Pressure	7.5	7.5	7.5	MPa
Reheat Temp. (inlet)	540	540	540	^{0}C
2nd Extraction Pressure	7.5	7.5	7.5	MPa
3rd Extraction Pressure	5	5	3.5	MPa
4th Extraction Pressure	2	2	1.5	MPa
5th Extraction Pressure	0.5	0.5	0.5	MPa
6th Extraction Pressure	0.1	0.1	0.2	MPa
7th Extraction Pressure	-	-	0.05	MPa
Condenser				
Pressure	0.005	0.005	0.005	Mpa

The table above shows the operating conditions of the three different design options. The pressure in the heat generating unit is 540 ^{o}C, the maximum pressure in the superheater is 20Mpa, and the condenser pressure is 0.005 Mpa.

3. Summary of Calculations

The summary of calculations is composed of calculations for the three design options, the calculations for the fuel and boiler efficiency, calulations for turbine selection, and the environmental parameters

A. Design Options

Summary of Calculations for Design Option 1

Table 5

Operating Conditions for Design Option 1

Parameter	Unit	Value
High Pressure Turbine		
Pressure	20	20
Temperature (inlet)	540	540
Intermediate Pressure Turbine		
Pressure / Reheat Pressure	7.5	MPa
Reheat Temperature (inlet)	540	^{0}C
First Extration Pressure	7.5	MPa
Second Extraction Pressure	5	MPa
Third Extraction Pressure	2	MPa
Fourth Extraction Pressure	0.5	MPa
Fifth Extraction Pressure	0.1	MPa
Condenser		
Pressure	0.005	0.005

Table 5 shows the operating pressure and temperature conditions necessary for calculations.

Table 6

Mass and Heat Balance for each State Point of Design Option 1

State Point	Pressure (Mpa)	Temp. (^{o}C)	Enthalpy (kJ/kg)	$Mass_{steam}$ (kg/s)
1	20	540	3366.370	419.910
2	7.5	375.498	3080.280	36.005
3	7.5	540	3502.650	384.223
4	5	469.812	3363.980	348.218
5	2	330.068	3092.920	307.504
6	0.5	163.635	2775.750	278.926
7	0.1	99.6059	2498.250	237.867
8	0.005	32.8743	2119.920	237.867
9	0.005	32.8743	137.749	384.223
10	0.1	32.8768	137.845	307.504
11	0.1	99.6059	417.504	76.719
12	0.5	99.6335	417.921	307.504
13	0.5	151.831	640.085	28.578
14	2	151.999	641.724	307.504
15	2	212.377	908.498	40.715
16	5	212.935	912.028	307.504
17	5	263.941	1154.640	419.910
18	7.5	284.692	1157.856	419.910
19	7.5	290.535	1292.930	36.005
20	20	295.439	1310.326	419.910

Table 6 shows the obtained temperature, enthalpy, and steam flow for the operating conditions in design option 2. Values were obtained from SteamTab Companion software from ChemicaLogic Corporation. The actual enthalpies were obtained using a turbine efficiency of 53% and a pump efficiency of 85%.

Table 7

Summary of Calculation of Mass Balance of Design Option 1

Symbol	Equation	Value	Unit
m_1	$m_1\ (h_2' - h_{19}) = m\ (h_{20} - h_{18}')$	35.68721014	kg/s
m_2	$m_2\ h_4' - h_{16}) = m\ (h_{17} - h_{16}) - m_1(h_{19} - h_6')$	36.00473013	kg/s
m_3	$m_3(h_5' - h_{15}) = (m - m_1 - m_2)\ (h_{16} - h_{14})$	40.71466011	kg/s
m_4	$m_4(h_6' - h_{13}) = (m - m_1 - m_2)\ (h_{14} - h_{12}) - m_3(h_{15} - h_{13})$	28.5777881	kg/s
m_5	$m(h_7' - h_{11}) = (m - m_1 - m_2)\ (h_{12} - h_{10}') - (m_3 + m_4)\ (h_{13} - h_{11})$	41.05895598	kg/s
m	$W_T = \sum m\ (h_{in} - h_{\ out})$	356.6383313	kg/s

Table 7 shows the mass balance calculations for design option 1. The work produced by the turbine is 300MW and the total mass of steam required to produce the output is 356.6383313 kg/s

Table 8

Summary of Individual Turbine Work for Design Option 1

Symbol	Equation	Value	Unit
$W_{1\text{-}2'}$	$m\ (h_1 - h_2')$	53.28022109	MW
$W_{3\text{-}4'}$	$(m - m_1)\ (h_3 - h_4')$	50.02568176	MW
$W_{4'\text{-}5'}$	$(m - m_1 - m_2)(h_4' - h_5')$	72.45438297	MW
$W_{5'\text{-}6'}$	$(m - m_1 - m_2 - m_3)\ (h_5' - h_6')$	71.91183431	MW
$W_{6'\text{-}7'}$	$(m - m_1 - m_2 - m_3 - m_4)\ (h_6' - h_7')$	76.51916214	MW
$W_{7'\text{-}8'}$	$(m - m_1 - m_2 - m_3 - m_4 - m_5)\ (h_7' - h_8')$	53.28022109	MW
W_T	$W_{1-2'} + W_{2'-3'} + W_{4-5'} + W_{5-6'}$	300	MW

Table 8 shows the calculations used to obtain the work of the turbine in design option 1 from individual state points and also the total output which is 300 MW.

Table 9

Summary of Pump Work for Design Option 1

Symbol	Equation	Value	Unit
W_{P1}	$(m - m_1 - m_2)\ (h_{10}{}' - h_9)$	0.026726847	MW
W_{P2}	$m\ (h_{18}{}' - h_{17})$	1.317484306	MW
W_P	$W_{P1} + W_{P2}$	1.344211154	MW

Table 9 enlists the calculations used for the work of the condensate pump and the open feedwater pump. The total pump work is 1.344211154 MW.

Summary of Calculations for Design Option 2

Table 10

Operating Conditions for Design Option 2

Parameter	Unit	Value
High Pressure Turbine		
Pressure	20	MPa
First Extraction Pressure	10	Mpa
Temperature (inlet)	540	^{0}C
Intermediate Pressure Turbine		
Pressure / Reheat Pressure	7.5	MPa
Reheat Temperature (inlet)	540	^{0}C
Second Extraction Pressure	7.5	MPa
Third Extraction Pressure	5	MPa

Fourth Extraction Pressure	2	MPa
Fifth Extraction Pressure	0.5	MPa
Sixth Extraction Pressure	0.1	MPa
Condenser		
Pressure	005	MPa

Table 10 shows the operating pressure and temperature conditions necessary for calculations.

Table 11

Mass and Heat Balance for each State Point of Design Option 2

State Point	Pressure (Mpa)	Temp. (^oC)	Enthalpy (kJ/kg)	Mass of Steam (kg/s)
1	20	540	3366.370	402.439
2	10	454.945	3255.865	27.381
3	7.5	404.933	3162.805	375.058
4	7.5	540	3502.650	348.708
5	5	497.647	3429.155	317.278
6	2	401.112	3250.791	282.359
7	0.5	268.311	2999.019	254.752
8	0.1	128.437	2733.612	221.856
9	0.005	32.8743	2397.241	221.856
10	0.005	32.8743	137.749	317.278
11	0.1	32.886	137.802	317.278
12	0.1	45.8063	417.921	95.423
13	0.5	81.3169	421.677	317.278
14	0.5	81.3169	640.085	31.430
15	2	155.419	656.473	317.278
16	2	212.377	908.498	34.919
17	5	219.887	943.801	317.278

18	5	263.941	1154.640	402.439
19	7.5	271.543	1192.475	402.439
20	7.5	290.535	1292.930	27.607
21	10	310.997	1299.771	402.439
22	10	310.997	1408.060	32.897
23	20	316.545	1425.491	402.439

Table 11 shows the obtained temperature, enthalpy, and steam flow for the operating conditions in design option 2. Values were obtained from SteamTab Companion software from ChemicaLogic Corporation. The actual enthalpies were obtained using a turbine efficiency of 53% and a pump efficiency of 85%.

Table 12

Summary of Calculation of Mass Balance of Design Option 2

Symbol	Equation	Value	Unit
m_1	$m_1\ (h_2' - h_{22}) = m\ (h_{23} - h_{21})$	27.38094375	kg/s
m_2	$m_2(h_4' - h_{16}) = m\ (h_{21} - h_{19}') - m_1(h_{22} - h_{20})$	26.34971427	kg/s
m_3	$m_3(h_5' - h_{17}) = m\ (h_{18} - h_{17}) - (m_1 + m_2)(h_{20} - h_{17})$	31.43026046	kg/s
m_4	$m_4(h_6' - h_{16}) = (m - m_1 - m_2 - m_3)\ (h_{17} - h_{15})$	34.9187646	kg/s
m_5	$m_5(h_7' - h_{14}) = (m - m_1 - m_2 - m_3)\ (h_{15} - h_{13}) - m_4\ (h_{16} - h_{14})$	27.60703378	kg/s
m_6	$m_1\ (h_{18} - h_{12}) = (m - m_1 - m_2 - m_3)\ (h_{13} - h_{11}') - (m_4 + m_5)\ (h_{14} - h_{12})$	32.89675604	kg/s
m	$W_T = \sum m\ (h_{in} - h_{\ out})$	419.9103376	kg/s

Table 12 shows the mass balance calculations for design option 2. The work produced by the turbine is 300MW and the total mass of steam required to produce the output 419.9103376 kg/s

Table 13

Summary of Individual Turbine Work for Design Option 2

Symbol	Equation	Value	Unit
$W_{1\text{-}2'}$	$m\ (h_1 - h_2')$	44.47152311	MW
$W_{3\text{-}4'}$	$(m - m_1)\ (h_3 - h_4')$	34.90292266	MW
$W_{4'\text{-}5'}$	$(m - m_1 - m_2)(h_4' - h_5')$	25.62835541	MW
$W_{5'\text{-}6'}$	$(m - m_1 - m_2 - m_3)\ (h_5' - h_6')$	55.96860863	MW
$W_{6'\text{-}7'}$	$(m - m_1 - m_2 - m_3 - m_4)\ (h_6' - h_7')$	70.21184978	MW
$W_{7'\text{-}8'}$	$(m - m_1 - m_2 - m_3 - m_4 - m_5)\ (h_7' - h_8')$	66.6873736	MW
W_T	$W_{1-2'} + W_{2'-3'} + W_{4-5'} + W_{5-6'}$	73.45226665	MW

Table 13 shows the calculations used to obtain the work of the turbine in design option 2 from individual state points and also the total output which is 300 MW.

Table 14

Summary of Pump Work for Design Option 2

Symbol	Equation	Value	Unit
W_{P1}	$(m - m_1 - m_2)\ (h_{10}' - h_9)$	1.881851816	MW
W_{P2}	$m\ (h_{18}' - h_{17})$	9.348160733	MW
W_P	$W_{P1} + W_{P2}$	11.23001255	MW

Table 14 enlists the calculations used for the work of the condensate pump and the open feedwater pump. The total pump work is 1.344211154 MW.

Summary of Calculations for Design Option 3

Table 15

Operating Conditions for Design Option 2

Parameter	Unit	Value
High Pressure Turbine		
Pressure	20	Mpa
First Extraction Pressure	10	Mpa
Temperature (inlet)	540	^0C
Intermediate Pressure Turbine		
Pressure / Reheat Pressure	7.5	MPa
Reheat Temperature (inlet)	540	^0C
Second Extraction Pressure	7.5	
Third Extraction Pressure	3.5	MPa
Fourth Extraction Pressure	1.5	MPa
Fifth Extraction Pressure	0.5	MPa
Sixth Extraction Pressure	0.2	MPa
Seventh Extraction Pressure	0.05	MPa
Condenser		
Pressure	0.005	Mpa

Table 15 shows the operating pressure and temperature conditions necessary for calculations.

Table 16

Mass and Heat Balance for each State Point of Design Option 3

State Point	Pressure (Mpa)	Temp. (^oC)	Enthalpy (kJ/kg)	$Mass_{steam}$ (kg/s)
1	20	540	3366.370	406.494
2	10	454.945	3255.865	27.657
3	7.5	404.933	3162.805	378.837
4	7.5	540	3502.650	345.311
5	3	467.83	3384.948	324.697
6	1.5	385.178	3224.385	314.426
7	0.5	274.7936	3012.732	255.134
8	0.25	187.826	2843.513	227.089
9	0.1	99.6059	2597.888	190.685
10	0.005	32.8743	2351.307	190.685
11	0.005	32.8743	137.749	324.697
12	0.1	32.886	137.802	324.697
13	0.1	99.6059	417.504	134.012
14	0.25	99.6163	417.660	324.697
15	0.25	127.411	535.245	36.405
16	0.5	127.434	535.612	324.697
17	0.5	151.831	915.290	59.292
18	1.5	198.287	916.383	324.697
19	1.5	198.287	844.557	10.270
20	3	198.535	846.288	324.697
21	3	233.853	1008.340	406.494
22	7.5	244.823	1060.900	406.494
23	7.5	290.535	1292.930	36.405
24	10	292.171	1299.771	406.494
25	10	310.997	1408.060	33.526
26	20	316.545	1425.491	406.494

Table 16 shows the obtained temperature, enthalpy, and steam flow for the operating conditions in design option 3. Values were obtained from SteamTab Companion software from ChemicaLogic Corporation. The actual enthalpies were obtained using a turbine efficiency of 53% and a pump efficiency of 85%.

Table 17

Summary of Calculation of Mass Balance of Design Option 3

Symbol	Equation	Value	Unit
m_1	$m_1 (h_2' - h_{22}) = m (h_{23} - h_{21})$	27.65681659	kg/s
m_2	$m_2(h_4' - h_{16}) = m (h_{21} - h_{19}') - m_1(h_{22} - h_{20})$	33.52580983	kg/s
m_3	$m_3(h_5' - h_{17}) = m (h_{18} - h_{17}) - (m_1 + m_2)(h_{20} - h_{17})$	20.61445805	kg/s
m_4	$m_4(h_6' - h_{16}) = (m - m_1 - m_2 - m_3) (h_{17} - h_{15})$	10.27033512	kg/s
m_5	$m_5(h_7' - h_{14}) = (m - m_1 - m_2 - m_3) (h_{15} - h_{13}) - m_4 (h_{16} - h_{14})$	59.29194521	kg/s
m_6	$m_6 (h_{18} - h_{12}) = (m - m_1 - m_2 - m_3) (h_{13} - h_{11}') - (m_4+m_5) (h_{14} - h_{12})$	28.04492697	kg/s
m_7	$m_7(h_{18} - h_{12}) = (m - m_1 - m_2 - m_3)(h_{14} - h_{12}') - (m_4+m_5 + m_6)(h_{15} - h_{13})$	36.40490734	kg/s
m	$W_T = \sum m (h_{in} - h_{out})$	402.4390128	kg/s

Table 17 shows the mass balance calculations for design option 2. The work produced by the turbine is 300MW and the total mass of steam required to produce the output is 402.4390128 kg/s

Table 18

Summary of Individual Turbine Work for Design Option

Symbol	Equation	Value	Unit
$W_{1\text{-}2'}$	$\mathrm{m}\ (\mathrm{h}_1 - \mathrm{h}_2{}')$	44.91958968	MW
$W_{2'\text{-}3'}$	$(\mathrm{m} - \mathrm{m}_1)\ (\mathrm{h}_2 - \mathrm{h}_3{}')$	35.25458214	MW
$W_{4\text{-}5'}$	$(\mathrm{m} - \mathrm{m}_1 - \mathrm{m}_2)(\mathrm{h}_4 - \mathrm{h}_5{}')$	40.64394569	MW
$W_{5'\text{-}6'}$	$(\mathrm{m} - \mathrm{m}_1 - \mathrm{m}_2 - \mathrm{m}_3)\ (\mathrm{h}_5{}' - \mathrm{h}_6{}')$	52.1340169	MW
$W_{6'\text{-}7'}$	$(\mathrm{m} - \mathrm{m}_1 - \mathrm{m}_2 - \mathrm{m}_3 - \mathrm{m}_4)\ (\mathrm{h}_6{}' - \mathrm{h}_7{}')$	66.5492868	MW
$W_{7'\text{-}8'}$	$(\mathrm{m} - \mathrm{m}_1 - \mathrm{m}_2 - \mathrm{m}_3 - \mathrm{m}_4 - \mathrm{m}_5)\ (\mathrm{h}_7{}' - \mathrm{h}_8{}')$	43.17374351	MW
$W_{8'\text{-}9'}$	$(\mathrm{m} - \mathrm{m}_1 - \mathrm{m}_2 - \mathrm{m}_3 - \mathrm{m}_4 - \mathrm{m}_5 - \mathrm{m}_6)\ (\mathrm{h}_8{}' - \mathrm{h}_9{}')$	55.7787587	MW
$W_{9'\text{-}10}$	$(\mathrm{m} - \mathrm{m}_1 - \mathrm{m}_2 - \mathrm{m}_3 - \mathrm{m}_4 - \mathrm{m}_5 - \mathrm{m}_6 - m_7)\ (\mathrm{h}_9{}' - \mathrm{h}_{10})$	47.01927295	MW
W_T	$\mathrm{W}_{1-2'} + \mathrm{W}_{2'-3'} + \mathrm{W}_{4-5'} + \mathrm{W}_{5-6'} + \mathrm{W}_{7'-8'} + \mathrm{W}_{8'-9'}$	300	MW

The table above shows the calculations used to obtain the work of the turbine in design option 3 from individual state points and also the total output which is 300 MW.

Table 19

Summary of Pump Work for Design Option 2

Symbol	Equation	Value	Unit
W_{P1}	$(\mathrm{m} - \mathrm{m}_1 - \mathrm{m}_2)\ (\mathrm{h}_{10}{}' - \mathrm{h}_9)$	0.011611988	MW
W_{P2}	$\mathrm{m}\ (\mathrm{h}_{18}{}' - \mathrm{h}_{17})$	13.1933806	MW
W_P	$\mathrm{W}_{P1} + \mathrm{W}_{P2}$	13.20499259	MW

Table 19 enlists the calculations used for the work of the condensate pump and the open feedwater pump. The total pump work is 13.20499259 MW.

Table 20

Summary of Design Calculations

Parameters	Design Option 1	Design Option 2	Design Option 3
Heat Added	973.9748222 MW	899.5922049 MW	917.7009625 MW
Work of Turbine	300 MW	300 MW	300 MW
Work of Pump	1.344211154 MW	13.20499259 MW	1.543884 MW
Net Work	298.6557888 MW	286.7950074 MW	289.9592642 MW
Thermal Efficiency	0.306636046	**0.318805366**	0.315962689

The table above shows the computed values needed to determine the thermal efficiency. The calculations show that design option 2 has the most desirable thermal efficiency of 31.8805572%.

B. Fuel and Boiler Efficiency

Table 21

Summary of Calculations for Heat Losses in the Boiler

Heat Loss	Equation	Symbol	Value	Unit
Dry flue gas loss	$\frac{m_t * Cp * (T_g - T_a) * 100}{HHV}$	(Ldg)%	**1.222702651**%	%
Moisture loss	$\frac{(9H_2 + m) * [584 + Cp * (T_g - T_a)] * 100}{HHV}$	(Lm)%	**1.372204302**	%
Humidity loss	$\frac{(A/F_{actual}) * W_h * Cp * (T_g - T_a) * 100}{HHV}$	(Lh)%	**0.006042536**	%

Unburnt loss	$\frac{100 - \%\ \text{carbon in the residue}}{\%\ \text{total carbon at inlet}}$	C_b	$\mathbf{1.407816}$	%
Radiation loss	$\%\ \text{radiation(assumed)}$	$(Lr)\%$	$\boldsymbol{1}$	%
Unaccountable loss	$assumed$	$(Lu)\%$	$\boldsymbol{10}$	%
Total Boiler Loss	$\sum \text{Loss}_{\text{boiler}}$	$(TBL)\%$	$\mathbf{15.00876549}$	%
Gross efficiency of boiler	$100 - \sum \text{Loss}_{\text{boiler}}$	n_b	$\mathbf{84.99167046}$	%

Table 21 shows the calculations of different losses factored in determining the overall efficiency of the boiler. These losses are chimney loss, unburnt loss, radiation loss, and unaccountable loss. The overall efficiency of the boiler is 84.99167046%.

Fuel Computations

The fuel to be used will be sub-bituminous coal from Semirara Coal and Mining Corporation. The data below shows the ultimate analysis of sub-bituminous coal from Semirara. Through the data gathered, the researchers were able to determine the properties that may affect the overall plant operations. It also pictures the possible emissions from the combustion or utilization of the said coal as fuel.

Hydrogen = 4.318%

Carbon = 56.556%

Nitrogen = 1.038%

Sulfur = 0.752%

Oxygen = 16.336%

Ash = 21%

Table 22

Summary of Fuel Properties

Parameter	Equation	Value
HHV	$HHV = 33820\ C + 144212\ \left(H - \frac{O}{8}\right) + 9304\ S$	22479.4704 kJ/kg
HHV_{actual}	$HHV_{actual} = (n_b)(HHV)$	19105.5794 kJ/kg
A/F_{theo}	$\frac{A}{F} = 11.5\ C + 34.5\ \left(H_2 - \frac{O_2}{8}\right) + 4.3\ S$	7.321496 kg_{air}/kg_{fuel}
A/F_{actual}	$A/F_{actual} = A/F_{theo}(1 + e)$	8.98519387 kg_{air}/kg_{fuel}

The higher heating value was obtained using Dulongs Formula with the given fuel contents. The boiler efficiency was computed to determine the actual heating value for operations. The theoretical air-fuel ratio was determined. The excess air fuel ratio and the humidity of the air was considered in determining the actual air fuel ratio.

Table 23

Summary of Calculations for the Fuel Flow Rate

Equation	Design Option 1	Design Option 2	Design Option 3
$m_f = \frac{Q_A}{HHV_{actual}}$	50.97855458 kg/s	**47.08531399 kg/s**	48.0331396 kg/s

The calculations for the fuel flow rate shows that design option 2 has the least fuel requirement reducing the fuel costs for operation.

C. Coal Transport and Storage

The coal consumption for 1 day is 8136.34 tons and requires coal transport of 66, 3000 ton capacity barges per month.

In case of unexpected hindrances with the transport of coal, the plant has a coal storage capacity good for 1 month with a total area of 2x260mx125m.

D. Chimney Calculations

Table 24

Summary of Calculations for the Chimney

Parameter	Equation	Value
AF_{fg}	$AF_{fg} = AF_{actual} + 1$	9.98519387 kg_{air}/kg_{fuel}
m_{fg}	$m_{fg} = AF_{fg} x m_f$	470.1559387 kg/s
ρ_{fg}	$\rho_{fg} = \frac{P}{RT}$	0.8643457kg/m^3
Q_{fg}	$Q_{fg} = \frac{m_{fg}}{\rho_{fg}}$	8.98519387 kg_{air}/kg_{fuel}
D	$Q = AV; A = \frac{\pi}{4} D^2$	9.6095m^2≈10m^2
$P.D.$	$P.D. = H(\rho_o - \rho_{fg})g$	706.9033026Pa

For the chimney computations, the flue gasses were assumed to all exit the chimney. The exit temperature was assumed 150 ^{o}C. Ambient air conditions were used for the outside air density. The maximum allowable flue gas velocity is 7.5m/s. The chimney diameter to be built is 10m. For a chimney height of 220m, the pressure drop was 706.9033026Pa.

E. Cooling Water Requirement

The circulating water pump has a flowrate of 50m^3/s and will have a temperature increase of 3.444917 ^{o}C in order to condense the steam. The temperature difference was obtained with the heat balance formula:

$$m_w C_p \Delta T = m_s \Delta h$$

The change in enthalpy occurs on statepoint 9 and statepoint 10, while the initial temperature of the water from Balayan Bay is 30 ^{o}C.

F. Environmental Parameters

The selection of the best design option are also compared based on the environmental effects of the gases resulted in the combustion of primary fuel which is the lignite coal. The environmental parameters being compared are the carbon oxides emission (CO_x), nitrogen oxides emission (NO_x), sulfur oxides emission (SO_x), and ash disposal. The summary of heat losses in the boiler are also tabulated as follows.

Table 25

Summary of Calculated Emissions of the Three Design Options

Symbol	Equation	Design Option 1	Design Option 2	Design Option 3
m_{CO_x}	$\text{mass of } CO_x * m_f$	99.96554696 kg/s	**92.3316171 kg/s**	94.18978455 kg/s
m_{NO_x}	$\text{mass of } NO_x * m_f$	1.658259554 kg/s	**1.392379999 kg/s**	1.562449412 kg/s
m_{SO_x}	$\text{mass of } SO_x * m_f$	0.734091186 kg/s	**0.6780285215 kg/s**	0.7000815183kg/s
m_{ash}	$\text{mass of ash} * m_f$	12.59680084 kg/s	**11.64478109 kg/s**	11.8689888 kg/s

Table 25 shows that design option 2 has the least emission due to it also consuming the least amount of fuel. Design option 2 has a Carbon emission of 92.3316171 kg/s, nitrogen oxide emission of 1.392379999 kg/s Sulfur Oxide emission of 0.6780285215 kg/s, and ang ash flow of 11.64478109 kg/s.

Equipment Selection

Based on the thermal efficiency, fuel consumption, and environmental parameters, design option 2 is the best option. The computations were based on the turbine SST-5000. SST-4000 and STF-D650 are also viable options for the power plant and comparisons were made for the three turbines.

Table 26

Summary of Calculations for SST 5000, SST 4000, and STF D650 based on Design Option 2

Parameters	SST 5000	SST 4000	STF D650
Technical Data			
Power Output	250-500 MW	100-500 MW	≤ 700 MW
Frequency	50 or 60 Hz	50 or 60 Hz	50 or 60 Hz
Efficiency	53%	43%	47.50%
Maximum Pressure	26 Mpa	10.5 Mpa	19 Mpa
Technical Parameters			
Heat Added	899.5922049 MW	1103.343129 MW	1103.343129 MW
Work of Turbine	300 MW	300 MW	300 MW
Work of Pump	13.20499259 MW	1.750903776 MW	14.34613468 MW
Net Work	286.7950074 MW	298.2490962 MW	285.6538653 MW
Mass of Steam	402.4390128 kg/s	482.6258918 kg/s	433.7365554 kg/s
Mass of Fuel	**47.08531399 kg/s**	57.74978638 kg/s	50.3360314 kg/s
Thermal Efficiency	**0.318805366**	0.270314001	0.297030414
Environmental Parameter			
Carbon oxide emission	**92.3316171 kg/s**	113.2434757 kg/s	98.70560184 kg/s
Nitrogen oxide emission	**1.392379999 kg/s**	1.878517962 kg/s	1.637359193 kg/s
Sulfur oxide emission	**0.6780285215 kg/s**	0.831596844 kg/s	0.7248388522 kg/s
Ash disposal	**11.64478109 kg/s**	11.8689888 kg/s	12.43803336 kg/s

Table 26 presents the summary of calculations for the 3 steam turbines' performance with design option 2. It can be seen that SST 500 is the best choice in terms of efficiency, fuel consumption, and environmental impact.

Table 27

Equipment Selection

	Relative capital cost	Php/kW	Average Efficiency	T1 years	T2 years	O&M
SIEMENS SST 5000	Php 193,911,717,260.0	9.8599	53%	1	25	Php 16,173,062,400.00
SIEMENS SST 4000	Php 197,507,050,260.00	9.8599	43%	1	25	Php 17,214,143,300.00
GE STF D650	Php 200,126,507,160.00	9.8599	47.5%	1	25	Php 18,093,264,348.00

T_1 – Interval of Major Maintenance
T_2 – Interval Between Complete Replacement

Table 27 shows how the equipment is selected. The equipment selection is based on the relative capital cost, the Php/kW, average efficiency, interval of major maintenance, interval between complete replacement and the cost of operation and maintenance. After comparing the three equipment, SIEMENS SST 5000 is chosen to be the equipment for the design for it has the lowest relative capital cost and highest overall efficiency in the three manufacturers.

Summary of Equipment

The summary of equipment shows how the specification of each component are chosen based on the selection parameter required in the calculation of the design options.

Table 28

Summary of Equipment

Tag. No.	Component	Selection Parameter	Specification	Page No.
BT-10X	Boiler	**Fuel**: Sub-Bituminous **Capacity**: 962.25 MW **Pressure**: 200 bar **Reheat Temperature**: 540 °C **Reheat Pressure**: 65 bar **Reheat Temperature**: 540 °C	**Typical Fuels**: Bituminous, sub-bituminous. Lignite A, Oil and gas **Capacity**: up to 1350 MWe **Pressure**: up to 330 bar **Temperature**: 650/670°C **Reheat Pressure**: 330 bar **Reheat Temperature**: 650/670°C	Appendix B, page 124
ST-10X	Steam Turbine	**Power Output**: 300 MW **Inlet Pressure**: 200 bar **Inlet Temperature**: 540°C **Reheat Temperature**: 540°C	**Power Output**: 200 MW – 500 MW **Frequency**: 60 Hz **Inlet Pressure**: up to 260 bar/ 3770 psi **Inlet Temperature**: up to 600°C/ 1112°F **Reheat Temperature**: up to 610°C/ 1130°F	Appendix B, page 123
C-10X	Condenser	**Pressure**: 50 mbar **Circulating Water Temperature**: 30°C	**Condenser Thermal Load**: 1820 MW **Pressure**: 55 mbar **Circulating Water Temperature**: 25°C	Appendix B, page 124
CFWH-10X	Close Feed water Heater	**Pressure**: 928.3 psig	**Pressure ratings**: 400-800 psig (low to high pressure)	Appendix B, page 127
DRT-10X	Deaerator	**Mass flow rate:** 3240 kg/h	**Total Tank Volume**: 11,575 liters **Steam Requirements**: 3240 kg/h	Appendix B, page 124
BFP-10X	Boiler Feed Pump	**Flows**: 1450m^3/h **Pressure**: 50 bar **Temperature**: 263°C **Efficiency**:85%	**Flows**: 5220m^3/h **Head**: 100 m **Pressure**: up to 517 bar **Temperature range**: up to 318°C **Efficiency**: up to 85%	Appendix B, page 125
CP-10X	Condensate Extraction Pump	**Flows**: 1144m^3/h **Pressure**: 0.05 bar **Temperature**: 32°C **Efficiency**:85%	**Flows**: 13600m^3/h **Head**: 1070 m **Pressure**: up to 100 bar **Temperature range**: up to 230°C **Efficiency**:85%	Appendix B, page 125

FGP-10X	Flue Gas Pump	**Flows**: 543m³/h **Temperature**: 150°C	**Flows**: 9085m³/h **Head**: 100 m **Temperature range**: up to 150°C	Appendix B, page 126
CWP-10X	Circulating Water Pump	**Flows**: 180000m³/h **Pressure**: up to 517 bar **Temperature**: 30°C	**Flows**: 181700m³/h **Head**: 110 m **Pressure**: up to 5bar **Temperature range**: up to 318°C	Appendix B, page 126
G-10X	Generator	**Power**: 300 MVA **Efficiency**: 100%	**Frequency**: 60 Hz **Power factor**: 0.85 **Apparent Power**: 510 MVA to 1400 MVA **Efficiency**: Up to 99% **Terminal Voltage:** 19-25 kV **Output Voltage: 26kV**	Appendix B, page 126

Table 28 shows the summary of equipment to be used in the construction of the 600 MW coal – fired power plant. Each component is named by tag numbers and has selection parameter used in the calculation of the design options. The specifications of the components are chosen based on the required parameter of the design.

Components of a Coal-Fired Power Plant

1. Steam Turbine

The steam turbine serves as the heart of the power plant as it is responsible in converting the kinetic energy of steam into mechanical energy from the blades in order to generate electric energy in the generator. The steam turbine to be used is SST-5000 manufactured by Siemens Company with an operating capacity of 200MW-500MW, inlet pressure of up to 260 bar, main and reheat temperature of 600°C, frequency of 60 Hz, and efficiency of 53%.

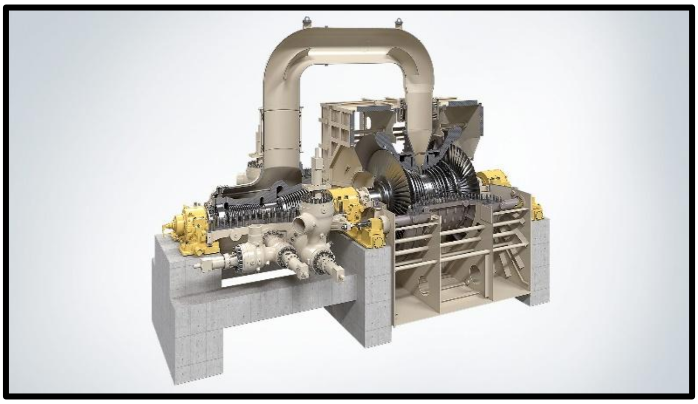

Figure 10. SST 5000, SIEMENS

2. Boiler

Two-Pass Boiler by GE CFB Technology will be installed for the proposed coal fired power plant design. The sub-bituminous coal from Semirara is a suitable type of fuel for this boiler. The boiler has a capacity of 1350 MW, a pressure of 330 bar and a temperature ranges from 650-670^{o}C.

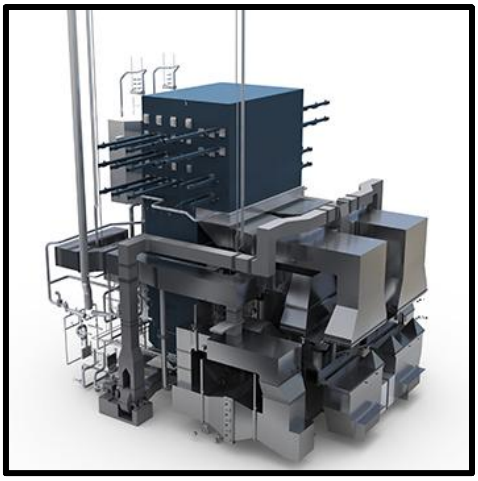

Figure 11. Two Pass Boiler, GE

3. Condenser

The condenser equipment to be used is 2017 Steam Power Systems Product Catalog (GE Single Vacuum Type Condenser) having an operating pressure of 0.05 bar, circulating seawater temperature of 30^{o}C rising to 33 ^{o}C, circulating water flow of 50m^{3}/s, and a tube length of 16.5 meters.

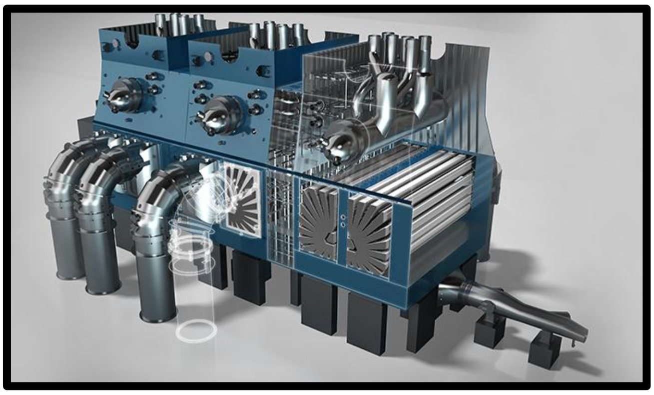

Figure 12. Condenser, GE

4. Generator

A water-cooled generator is used for the coal fired power plant. A water cooled generator is well suited for large power station applications where output requirements exceed the cooling capabilities of air-cooled or conventional hydrogen-cooled options. The apparent power of the generator is up to 1120 MVA and has a terminal voltage of up to 26 kV.

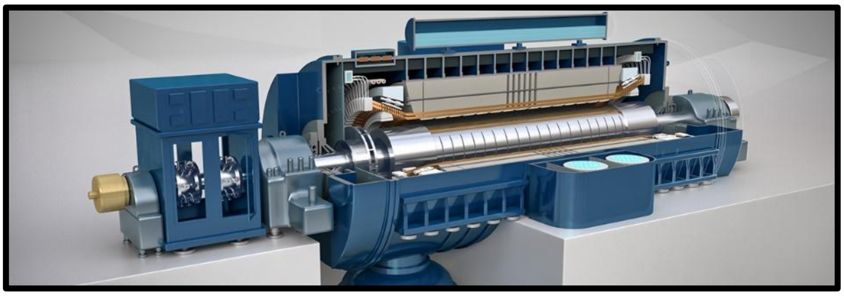

Figure 13. Gigatop Generator. GE

5. Feed water Heater

Feed water heaters are provided for the temperature increase of the feed water before it circulates in the boiler. Six feedwater heaters will be used for each unit. The feed water heater to be used is Energyen Spx Heater, a versatile heater that can be installed both in high pressure and low pressure.

Figure 14. SPX Heater, Energyen

6. Deaerator

A single deaerator is installed per unit. The deaerator's purpose is to remove dissolved gases from the feed water to prevent corrosion. Steam from the intermediate pressure turbine and feedwater from the feedwater heater will openly mix increasing the feedwater temperature. A thermal deaerator from Eurowater is installed in the plant

Figure 15. Deaerator, Eurowater

7. Pump

The pump that will be installed in the coal fired power plant is from Flowserve. The boiler feed pump can deliver a maximum flowrate of $1.45m^3/s$ with a head up to 4270m and a temperature limit of 315C. The circulating water pump has an operational flow rate of $50m^3/s$ with a head of 110m. The selected design is a vertical wel-pit pump suitable for extended operation in condenser cooling water service. The condensate extraction pump has a maximum flow rate of $3.778m^3/s$

with a head of up to 1070m designed for continuous plant operations. The flue gas desulfurization pump flows up to 2.5m3/s with a 100m head and temperature limit of 150C.

8. Pulveriser

The pulveriser is responsible for coal preparation for increased combustion efficiency. A pulverized reject hopper is installed together with the pulverizer. The hopper returns the coal not small enough for the combustion process. Suitably pulverized coal will be transported to the feeder for combustion.

9. Chimney

The product of combustion of the boiler is exhausted in the chimney as a flue gas. A flue-gas type of chimney is to be used for it is fitted on the design consideration of the power plant. It can be observed that in a flue-gas type of chimney, condensate is being spitted. The chimney has a height of 220m and a diameter of 10m.

10. Coal Conveyor

The coal conveyor serves as the component responsible in transmitting the coal into the furnace. The coal conveyor spans from the port were the cargo vessels transport the coal up to the coal yard. Other units of coal conveyor will transport the coal from the coal yard to the boiler's coal silo.

11. Coal Feeder

For maximum handling efficiency of coal, aluminum coal feeders will be utilized. Unloaded coal from the coal silo is placed on the bottom rails and feeder gates are provided. Rotary coupler is also provided for rotary dumping.

Process/Schematic/System Diagram

Other systems in the power plant includes flue gas treatment system for the removal of dust and components of combustion; ash handling system for the proper disposal of bottom ash product from the combustion process; and water treatment system for the reverse osmosis and demineralization of water to remove elements and minerals from seawater which causes damage in the components of power plant and in the piping system.

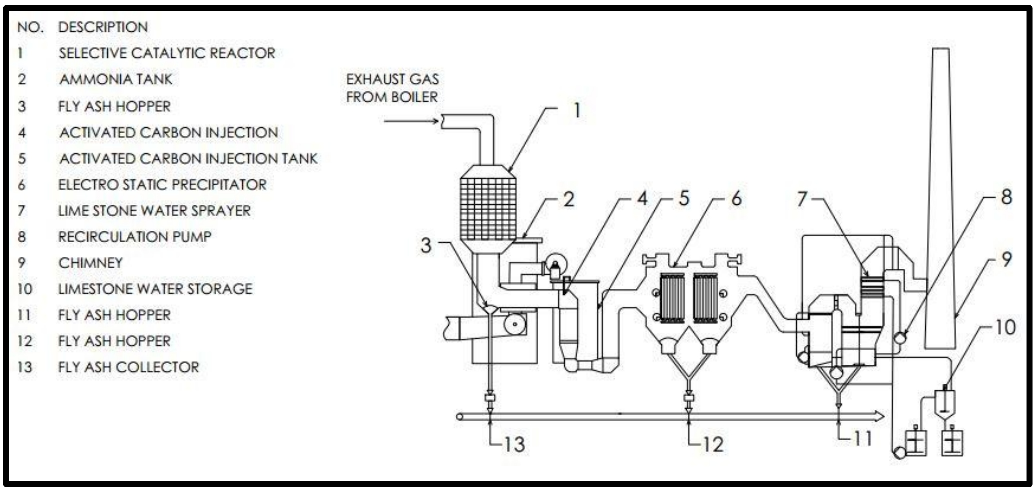

Figure 16. Flue Gas Treatment System

The treatment of flue gases enters the selective catalytic reactor which uses ammonia as the catalyst from the ammonia tank for denitrification converting nitrogen oxide emissions (NO_x) to diatomic non-polluting nitrogen (N_2). Removal of suspended dust in the electrostatic precipitator happens by applying a high-voltage charge in the flowing gas. For desulfurization, seawter is sprayed into the gas which chemically reacts to the sulfur content in the stream reducing sulfur emissions. All the fly ash will be collected and will be sold to cement companies. Used waste water will be transported to waste water storage basin were it will be properly treated before being released to the sea.

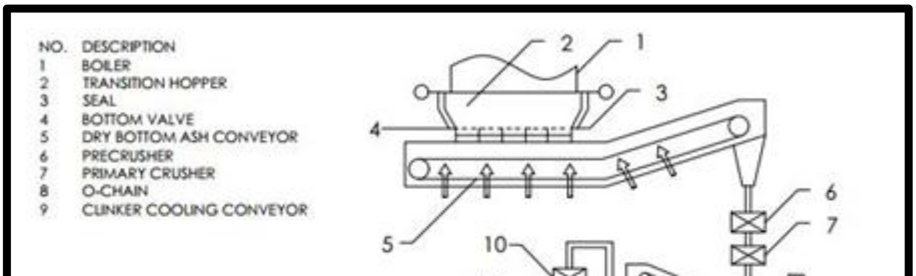

Figure 17. Ash Handling System

The ash from the combustion of coal is properly handled through ash handling system. This system cools down the raw ash to a manageable temperature before transferring it to the slurry tank. The coarse ash from the boiler is conveyed and treated to reduce its size for better handling. The collected ash in the bottom is transported in a to store it temporarily.

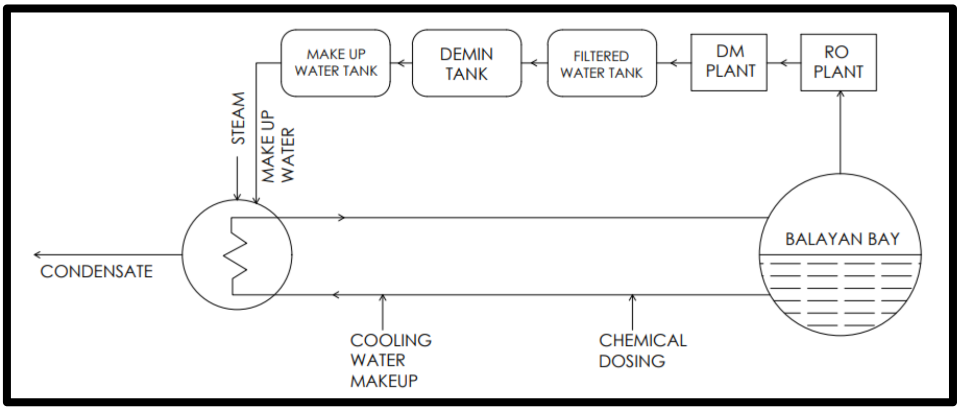

Figure 18. Water Treatment System Diagram

Water treatment system obtains water from Balayan Bay to be used in the power plant. The sea water is pumped to the reverse osmosis plant to desalinate the water. It is then pumped to the demineralization plant to purify the water and will be then transferred to the filtered water tank, demineralization tank, and make up water tank prior to entering the condenser were it will be used as either cooling water or makeup water. The waste water will be treated before being returned to Balayan Bay to ensure environmental protection.

Environmental Impact Assessment (EIA)

A power plant is very important for a developing country, particularly for its nation's trade and industry. One such scheme that is becoming common among nations is the generation of steam power. The environmental effects of the design project buildings, as well as the effect during building and operation, will always be evaluated in the building of a steam power plant. It also believes an action to be taken to decrease environmental pollution. There are things that cannot be avoided but can be minimized by means of studies and compliance with norms.

In determining the environmental effects to the society, the following components will be regarded: water, soil, air, nose, and fisheries, as the place of the plant is near the ocean. The effects will be examined in each to determine the environmental impacts on and after the plant's building.

A. Air

One of the major impacts of constructing a steam energy plant is the effect on air quality. During operation, the heat in the boiler will release several pollutants such as sulfur dioxide, nitrogen oxide, and other gasses into the environment. Other pollutants include intermittent fugitive dust emissions during the construction period; car exhausts used for transportation of employees, transportation of construction materials and basic equipment, and transportation during power plant operation.

Dust is produced during early construction activities due to the movement of cars and trucks, especially during earthworks such as excavation, foundation work, leveling, using sand and cement building. Harmful gasses emitted by generators, vehicles, and trucks can also affect air quality momentarily. Emissions from dangerous materials stored and used on site are also issues to be considered during the construction phase. This effect is considered to be temporary and has a slightly negative significance. As the main fuel, the power plant will burn coal. As a consequence, during the normal operation of the power plant, particulate matter and greenhouse gas emissions will be very high.

B. Solid Waste, Hazardous, and Special Waste and Soil Pollution

Several wastes such as packing waste, metal scrap, and surplus equipment, rooted vegetation, and excess soil will be produced during the building of the power plant. The waste produced may be a health hazard and may pollute waterways if disposed of incorrectly.

C. Water

For the cooling system, a steam power plant must operate close to a large body of water, hence there is a risk of water contamination affecting the surrounding animal life and the potential for human use.

D. Fish and Fisheries

The discharge of waste liquids into the river has an adverse effect on fishing and commercial fishing. These effluents of liquid waste can be contaminated with chemicals and should be treated before discharge. Natural dilution and dispersion in the building region will ensure a fast decrease to background levels of the suspended sediment load and elevated levels of pollutants.

G. Plant Noise

Disturbance to surrounding communities due to noise is also a major issue in the building of a power plant. Building activities will lead to higher noise levels at the project site and along the typical pipeline route of roadwork. Noise can also be produced from steam machines that blow off the atmosphere during operation.

Socio-economicc Benefits

Building a steam power plant provides some socio-economic benefits that will help satisfy present population demands without harming the capacity to satisfy the needs of future generations. The construction of power plants will most likely provide job opportunities for local people in order to have a favorable impact on the domestic economy.

Increased demand for materials, local source facilities, and work possibilities will be opened up. The project will also bring economic benefits to neighboring villages and communities like restaurants, gas stations, hotels and apartment buildings, local food markets, etc. In other words, it will have a positive indirect impact on the regional economy. The operation of the steam power plant will generate fresh taxes and revenue, helping to boost the finances and ultimately benefit the local population.

The power plant project enables a part of the production to be retained without the need to purchase carbon dioxide emission allowances related to the combustion of fuels.

Environmental Impact Mitigation Measures

The required steps will be integrated into the power plant design to avoid or minimize future environmental operational impacts. The following mitigation measures will be implemented to mitigate the potential adverse effects connected with the operation of the proposed power plant:

A. Waste Water

Water supply is one of the demands for the steam power plant's building and operation. This will be given in the project region from the creek and/or comparable water sources. As a result, the water used during building became polluted, contaminating water bodies that can influence both aquatic and human life.

It is necessary to meet and/or purchase drinking water for staff from the region's drinking water network from the market. In the wastewater treatment plant package, domestic wastewater from staff requirements will be handled.

B. Solid Waste, Hazardous, and Special Waste and Soil Pollution

The solid waste produced during the excavation and construction of the power plant, municipal solid waste such as paper and plastics and domestic organic waste from private food consumption shall be collected by the municipalities or organizations concerned separately and properly. To avoid too much waste dumping, recyclable materials must be separated from non-recyclable materials. The municipality shall periodically collect or move the solid waste to designated municipal areas. To prevent pollution of the environment, appropriate storage area, management systems, and disposal equipment shall be supplied.

Anti-degradation and Clean-up Policy

If the concentration of any parameters specified in this WQG exceeds the numerical limits for that particular parameter, the natural concentration shall not be added to that constituent. Variance to this policy shall not be made unless it can be affirmatively shown that a change is justifiable in order to provide the necessary economic or social development, that the degree of waste treatment necessary to preserve the existing quality can not be justified economically or socially, and that the current and expected uses of such water will be maintained and protected.

Important Considerations

In addition to meeting the requirements as mentioned earlier, the following provisions shall be complied with in accordance with the Water Quality Guidelines and General Effluent Standards of the Department of Environment and Natural Resources:

1) No individual shall discharge industrial effluents straight into water bodies or by using bypass channels and/or pumps and other unlawful means, entirely or partly, untreated or inadequately handled.

2) No water pollution establishment or source shall be operated in excellent order or inadequate operation without the control equipment or wastewater treatment scheme. No water pollution institution or source shall operate at concentrations beyond the operating boundaries or the capacity of the wastewater treatment facility to preserve the effluent quality in accordance with the relevant norms or conditions required by law and/or stipulated in the Discharge Permit.

3) No individual shall construct, erect, install or use any equipment, machinery or means by which an effluent discharge is concealed and/or diluted and otherwise infringes any provisions of these regulations.

4) No effluent, according to its classification, shall cause the quality of the receiving water body to drop below the recommended WQG.

5) No effluent shall be discharged into Class AA and SA waters from any point sources.

7) In order to prevent deterioration of the quality of the receiving bodies of water, no new industrial plant with high waste load potential shall discharge into a water body where the water body's dilution or assimilation capacity during dry weather is insufficient to maintain its prescribed WQG according to its classification.

Air Quality

Contractors on-site and should monitor the air mitigation steps and include at least the following:

- The removal of dust from the site will be used to avoid dust from becoming a nuisance during the building stage.
- Roads will be compacted and engraved during building if needed and maintained in good condition;
- Access roads from the site entrance will be compacted and water-sprayed to minimize the dust produced by cars and trucks;
- The building stage will start with the building of access roads to minimize the dust from car movements
- Stack and ambient air quality surveillance equipment and testing equipment shall be supplied to properly determine the nature and amount of air pollutants emitted as a consequence of the operation of the power plant.

The Clean Air Act

A plan of action for air quality control shall be formulated and implemented by the Department of Environment and Natural Resources (DENR) with public participation. The plan of action shall:

(a) Provide required equipment, techniques, systems, and processes for monitoring, compiling and analyzing information on ambient air quality to be established and operated;

(b) Include enforceable emission constraints and other control measures, means or methods, as well as compliance schedules and time tables as may be essential or suitable to comply with the relevant conditions of this Act;

(c) Include a program to provide for the following considerations:

(1) Implementation of the interventions outlined in the subparagraph;

(2) Regulating the modification and construction of any stationary source in the fields covered by the scheme in accordance with the policy on land use to guarantee that environmental air quality standards are met.

C. Noise

The following steps will mitigate the noise produced during the building. In the plant operation stage, the indoor regions will be put with the cooling scheme and turbines. The steam turbine will be the main noise source, but it will be provided with its own individual noise enclosure and noise will have no important tonal or impulsive personality. The enclosure is going to be housed within a building.

Also, consideration must be given to periodic maintenance of equipment and construction machinery. Appropriate protection instruments and equipment such as helmets, ear protectors or earplugs will be provided during both operation and construction stages to safeguard the health of employees exposed to noisy environments. To guarantee that there is no disruption at the closest residence, the plant will be situated far from the settlement fields.

CHAPTER III

ENGINEERING ECONOMIC ANALYSIS

In this chapter, the economic analysis of the proposed design of 600 MW Coal-Fired Power Plant located at Brgy. Balanga, Lemery, Batangas with the chosen design option using three catalogues (SIEMENS SST 5000 and SST 4000, and GE) is discussed and reviewed. The analysis includes the economic costing, depreciation, return of investment and other computations involved for the economic assets of the coal-fired power plant.

Power Demand Analysis

The proposed coal-fired power plant has a capacity of 600 MW. The electricity generated will be transmitted to the Luzon Grid of the National Grid Corporation of the Philippines for further distribution. According to the TransCo and National Grid Corporation (NGCP), the 2018's peak demand of Luzon Grid will exceed its peak of 10,385 Megawatts on May 2017, peaking at 10876 this June.

Table 29

Monthly System Peak Demand as of 2018 (in MW)

Month	(MW)
January	9,213
February	9,579
March	9,936
April	10,539
May	10,570
June	10,876
July	9,996
August	9,843

September	10,035
October	10,346
November	10,088
December	9,987

Source: TransCo and NGCP

This table shows the monthly peak demand in Luzon grid. The data gathered is around the year of 2018 on which the Luzon experienced a heightened increase in power demand it is given by National Grid Corporation (NGCP). Upon observing, the month of June experienced the highest peak demand at 10876 MW on which the country's temperature is at its maximum, however the month of January has the lowest peak demand on which the country's temperature is at its minimum.

Power Demand and Supply Balance

Table 30

Power Generation by Grid as of 2018 (in GWh)

Luzon	72, 728
Visayas	14, 266
Mindanao	12, 770
	Total: 99, 765

Source: DOE, Power Statistics Summary

Table 30 above presents the power generated by each grid as of 2018. The Philippines is composed of three electrical grids including the Luzon grid, Visayas Grid and the Mindanao grid. One characteristic of the grids is that most bulk generation sites are found far from the load centers, necessitating use of long distance transmission lines. The total power generated in the year 2018 amounts to 99, 765 GWh.

Table 31

Power Consumption by Sector as of 2018 (in GWh)

Residential	28, 261
Commercial	24, 016
Industrial	27, 587
Others	2, 753
Electricity Sales	82, 617
Utilities Own Use	8,141
Power Sales	9,007
Total	**99,765**

Source: DOE, Power Statistics Summary

Table 31 above presents the power consumed by each sector in the year 2018. Total electricity sales sums up to 82, 617 GWh, adding the power consumption of utilities and power sales, total power expenditure amounts to 99, 765 GWh.

Table 32

Power Generation by Source in GWh, Total Philippines (2018)

Coal	**51, 932**
Oil-Based	**3,173**
Combined Cycle	522
Diesel	2,505
Gas Turbine	0
Oil Thermal	145
Natural Gas	**21, 334**
Renewable Energy (RE)	**23, 326**

Geothermal	10, 435
Hydro	9, 384
Biomass	1, 105
Solar	1, 249
Wind	1, 153
Total	**99, 765**

Source: DOE, Power Statistics Summary

Electricity in the Philippines is produced from various sources such as coal, oil, natural gas, biomass, hydroelectric, solar, wind, and geothermal sources. The allocation of electricity production according to data from the Department of Energy Power Statistics can be seen in the table above. The total power generation amounts to 99, 765 GWh.

Table 33

Installed Generating Capacity in MW (2018)

Coal	**8, 844**
Oil-Based	**4, 292**
Natural Gas	**3, 453**
Renewable Energy(RE)	**7, 227**
Geothermal	1, 944
Hydro	3, 701
Biomass	258
Solar	896
Wind	427
Total	**23, 815**

Source: DOE, Power Statistics Summary

Table 33 above shows the installed generating capacity in MW as of 2018 by the different sources of power in the Philippines. Natural gas has an installed generating capacity of 3, 453 MW, coal has 8, 844 MW, renewable energy has 7, 227 MW. Total installed generating capacity as of 2018 amounts to 23, 815 MW.

Table 34

Dependable Generating Capacity in MW (2018)

Coal	**8, 368**
Oil-Based	**2, 995**
Natural Gas	**3, 286**
Renewable Energy(RE)	**6, 592**
Geothermal	1, 770
Hydro	3, 473
Biomass	182
Solar	740
Wind	427
Total	**21, 241**

Source: DOE, Power Statistics Summary

Table 34 above presents the data about the dependable generating capacity in MW of the different sources of energy in the Philippines. Natural Gas has a dependable capacity of 3, 286 MW, Coal has 8, 368 MW, Renewable Energy has 6, 592 MW. The generation data includes grid connected, embedded and off-grid generator.

Table 35

Peak Demand at Batangas

Name of Cooperative	Peak Demand (MW)
BATELEC I	67.34
BATELEC II	156.43
FBPC	9.03
IEEC	4.74
Total	**234.54**

Source: Department of Energy

The table shows the peak demand in each cooperative for Batangas. The BATELEC II has the highest peak demand with 156.43, constituting 66.7% of the total demand of the province. The FBPC and IEEC has the lowest peak demand with just 9.03 and 4.74 MW, respectively. The proposed 600 MW coal-fired power plant would be a great factor in increasing the power source within the Luzon Grid. With the increasing population and demand, the current source of power will be insufficient with the years to come, and one of the solutions is building a power plant to satisfy the needs of power.

Table 36

Power Consumption by Sector as of 2018 in Batangas (in MWh)

Residential	492,316
Commercial	273,870
Industrial	242,285
Others	93,117
Total	**1,101,588**

Source: DOE, Power Statistics Summary

This table presents the power consumption by each sector in the year 2018 which will be covered by the proposed 600 MW coal-fired power plant.

The energy consumed in residential sectors were 492,316 MWh, in commercial sectors were 273,870 MWh, while in industrial sectors were 242,285 MWh and others were 93,117 MWh. The total electricity sales sums up to 1,101,588 MWh.

Economic Cost

Table 37

Power Demand Analysis (SIEMENS SST 5000)

installed capacity	[MW]	600
capacity factor		0.40
Energy	GWh/year	2102.400
cost/kW	[Php/kW]	9.7599
capital cost	[Php]	317,380,808,316.37
Life	Years	25
discount rate		0.05
Capital recovery factor		0.070952457
Annual capacity cost	PHP	31,738,080,831.64
Fixed O&M	PHP	16,173,062,400.00
total fixed cost	Php	317,380,808,316.37
Fixed cost/kWh	[Php /kWh]	146,732,581.52
Variable cost/kWh	[Php /kWh]	5,139,246.785
LCOE	[Php /kWh]	21.9836457

Table 37 presents the Power Demand Analysis of Design option 3 using SIEMENS SST 5000 catalogue. The parameters included are installed capacity that has a value of 600 MW, capacity factor of 40%, and the assumed and computed energy per year, cost per kilowatt, capital cost, life years, discount rate, capital recovery factor, annual capacity cost, fixed operation and maintenance cost, total fixed cost, fixed cost per kilowatt, variable cost per kilowatt and LCOE based on the catalogue selected.

The proposed coal-fired power plant design option will be having a 365-day operation.

Table 38

Depreciation (SIEMENS SST 5000)

	Book Value(Php)	Salvage Value	Service Life (yrs)	Depreciation (BV-SV)/SL
Purchased Equipment	193,911,717,260.00	69,885,146,260.00	25	4,961,062,839.00
Instrumentation and Control	38,782,343,452.00	13,977,029,252.00	25	992,212,567.00
Service Facilities	19,391,171,726.00	6,988,514,626.00	25	496,106,283.00
Etc	29,086,757,589.00	10,482,771,939.00	25	744,159,425.00
			Total	7,193,541,117.00

Table 38 above presents the depreciation values of the purchased equipment, instrumentation and control, service facilities and auxiliary systems with a service life of 25 years.

Table 39

Return of Investment (SIEMENS SST 5000)

Year	Period	TCI	Net Income After Tax	ROI
		(Php)	(Php)	(%)
2019	2	316,888,599,133.8	45,118,262,840.00	14.2378939
2020	3	271,770,336,293.8	45,118,262,840.00	16.6016142
2021	4	226,652,073,453.8	45,118,262,840.00	19.9063975
2022	5	181,533,810,613.8	45,118,262,840.00	24.8539171
2023	6	136,415,547,773.8	45,118,262,840.00	33.0741352
2024	7	91,297,284,933.8	45,118,262,840.00	49.4190630
2025	8	46,179,022,093.8	45,118,262,840.00	97.7029412
			Average	**36.5422803**

Table 39 shows the return of investment of the proposed plant through the first 7-year service life with an average of 36.5422803% ROI. On the 6th year, the power plant will be able to return the investment with a rate of 97.%.

Table 40

Payback Period (Siemens SST 5000)

Year	Net Income after Tax (Php)	TCI (Php)	Depreciation (Php)
2019	45,118,262,840.00	316,888,599,133.8	7,193,541,117.95
2020	45,118,262,840.00	271,770,336,293.8	7,193,541,117.95
2021	45,118,262,840.00	226,652,073,453.8	7,193,541,117.95
2022	45,118,262,840.00	181,533,810,613.8	7,193,541,117.95
2023	45,118,262,840.00	91,297,284,933.8	7,193,541,117.95
2024	45,118,262,840.00	46,179,022,093.8	7,193,541,117.95
Payback Period	5 years		

Table 40 presents the depreciation through the 5-year service life of the proposed coal fired power plant and the payback period by dividing the total annual cost to the profit element. The chosen design option using the SIEMENS SST 500 catalogue has a total of 5 years of payback period.

Table 41

Sensitivity Analysis (SIEMENS SST 5000)

	Change	ENPV	EIRR
Base Case		PHP	%
Construction delay	1 year	97,456,823.15	11.674333
Reduce of Power Generation by 10%	10%	55,220,734,218	0.7643
Increase of Fuel Price by 10%	10%	83,892,331,143	8.2321
Drop of Fuel Price by 10%	10%	93,342,756,912	9.1181

Table 41 shows the sensitivity analysis using the SIEMENS SST 500 catalogue when the power generation is reduced by 10%, the fuel price is increase by 10%, and when the fuel price drop by 10%.

CASE 1. Reduce of Power Generation by 10%

The first case is a sudden reduce of the generated power by 10% in the span of 25 years is shown by the graph to find the breakeven point for design option 2 using SST 5000:

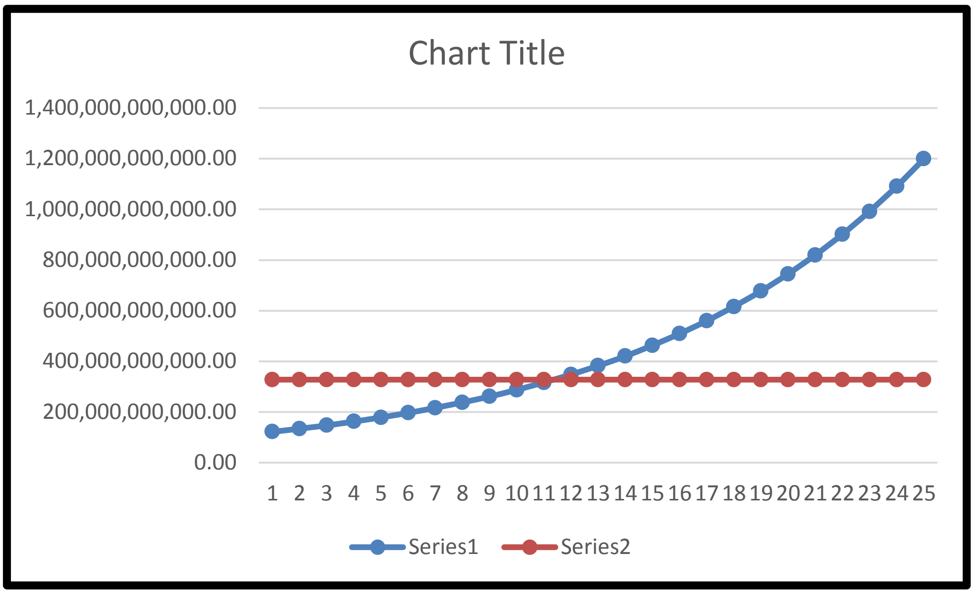

Figure 19. Break-Even Graph (Case 1/ SST 5000)

This graph shows the behavior of the cash inflow and cash outflow for design option 2 using SST 5000. The intersection point is the breakeven point in which the power plant recovers its initial capital. The breakeven point of the plant is on the 11.5th year.

CASE 2. Increase in fuel cost by 10% every year.

The second case is an increase in fuel cost by 10% in the span of 25 years is shown by the graph to find the breakeven point for design option 2 using SST 5000:

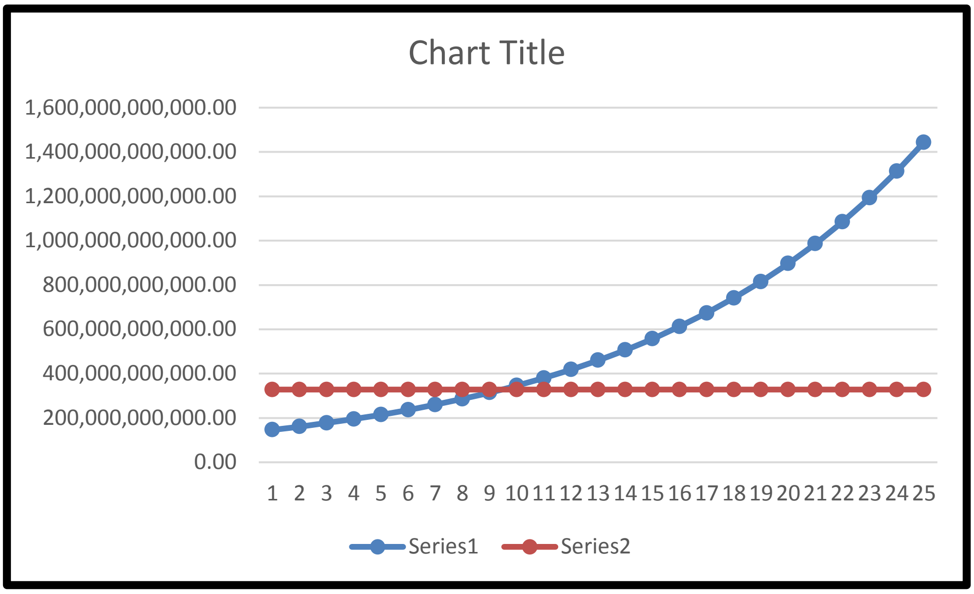

Figure 20. Break-Even Graph (Case 2/ SST 5000)

This graph shows the behavior of the cash inflow and cash outflow for design option 2 using SST 5000. The breakeven point is the intersection point in which the power plant recovers its initial capital. The breakeven point of the plant is on the 9th year.

CASE 3. Drop of fuel price by 10%

The third case is a sudden drop of fuel price by 10% in the span of 25 years is given by the graph to find the breakeven point for design option 2 using SST 5000:

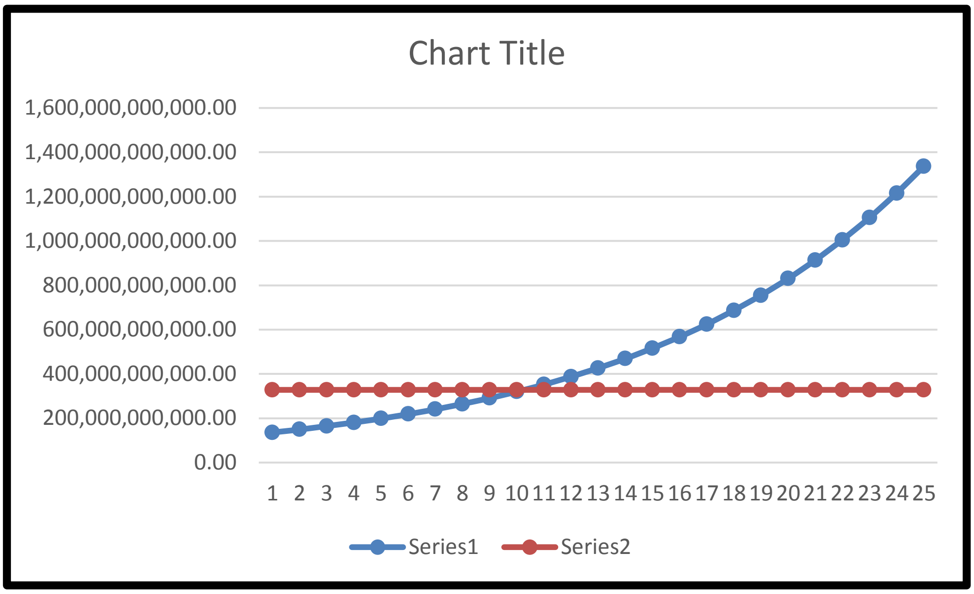

Figure 21. Break-Even Graph (Case 3/ SST 5000)

This graph shows the behavior of the cash inflow and cash outflow for design option 2 using SST 5000. The breakeven point is the intersection point in which the power plant recovers its initial capital. The breakeven point of the plant is on the 10^{th} year.

Table 42

Power Demand Analysis (SIEMENS SST 4000)

installed capacity	[MW]	600
capacity factor		0.40
Energy	GWh/year	2102.400
cost/kW	[Php/kW]	9.7599
capital cost	[Php]	323,352,682,813.56
Life	Years	25
discount rate		0.05
Capital recovery factor		0.070952457
Annual capacity cost	PHP	32,335,268,281.35
Fixed O&M	PHP	17,214,143,300.00
total fixed cost	Php	323,352,682,813.56
Fixed cost/kWh	[Php /kWh]	138,651,234.52
Variable cost/kWh	[Php /kWh]	5,923,653.164
LCOE	[Php /kWh]	23.2834761

Table 42 presents the Power Demand Analysis of Design option 2 using SIEMENS SST 4000 catalogue. The parameters included are installed capacity that has a value of 600 MW, capacity factor of 40%.

Table 43

Depreciation (Siemens SST 4000)

	Book Value(Php)	Salvage Value	Service Life (yrs)	Depreciation (BV-SV)/SL
Purchased Equipment	197,507,050,260.00	69,885,146,260.80	25	5,053,046,311.59
Instrumentation and Control	39,501,410,052.00	13,977,029,252.16	25	1,010,609,262.31
Service Facilities	19,750,705,026.00	6,988,514,626.08	25	505,304,631.15
Etc	29,626,057,539.00	10,482,771,939.12	25	757,956,946.73
			Total	7,326,917,151.81

Table 43 above presents the depreciation values of the purchased equipment, instrumentation and control, service facilities and auxiliary systems with a service life of 25 years.

Table 44

Return of Investment (Siemens SST 4000)

Year	Period	TCI	Net Income After Tax	ROI
		(Php)	(Php)	(%)
2019	2	322,748,991,923.8	45,118,262,840.00	13.97936
2020	3	277,630,729,083.8	45,118,262,840.00	16.25117
2021	4	232,512,466,243.8	45,118,262,840.00	19.40466
2022	5	187,394,203,403.8	45,118,262,840.00	24.07665
2023	6	142,275,940,563.8	45,118,262,840.00	31.71180
2024	7	97,157,677,723.8	45,118,262,840.00	46.43818
2025	8	52,039,414,883.8	45,118,262,840.00	86.70017
			Average	**34.08028**

Table 44 shows the return of investment of the proposed plant through the first 9-year service life with an average of 34.08028943% ROI. On the 7th year, the power plant will be able to return the investment with a rate of 86.70%.

Table 45

Payback Period (Siemens SST 4000)

	Net Income	TCI	Depreciation
	after Tax (Php)	(Php)	(Php)
2019	4,511,826,840.00	322,748,991,923.8	7,326,917,151.81
2020	4,511,826,840.00	277,630,729,083.8	7,326,917,151.81
2021	4,511,826,840.00	232,512,466,243.8	7,326,917,151.81
2022	4,511,826,840.00	1873,94,203,403.8	7,326,917,151.81
2023	4,511,826,840.00	142,275,940,563.8	7,326,917,151.81
2024	4,511,826,840.00	97,157,677,723.8	7,326,917,151.81
2025	4,511,826,840.00	52,039414,,883.8	7,326,917,151.81
Payback Period	6 years		

The table presents the depreciation through the 6-year service life of the proposed coal fired power plant and the payback period by dividing the total annual cost to the profit element. The chosen design option using the SIEMENS SST 4000 catalogue has a total of 6 years of payback period.

Table 46

Sensitivity Analysis (Siemens SST 4000)

	Change	ENPV	EIRR
Base Case		PHP	%
Construction delay	1 year	93,543,765.21	10.312423
Reduce of Power Generation by 10%	10%	43,110,238,275	0.69141
Increase of Fuel Price by 10%	10%	76,546,123,976	7.8364
Drop of Fuel Price by 10%	10%	84,742,528,369	8.9262

Table 46 shows the sensitivity analysis using the Siemens SST 4000 catalogue when the power generation is reduced by 10%, the fuel price is increase by 10%, and when the fuel price drop by 10%.

CASE 1. Reduce of Power Generation by 10%

The first case is a sudden reduce of the generated power by 10% in the span of 25 years is shown by the graph to find the breakeven point for design option 2 using SST 4000:

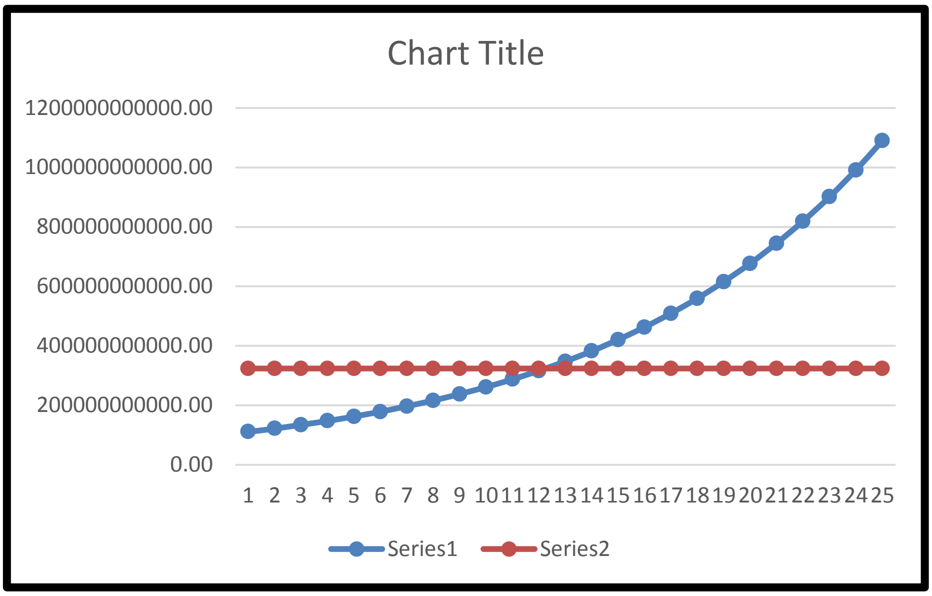

Figure 22. Break-Even Graph (Case 1/SST 4000)

This graph shows the behavior of the cash inflow and cash outflow for design option 2 using SST 4000. The intersection point is the breakeven point in which the power plant recovers its initial capital. The breakeven point of the plant is on the 12th year.

CASE 2. Increase in fuel cost by 10% every year.

The second case is an increase in fuel cost by 10% in the span of 25 years is shown by the graph to find the breakeven point for design option 2 using SST 4000:

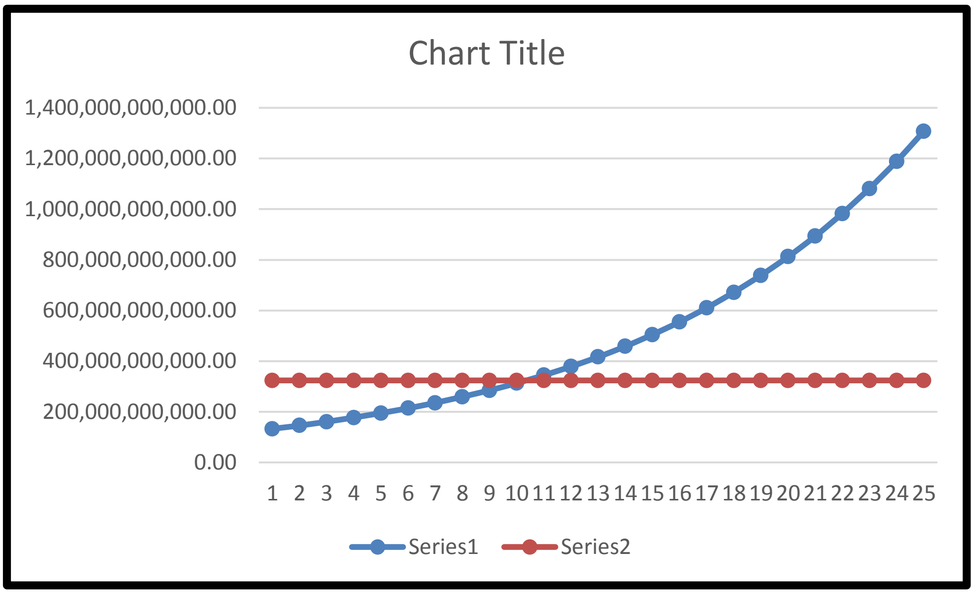

Figure 23. Break-Even Graph (Case 2/SST 4000)

This graph shows the behavior of the cash inflow and cash outflow for design option 2 using SST 4000. The breakeven point is the intersection point in which the power plant recovers its initial capital. The breakeven point of the plant is on the 10.5th year.

CASE 3. Drop of fuel price by 10%

The third case is a sudden drop of fuel price by 10% in the span of 25 years is given by the graph to find the breakeven point for design option 2 using SST 4000:

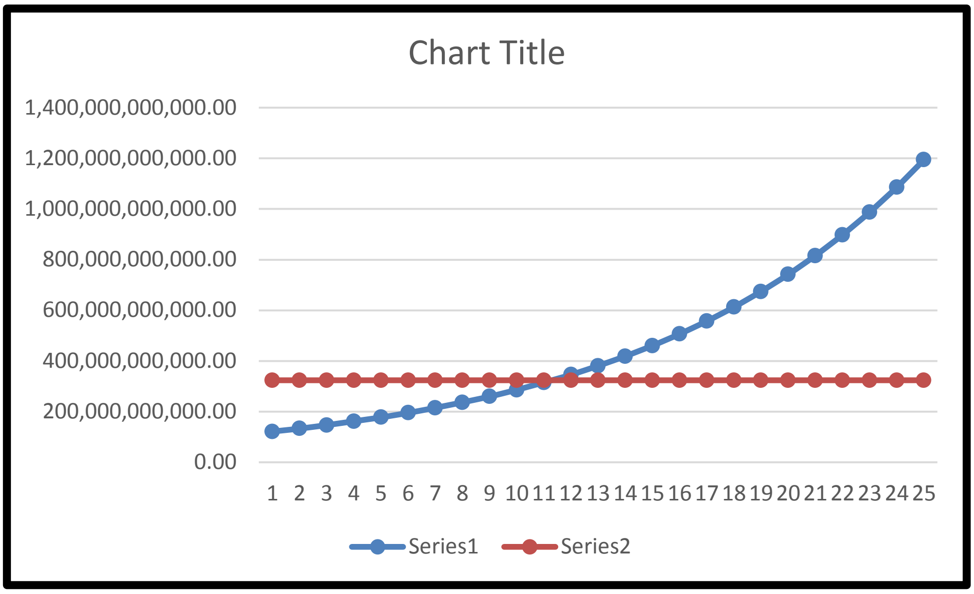

Figure 24. Break-Even Graph (Case 3/SST 4000)

This graph shows the behavior of the cash inflow and cash outflow for design option 2 using SST 5000. The breakeven point is the intersection point in which the power plant recovers its initial capital. The breakeven point of the plant is on the 11th year.

Table 47

Power Demand Analysis (GE STF D650)

installed capacity	[MW]	600
capacity factor		0.40
Energy	GWh/year	2102.400
cost/kW	[Php/kW]	9.7599
capital cost	[Php]	327,544,792,888.92
Life	Years	25
discount rate		0.05
Capital recovery factor		0.070952457
Annual capacity cost	PHP	32,754,479,288.89
Fixed O&M	PHP	18,093,264,348.00
total fixed cost	Php	327,544,792,888.92
Fixed cost/kWh	[Php /kWh]	133,631,234.52
Variable cost/kWh	[Php /kWh]	6,375,836.785
LCOE	[Php /kWh]	26.342765

Table 47 presents the Power Demand Analysis of Design option 3 using GE STF D650 catalogue. The parameters included are installed capacity that has a value of 600 MW, capacity factor of 40%, and the assumed and computed energy per year, cost per kilowatt, capital cost, life years, discount rate, capital recovery factor, annual capacity cost, fixed operation and maintenance cost, total fixed cost, fixed cost per kilowatt, variable cost per kilowatt and LCOE based on the catalogue selected. The proposed coal fired power plant design option will be having a 365-day operation.

Table 48

Depreciation (GE STF D650)

	Book Value(Php)	**Salvage Value**	**Service Life (yrs)**	**Depreciation (BV-SV)/SL**
Purchased Equipment	200,126,507,160.00	72,124,936,136.72	25	5,120,062,840.93
Instrumentation and Control	40,025,301,432.00	14424987227.34	25	1,024,012,568.18
Service Facilities	20,012,650,716.00	7,212,493,613.67	25	512,006,284.09
Etc	30,018,976,074.00	10,818,740,420.50	25	768,009,426.13
			Total	7,424,091,119.34

Table 48 above presents the depreciation values of the purchased equipment, instrumentation and control, service facilities and auxiliary systems with a service life of 25 years.

Table 49

Return of Investment (GE STF D650)

Year	**Period**	**TCI**	**Net Income After Tax**	**ROI**
		(Php)	**(Php)**	**(%)**
2019	2	327018706670.8	45,118,262,840.00	13.79684
2020	3	281900443830.8	45,118,262,840.00	16.00503
2021	4	236782180990.8	45,118,262,840.00	19.05475
2022	5	191663918150.8	45,118,262,840.00	23.54030
2023	6	146545655310.8	45,118,262,840.00	30.78785
2024	7	101427392470.8	45,118,262,840.00	44.48331
2025	8	56309129630.8	45,118,262,840.00	80.12601
			Average	**32.54201**

Table 49 shows the return of investment of the proposed plant through the first 9-year service life with an average of 32.5420166% ROI. On the 7th year, the power plant will be able to return the investment with a rate of 80.12%.

Table 50

Payback Period (GE STF D650)

Year	Net Income after Tax (Php)	TCI (Php)	Depreciation (Php)
2019	4,511,826,840.00	327018706670.8	7,326,917,151.81
2020	4,511,826,840.00	281900443830.8	7,326,917,151.81
2021	4,511,826,840.00	236782180990.8	7,326,917,151.81
2022	4,511,826,840.00	191663918150.8	7,326,917,151.81
2023	4,511,826,840.00	146545655310.8	7,326,917,151.81
2024	4,511,826,840.00	101427392470.8	7,326,917,151.81
2025	4,511,826,840.00	56309129630.8	7,326,917,151.81
Payback Period	6 years		

Table 50 presents the depreciation through the 6-year service life of the proposed coal fired power plant and the payback period by dividing the total annual cost to the profit element. The chosen design option using the GE STF D650 catalogue has a total of 6 years of payback period.

Table 51

Sensitivity Analysis (STF D650)

	Change	ENPV	EIRR
Base Case		PHP	%
Construction delay	1 year	89,001,730.15	10.674333
Reduce of Power Generation by 10%	10%	50,091,723,000	0.7198
Increase of Fuel Price by 10%	10%	81,063,172.00	7.7361
Drop of Fuel Price by 10%	10%	90,149,001,.98	8.6972

Table 51 shows the sensitivity analysis using the GE STF D650 catalogue when the power generation is reduced by 10%, the fuel price is increase by 10%, and when the fuel price drop by 10%

CASE 1. Reduce of Power Generation by 10%

The first case is a sudden reduce of the generated power by 10% in the span of 25 years is shown by the graph to find the breakeven point for design option 2 using STF D650:

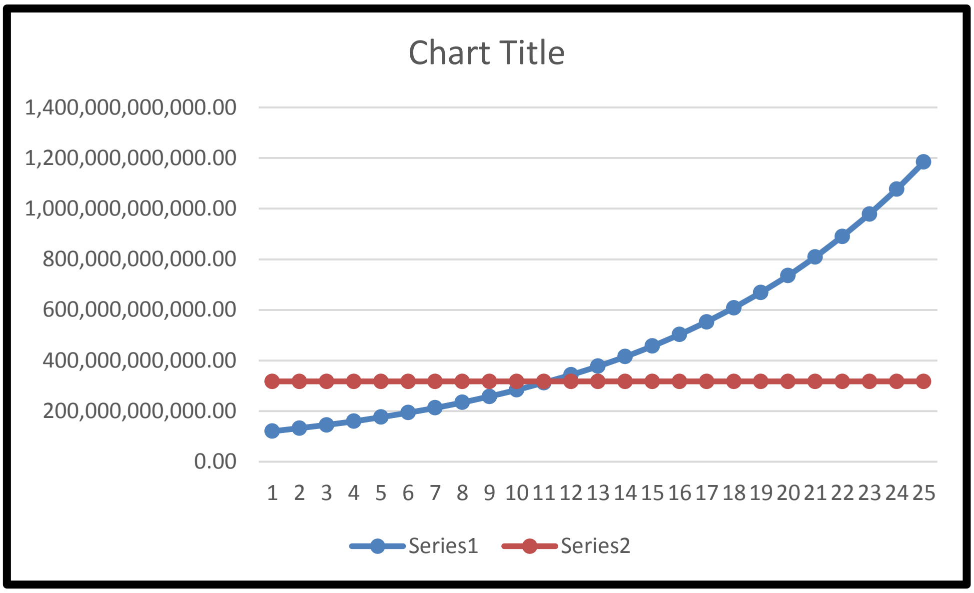

Figure 25. Break-Even Graph (Case 1/ STF D650)

This graph shows the behavior of the cash inflow and cash outflow for design option 2 using STF D650. The breakeven point is the intersection point in which the power plant recovers its initial capital. The breakeven point of the plant is on the 11th year.

CASE 2. Increase in fuel cost by 10% every year.

The second case is an increase in fuel cost by 10% in the span of 25 years is shown by the graph to find the breakeven point for design option 2 using STF D650:

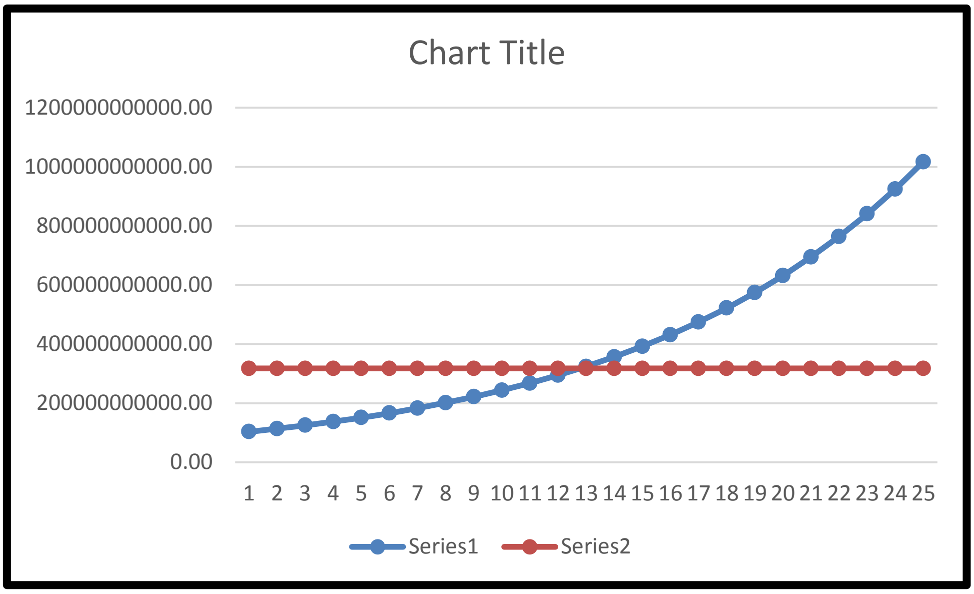

Figure 26. Break-Even Graph (Case 2/ STF D650)

This graph shows the behavior of the cash inflow and cash outflow for design option 2 using STF D650. The breakeven point is the intersection point in which the power plant recovers its initial capital. The breakeven point of the plant is on the 12.5th year.

CASE 3. Drop of fuel price by 10%

The third case is a sudden drop of fuel price by 10% in the span of 25 years is given by the graph to find the breakeven point for design option 2 using STF D650:

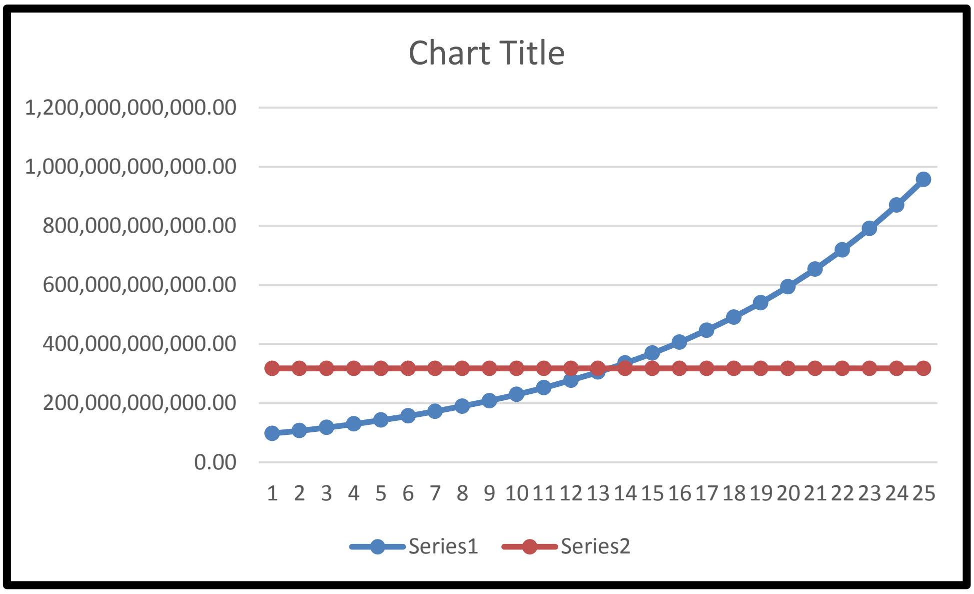

Figure 27. Break-Even Graph (Case 3/ STF D650)

This graph shows the behavior of the cash inflow and cash outflow for design option 2 using STF D650. The breakeven point is the intersection point in which the power plant recovers its initial capital. The breakeven point of the plant is on the 13^{th} year.

Table 52

Economic Analysis of the Three Catalogues (Design Option 2)

Parameters	**SIEMENS SST 5000**	**SIEMENS SST 4000**	**GE STF D650**
Cost (Php)	Php 193,911,717,260.0	Php 197,507,050,260.00	Php 200,126,507,160.00
Payback Period	5 years	6 years	6 years

Table 52 shows the summary of the economic analysis using the three catalogues in terms of the total cost and the payback period. It shows that best catalogue to use in design option two is the Siemens SST 5000 catalogue.

CHAPTER IV

OBSERVATION, COMMENTS AND RECOMMENDATIONS

This chapter presents the observations, comments, and recommendations on the design selected for the proposed 300 MW Coal-Fired Power Plant.

Observation

After the analysis and evaluation of all the data gathered, the following are the observations are listed:

The proposed location of 600 MW Coal-Fired Power Plant which is at Barangay Balanga, Lemery, Batangas was observed to be feasible and advantageous for the construction and operation of the proposed power plant. The transmission of the generated electricity of the proposed power plant for the Luzon Grid will be the responsibility of the National Grid Corporation of the Philippines (NGCP) and this company will distribute the generated electricity to the customers of the Batangas province electric cooperatives namely; BATELEC I, BATELEC II, First Bay Power Corporation (FBPC) and Ibaan Electric Engineering Corporation (IEEC) will transmit the generated electricity to within reach provinces.

Comments and Recommendations

From the data and findings of the proposed 600 MW Coal-Fired Power Plant, the following comments were made:

1. The proposed coal-fired power plant appeared in all aspects of design consideration in designing a power plant. Plant factors were determined high and satisfactory viable for the design to be considered acceptable.
2. Having a background and a broad technical knowledge about this kind of steam power plant would be a great advantage to come up with a better and acceptable design.
3. The obtained values from the calculations are within the range of the specifications of available power plant components.

4. All equipment and miscellaneous facilities were satisfactorily designed and evaluated.

5. Technical information has been at hand through the use of related references and the use of the internet, which provides the equipment catalogue and it is based on the manufacturer's specifications to get the best design possible for the proposed power plant.

For the improvement and development of the proposed 600 MW Coal-Fired Power Plant, the following recommendations were brought up:

1. Further research and evaluation of the present technologies, equipment, and operation of existing power plants are essential for more advanced and progressive design.
2. The proponents should be more familiar with each of the equipment specifications and it's functions which are important in designing and constructing a power plant.
3. Assessment of the environmental impact of the plant should be evaluated following the guidelines presented by the power development program of the national energy policy
4. Additional information through consultation with the concerned person helps the proposed power plant to enhance the design and make it possible and presentable for the actual plant construction.
5. Economic analysis must be done for the designed power plant for a better presentation of profits to attract more investors.

CHAPTER V

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APPENDIX A

COMPUTATIONS

BOILER EFFICIENCY

The losses in the boiler are made up of chimney losses(dry gas loss, moisture loss, humidity loss), unburnt losses, radiation losses, and unaccountable losses

1. Chimney Loss

The typical flue gas temperature for thermal power plants is equal to 160 ^oC, and the location's ambient temperature is 27 ^oC.

a. Dry Flue Gas Loss

$$(Ldg)\% = \frac{m_t * Cp * (T_g - T_a) * 100}{HHV}$$

$$(Ldg)\% = \frac{8.98519387 * 0.23 * (160 - 27) * 100}{22479.4704}$$

$$(\boldsymbol{Ldg})\% = \mathbf{1.222702651}\%$$

b. Moisture Loss

$$(Lm)\% = \frac{(9H_2 + m) * [H + Cp * (T_g - T_a)] * 100}{HHV}$$

$$(Lm)\% = \frac{[(9 * 0.0404) + 0.12] * [578 + 0.45 * (160 - 27)] * 100}{22479.4704}$$

$$(\boldsymbol{Lm})\% = \mathbf{1.372204302}\%$$

c. Humidity Loss

$$(Lh)\% = \frac{W_h * Cp * (T_g - T_a) * 100}{HHV}$$

$$(Lh)\% = \frac{0.02269557479 * 0.45 * (160 - 27) * 100}{22479.4704}$$

$$(\boldsymbol{Lh})\% = \mathbf{0.006042536}\%$$

2. Unburnt Loss

5% of Carbon residue was assumed

$$C_b = \frac{100 - \%\ carbon\ in\ the\ residue}{\%\ total\ carbon\ at\ inlet}$$

$$C_b = \frac{100 - 24.71}{53.48}$$

$$\boldsymbol{C_b} = \mathbf{1.407816}\ \%$$

3. Radiation Loss

Radiation Loss is assumed to contribute 1% at maximum.

4. Unaccountable Loss

Unaccountable losses was assumed to contribute 10% of losses.

Adding up all the losses:

$$(TBL)\% = Stack\ Losses_{a\ to\ c} + Unburnt\ Losses + Radiation\ Losses + Unaccountable\ Losses$$

$$(TBL)\% = (1.222702651 + 1.372204302 + 0.00560658825) + 1.407816 + 1 + 10$$

$$(\boldsymbol{TBL})\% = \mathbf{15.00876549}\%$$

Solving for the boiler efficiency:

$$n_b = 100 - \ (TBL)\%$$

$$n_b = 100 - \ 15.00832954\%$$

$$\boldsymbol{n_b} = \mathbf{84.99167046}\%$$

COAL ANALYSIS

Ultimate Analysis of Sub-Bituminous Coal

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Ave.
Hydrogen	4.39	4.41	4.29	4.46	4.04	4.318
Carbon	57.34	58.29	55.21	58.46	53.48	56.556
Nitrogen	1.07	1.05	1.01	1.07	0.99	1.038
Sulfur	0.77	0.73	0.77	0.77	0.72	0.752
Oxygen	16.6	16.45	16.13	16.44	16.06	16.336
Ash	19.83	19.07	22.59	18.8	24.71	21

$$HHV = 33820\,C + 144212\,\left(H - \frac{O}{8}\right) + 9304\,S$$

$$HHV = 33820(0.56556) + 144212\,\left(0.0413 - \frac{0.16336}{8}\right) + 9304(0.00752)$$

$$\boldsymbol{HHV = 22479.4704 kJ/kg}$$

The higher heating value with the consideration of the boiler efficiency:

$$HHV_2 = (n_b)(HHV)$$

$$HHV_2 = (0.8499167046)(22479.4704\quad)$$

$$\boldsymbol{HHV_2 = 19105.5794\ kJ/kg}$$

$$\frac{A}{F} = 11.5\,C + 34.5\,\left(H_2 - \frac{O_2}{8}\right) + 4.3\,S$$

$$A/F = 11.5(0.56556) + 34.5\left(0.0413 - \frac{0.16336}{8}\right) + 4.3(0.00752)$$

$$\boldsymbol{\frac{A}{F} = 7.321496\,\frac{kg_{air}}{kg_{fuel}}}$$

Pulverized coal fired boilers run with an average of 20% excess air to burn the fuel completely:

$$A/F_{actual} = A/F_{theo}(1+e)$$

$$A/F_{actual} = 7.321496\ kg_{air}/kg_{fuel}(1+0.2)$$

$$\boldsymbol{\frac{A}{F_{actual}} = 8.7857952\,\frac{kg_{air}}{kg_{fuel}}}$$

The ambient temperature for the municipality of Lemery is 27 ^{o}C. Computing for the humidity of air:

$$P_{sat}\ @27^{o}C = 3.567\ kPa$$

$$W_h = \frac{0.622\ P_{sat}}{101.325 - \ P_{sat}}$$

$$W_h = \frac{0.622\ (3.567)}{101.325 - 3.567}$$

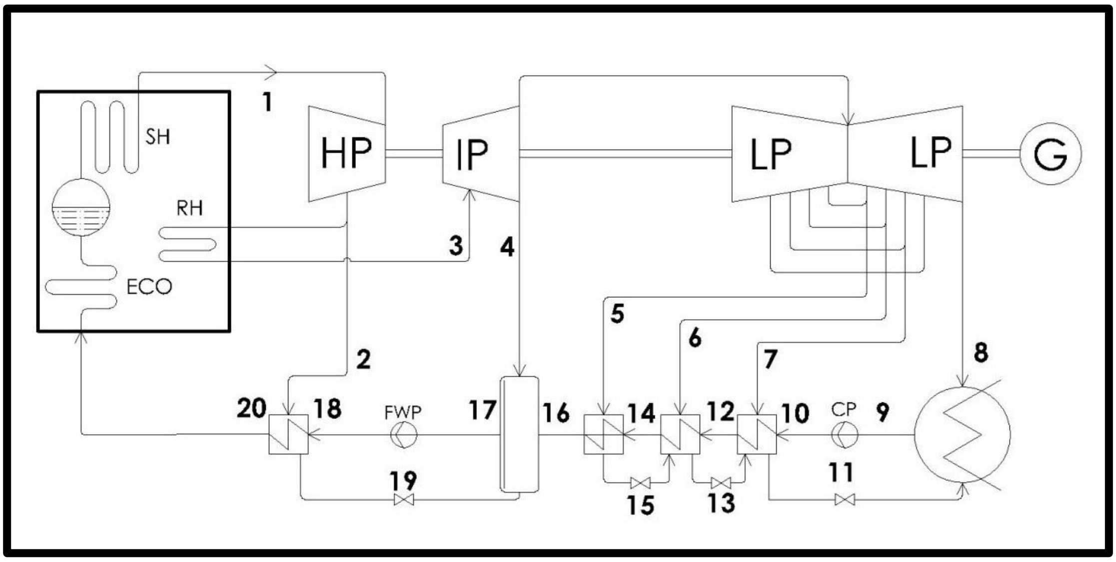
$$\boldsymbol{W_h = 0.02269557479\,\frac{kg}{kg_{dry\ air}}}$$

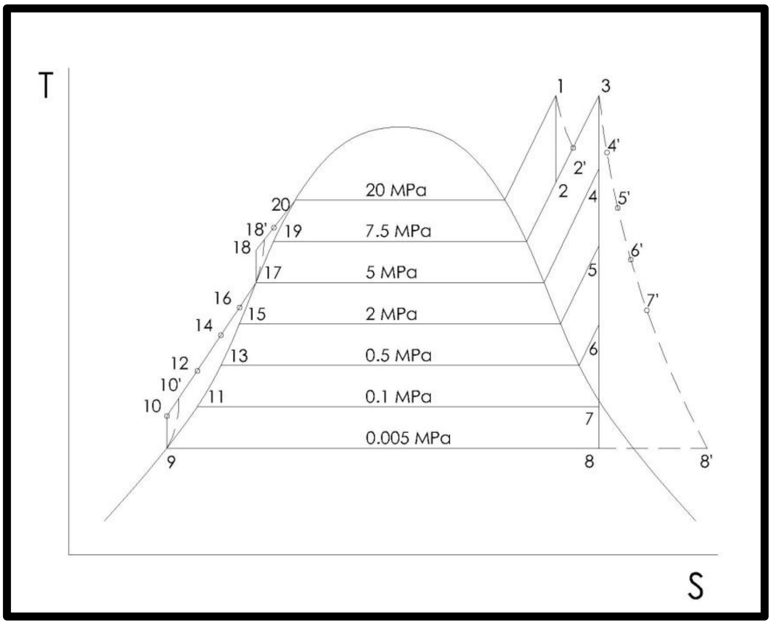
The actual air fuel ratio with consideration to excess air requirements along with the humidity of the air in the location is as follows:

$$\frac{A}{F_{actual}} = \frac{8.7857952kg_{air} + \left(\frac{0.0226957479kg_{vapor}}{1kg_{air}}\right)(8.7857952kg_{air})}{1kg_{fuel}}$$

$$\boldsymbol{\frac{A}{F_{actual}} = 8.98519387\,\frac{kg_{wet\ air}}{kg_{fuel}}}$$

Design Option 1





STATE POINT CALCULATIONS

State Point	Pressure (Mpa)	Temp. (^oC)	Enthalpy (kJ/kg)	$Mass_{steam}$ (kg/s)
1	20	540	3366.370	419.910
2	7.5	375.498	3080.280	36.005
3	7.5	540	3502.650	384.223
4	5	469.812	3363.980	348.218
5	2	330.068	3092.920	307.504

6	0.5	163.635	2775.750	278.926
7	0.1	99.6059	2498.250	237.867
8	0.005	32.8743	2119.920	237.867
9	0.005	32.8743	137.749	384.223
10	0.1	32.8768	137.845	307.504
11	0.1	99.6059	417.504	76.719
12	0.5	99.6335	417.921	307.504
13	0.5	151.831	640.085	28.578
14	2	151.999	641.724	307.504
15	2	212.377	908.498	40.715
16	5	212.935	912.028	307.504
17	5	263.941	1154.640	419.910
18	7.5	284.692	1157.856	419.910
19	7.5	290.535	1292.930	36.005
20	20	295.439	1310.326	419.910

MASS BALANCE

Mass balance for extracted steams in the turbines:

$$m_1 = \frac{m\ (h_{20} - h_{18}{}')}{h_2{}' - h_{19}}$$

$$m_1 = 0.0.084988\text{m}$$

$$m_2 = \frac{m\ (h_{17} - h_{16}) - m_1(h_{19} - h_6{}')}{h_4{}' - h_{16}}$$

$$m_2 = 0.085744m$$

$$m_3 = \frac{(m - m_1 - m_2)\ (h_{16} - h_{14})}{h_5{}' - h_{15}}$$

$$m_3 = 0.09696m$$

$$m_4 = \frac{(m - m_1 - m_2)\ (h_{14} - h_{12}) - m_3(h_{15} - h_{13})}{h_6{}' - h_{13}}$$

$$m_4 = 0.068056882m$$

$$m_5 = \frac{(m - m_1 - m_2)\ (h_{12} - h_{10}{}') - (m_3 + m_4)\ (h_{13} - h_{11})}{h_7{}' - h_{11}}$$

$$m_5 = 0.097780293m$$

SOLVING FOR THE MASS OF THE STEAM ASSUMING A TURBINE OUTPUT OF 300MW:

$$W_T = W_{1-2'} + W_{3-4'} + W_{4'-5'} + W_{5'-6'} + W_{6'-7'} + W_{7'-8'}$$

$$W_T = m\ (h_1 - h_2') + (m - m_1)\ (h_3 - h_4') + (m - m_1 - m_2)\left(h_4' - h_5'\right) + (m - m_1 - m_2 - m_3)\ (h_5' - h_6')$$

$$\boldsymbol{m = 419.9103376\ kg/s}$$

m_1 = 35.68721 kg/s

m_2 = 36.00473 kg/s

m_3 = 40.71466 kg/s

m_4 = 28.57779 kg/s

m_5 = 0.097780293kg/s

SOLVING FOR THE INDIVIDUAL WORK OF TURBINES

$$W_{1-2'} = m\ (h_1 - h_2')$$

$\boldsymbol{W_{1-2'} 63.67004 MW}$

$$W_{3-4'} = (m - m_1)\ (h_3 - h_4')$$

$$\boldsymbol{W_{3-4'} = 53.28022\ MW}$$

$$W_{4-5'} = (m - m_1 - m_2)(h_4' - h_5')$$

$$\boldsymbol{W_{4-5'} = 50.02568MW}$$

$$W_{5'-6'} = (m - m_1 - m_2 - m_3)\,(h_5{}' - h_6{}')$$

$$\boldsymbol{W_{5'-6'} = 72.45438MW}$$

$$W_{6'-7'} = (m - m_1 - m_2 - m_3 - m_4)\,(h_6{}' - h_7{}')$$

$$\boldsymbol{W_{6'-7'} = 71.91183MW}$$

$$W_{7'-8'} = (m - m_1 - m_2 - m_3 - m_4 - m_5)\,(h_7{}' - h_8{}')$$

$$\boldsymbol{W_{7'-8'} = 76.51916MW}$$

Heat added in the Boiler, Q_B

$$Q_B = m\,(h_1 - h_{20})$$

$$\boldsymbol{Q_B = 863.354\mathrm{MW}}$$

Heat added in Reheater, Q_{RH}

$$Q_{RH} = (m - m_1)\,(h_3 - h_2{}')$$

$$Q_{RH} = (356.6383313 - 15.06405705)\,(3512 - 3135.6)$$

$$\boldsymbol{Q_{RH} = 110.6208MW}$$

Total Heat Added, Q_A

$$Q_A = Q_B + Q_{RH}$$

$$\boldsymbol{Q_A = 973.9748\ MW}$$

Pump Work, W_p

$$W_{P1} = (m - m_1 - m_2)\,(h_{10}{}' - h_9)$$

$$\boldsymbol{W_{P1} = 0.026727\ MW}$$

$$W_{P2} = m\,(h_{18}{}' - h_{17})$$

$$\boldsymbol{W_{P2}} = \mathbf{1.317484}\text{MW}$$

$$W_p = W_{P1} + W_{P2}$$

$$\boldsymbol{W_p = 11.23001255\ \mathrm{MW}}$$

Net Cycle Work, W_{net}

$$W_{net} = W_T - W_p$$

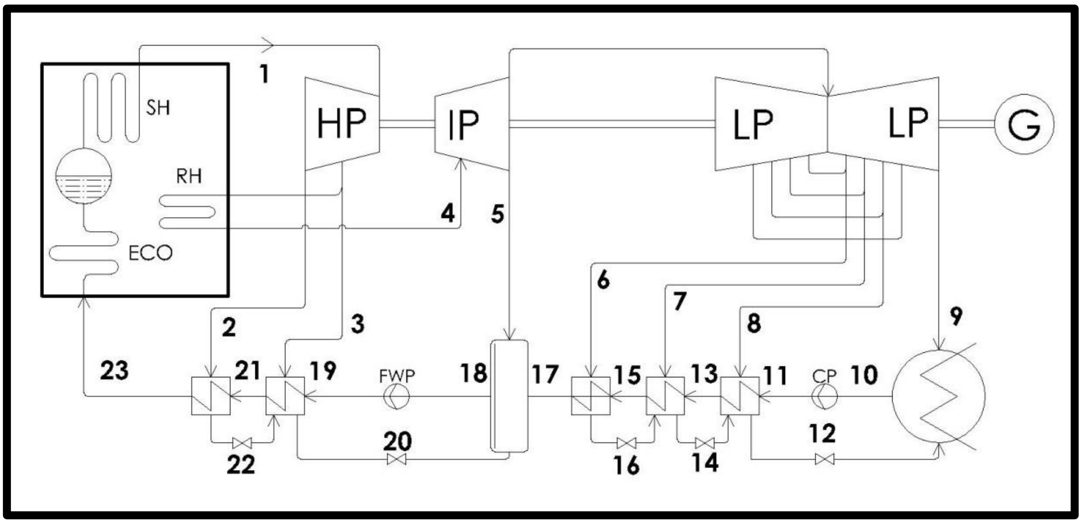
$$\boldsymbol{W_{net} = 298.6558 MW}$$

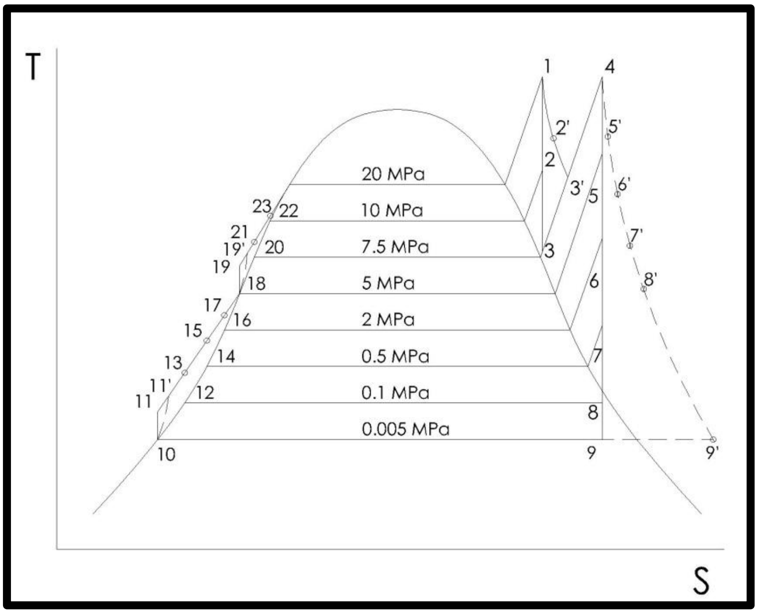
Thermal efficiency, e_{th}

$$e_{th} = \frac{W_{net}}{Q_A}\ x\ 100\%$$

$$\boldsymbol{e_{th} = 30.6636}\%$$

FOR DESIGN OPTION 2





STATE POINT CALCULATIONS

State Point	Enthalpy (kJ/kg)	Actual Enthalpy (kj/kg)
1	3366.37	
2	3157.87	3255.865
3	3080.28	3162.80495
4	3502.65	
5	3363.98	3429.1549

6	3092.62	3250.791403
7	2775.75	2999.019459
8	2498.25	2733.611646
9	2098.95	2397.240974
10	137.749	
11	137.7942	137.8021765
12	417.92126	
13	421.6766	
14	640.085	
15	656.47325	
16	908.498	
17	943.8005	
18	1154.64	
19	1186.79975	1192.475
20	1292.93	
21	1299.77105	
22	1408.06	
23	1425.49108	

Mass balance for extracted steams in the turbines:

$$m_1 = \frac{m\ (h_{23} - h_{21})}{h_2{}' - h_{22}}$$

$$m_1 = 0.068037m$$

$$m_2 = \frac{m\ (h_{21} - h_{19}{}') - m_1(h_{22} - h_{20})}{h_3{}' - h_{20}}$$

$$m_2 = 0.065475m$$

$$m_3 = \frac{m\ (h_{18} - h_{17}) - (m_1 + m_2)(h_{20} - h_{17})}{h_5{}' - h_{17}}$$

$$m_3 = 0.078099m$$

$$m_4 = \frac{(m - m_1 - m_2 - m_3)\ (h_{17} - h_{15})}{h_6{}' - h_{16}}$$

$$m_4 = 0.086768m$$

$$m_5 = \frac{(m - m_1 - m_2 - m_3)\ (h_{15} - h_{13}) - m_4\ (h_{16} - h_{14})}{h_7{}' - h_{14}}$$

$$m_5 = 0.068599m$$

$$m_6 = \frac{(m - m_1 - m_2 - m_3)\ (h_{13} - h_{11}{}') - (m_4 + m_5)\ (h_{14} - h_{12})}{h_8 - h_{12}}$$

$$m_6 = 0.081743m$$

Solving for m using energy balance in the turbine:

$$W_T = W_{1-2'} + W_{2'-3'} + W_{4-5'} + W_{5'-6'} + W_{6'-7'} + W_{7'-8'} + W_{8'-9'}$$

$$W_T = m\ (h_1 - h_2{}') + (m - m_1)\ (h_2{}' - h_3{}') + (m - m_1 - m_2)(h_4 - h_5{}') + (m - m_1 - m_2 - m_3)\ (h_5{}' - h_6{}')$$

$$+(m - m_1 - m_2 - m_3 - m_4)\ (h_6{}' - h_7{}') + (m - m_1 - m_2 - m_3 - m_4 - m_5)\ (h_7{}' - h_8{}') + (m - m_1 - m_2 - m_3 - m_4 - m_5 - m_6)\ (h_8{}' - h_9{}')$$

$$\boldsymbol{m = 402.4390128\ kg/s}$$

$$\boldsymbol{m_1 = 27.38094375\ kg/s}$$

$$\boldsymbol{m_2 = 26.34971427 kg/s}$$

$$\boldsymbol{m_3 = 31.43026046\ kg/s}$$

$$\boldsymbol{m_4 = 34.9187646\ kg/s}$$

$$\boldsymbol{m_5 = 27.60703378 kg/s}$$

$$\boldsymbol{m_6 = 32.89675604\ kg/s}$$

Solving for individual work of turbines:

$$W_{1-2'} = m\,(h_1 - h_2{}')$$

$$\boldsymbol{W_{1-2'}44.47152\ MW}$$

$$W_{2'-3'} = (m - m_1)\,(h_2 - h_3{}')$$

$$\boldsymbol{W_{2'-3'} = 34.90292MW}$$

$$W_{4-5'} = (m - m_1 - m_2)(h_4 - h_5')$$

$$\boldsymbol{W_{4-5'} = 25.62836\ MW}$$

$$W_{5'-6'} = (m - m_1 - m_2 - m_3)\,(h_5{}' - h_6{}')$$

$$\boldsymbol{W_{5'-6'} = 56.59083\ MW}$$

$$W_{6'-7'} = (m - m_1 - m_2 - m_3 - m_4)\,(h_6{}' - h_7{}')$$

$$\boldsymbol{W_{6'-7'} = 71.09016MW}$$

$$W_{7'-8'} = (m - m_1 - m_2 - m_3 - m_4 - m_5)\,(h_7{}' - h_8{}')$$

$$\boldsymbol{W_{7'-8'} = 67.61325\ MW}$$

$$W_{8'-9'} = (m - m_1 - m_2 - m_3 - m_4 - m_5 - m_6)\,(h_8{}' - h_9{}')$$

$$\boldsymbol{W_{8'-9'} = 74.6257MW}$$

Heat added in the Boiler, Q_B

$$Q_B = m\,(h_1 - h_{23})$$

$$Q_B = 421.9217944\ (3339.6 - 1488.561056)$$

$$\boldsymbol{Q_B = 781.0853966\ MW}$$

Heat added in Reheater, Q_{RH}

$$Q_{RH} = (m - m_1 - m_2)\ (h_4 - h_3{}')$$

$$Q_{RH} = (421.9217944\ - 62.00411321\ -\ 8.959184082)\ (3512 -\ 3135.6)$$

$$\boldsymbol{Q_{RH} = 118.5068083 MW}$$

Total Heat Added, Q_A

$$Q_A = Q_B + Q_{RH}$$

$$\boldsymbol{Q_A = 899.5922049\ MW}$$

Pump Work, W_p

$$W_{P1} = (m - m_1 - m_2 - m_3)\ (h_{11}{}' - h_{10})$$

$$W_{P1} = (421.9217944\ - 62.00411321\ -\ 8.959184082 - 34.28417738)(143.9713298 -\ 137.82)$$

$$\boldsymbol{W_{P1} = 0.011797495\ MW}$$

$$W_{P2} = m\ (h_{19}{}' - h_{18})$$

$\boldsymbol{W_{P2}}$ **= 13.1933806**MW

$$W_p = W_{P1} + W_{P2}$$

$$\boldsymbol{W_p = 13.2051781\ \mathrm{MW}}$$

Net Cycle Work, W_{net}

$$W_{net} =\ W_T - W_p$$

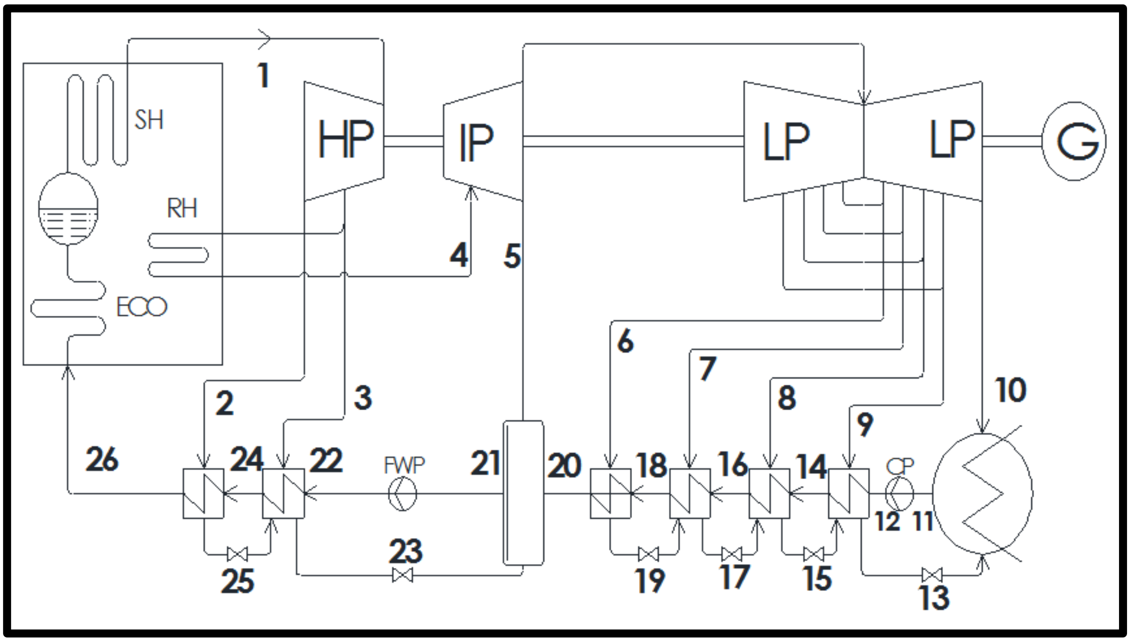
$$\boldsymbol{W_{net} = 286.7948219 MW}$$

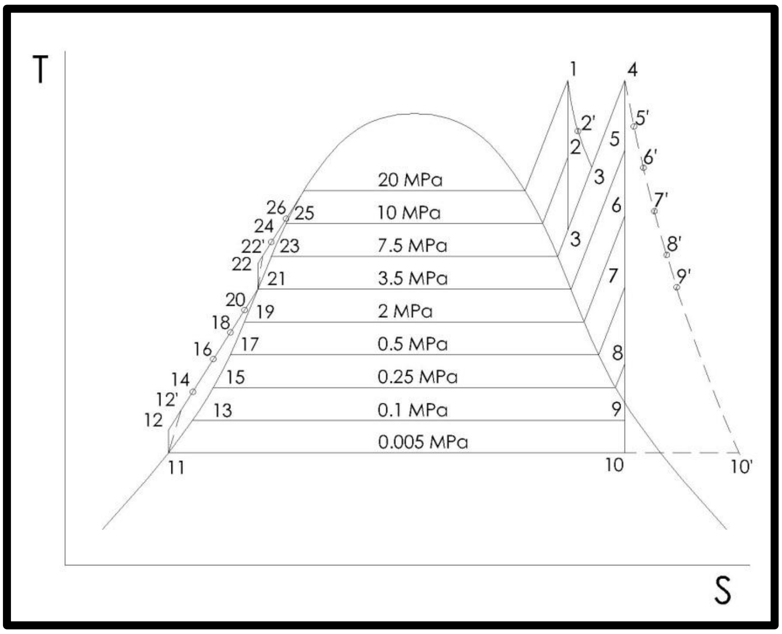
Thermal efficiency, e_{th}

$$e_{th} = \frac{W_{net}}{Q_A} \; x \; 100\%$$

$$\boldsymbol{e_{th} = 31.8805366\%}$$

FOR DESIGN OPTION 3





STATEPOINT CALCULATIONS

State Point	Enthalpy (kJ/kg)	Actual Enthalpy (kj/kg)
1	3366.37	
2	3157.87	3255.865
3	3080.28	3162.80495
4	3502.65	
5	3280.57	3384.9476
6	3082	3224.385372
7	2825.04	3012.732325
8	2693.45	2843.512693
9	2380.07	2597.888066
10	2132.64	2351.306591
11	137.749	
12	137.7942	137.8021765
13	417.504	
14	417.6604725	
15	535.245	
16	535.611805	
17	915.29	
18	916.38255	
19	844.557	
20	846.287805	
21	1008.34	
22	1053.015975	1060.899971
23	1292.93	
24	1299.77105	
25	1408.06	
26	1425.49108	

Mass balance for extracted steams in the turbines:

$$m_1 = \frac{m\,(h_{23} - h_{21})}{h_2{}' - h_{22}}$$

$$m_1 = 0.068037499m$$

$$m_2 = \frac{m\,(h_{21} - h_{19}{}') - m_1(h_{22} - h_{20})}{h_3{}' - h_{20}}$$

$$m_2 = 0.082475589m$$

$$m_3 = \frac{m\,(h_{18} - h_{17}) - (m_1 + m_2)(h_{20} - h_{17})}{h_5{}' - h_{17}}$$

$$m_3 = 0.050712856m$$

$$m_4 = \frac{(m - m_1 - m_2 - m_3)\,(h_{17} - h_{15})}{h_6{}' - h_{16}}$$

$$m_4 = 0.025265667m$$

$$m_5 = \frac{(m - m_1 - m_2 - m_3)\,(h_{15} - h_{13}) - m_4\,(h_{16} - h_{14})}{h_7{}' - h_{14}}$$

$$m_5 = 0.145861893\,m$$

$$m_6 = \frac{(m - m_1 - m_2 - m_3)\,(h_{13} - h_{11}{}') - (m_4 + m_5)\,(h_{14} - h_{12})}{h_8 - h_{12}}$$

$$m_6 = 0.068992274m$$

$$m_7 = \frac{(m - m_1 - m_2 - m_3)\,(h_{13} - h_{11}{}') - (m_4 + m_5 + m_6)\,(h_{14} - h_{12})}{h_9 - h_{13}}$$

$$m_6 = 0.089558349m$$

Solving for m using energy balance in the turbine:

$$W_T = W_{1-2'} + W_{2'-3'} + W_{4-5'} + W_{5'-6'} + W_{6'-7'} + W_{7'-8'} + W_{8'-9'} + W_{9'-10'}$$

$$W_T = m\,(h_1 - h_2{}') + (m - m_1)\,(h_2{}' - h_3{}') + (m - m_1 - m_2)(h_4 - h_5{}') + (m - m_1 - m_2 - m_3)\,(h_5{}' - h_6{}') + (m - m_1 - m_2 - m_3 - m_4)(h_6' - h_7') + (m - m_1 - m_2 - m_3 - m_4 - m_5)(h_7' - h_8') + (m - m_1 - m_2 - m_3 - m_4 - m_5 - m_6)(h_8' - h_9') + (m - m_1 - m_2 - m_3 - m_4 - m_5 - m_6 - m_7)(h_9' - h_{10}')$$

$$\boldsymbol{m = 406.4937304\ kg/s}$$

$$\boldsymbol{m_1 = 27.65681659\ kg/s}$$

$$\boldsymbol{m_2 = 33.52580983 kg/s}$$

$$\boldsymbol{m_3 = 20.61445805\ kg/s}$$

$$\boldsymbol{m_4 = 10.27033512\ kg/s}$$

$$\boldsymbol{m_5 = 59.29194521\ kg/s}$$

$$\boldsymbol{m_6 = 36.40490734\ kg/s}$$

$$\boldsymbol{m_7 = 32.89675604\ kg/s}$$

Solving for individual work of turbines:

$$W_{1-2'} = m\,(h_1 - h_2{}')$$

$$\boldsymbol{W_{1-2'} = 44.91958968\ MW}$$

$$W_{2'-3'} = (m - m_1)\,(h_2 - h_3{}')$$

$$\boldsymbol{W_{2'-3'} = 35.25458214\ MW}$$

$$W_{4-5'} = (m - m_1 - m_2)(h_4 - h_5')$$

$$\boldsymbol{W_{4-5'} = 40.64394569\ MW}$$

$$W_{5\prime-6\prime} = (m - m_1 - m_2 - m_3)\,(h_5{}' - h_6{}')$$

$$\boldsymbol{W_{5\prime-6\prime} = 52.1340169\ MW}$$

$$W_{6\prime-7\prime} = (m - m_1 - m_2 - m_3 - m_4)\,(h_6{}' - h_7{}')$$

$$\boldsymbol{W_{6\prime-7\prime} = 66.5492868\ MW}$$

$$W_{7\prime-8\prime} = (m - m_1 - m_2 - m_3 - m_4 - m_5)\,(h_7{}' - h_8{}')$$

$$\boldsymbol{W_{7\prime-8\prime} = 43.17374351\ MW}$$

$$W_{8\prime-9\prime} = (m - m_1 - m_2 - m_3 - m_4 - m_5 - m_6)\,(h_8{}' - h_9{}')$$

$$\boldsymbol{W_{8\prime-9\prime} = 55.7787587 MW}$$

$$W_{9'-10\prime} = (\mathrm{m} - \mathrm{m}_1 - \mathrm{m}_2 - \mathrm{m}_3 - \mathrm{m}_4 - \mathrm{m}_5 - \mathrm{m}_6 - m_7)\,(\mathrm{h}_9{}' - \mathrm{h}_{10})$$

$$\boldsymbol{W_{8'-9'} = 47.01927295\ MW}$$

Heat added in the Boiler, Q_B

$$Q_B = m\,(h_1 - h_{23})$$

$$Q_B = 421.9217944\ \ (3339.6 - 1488.561056)$$

$$\boldsymbol{Q_B = 788.9551125\ MW}$$

Heat added in Reheater, Q_{RH}

$$Q_{RH} = (m - m_1 - m_2)\,(h_4 - h_3{}')$$

$$Q_{RH} = (421.9217944\ - 62.00411321\ -\ 8.959184082)\,(3512 -\ 3135.6)$$

$$\boldsymbol{Q_{RH} = 128.7458499\ MW}$$

Total Heat Added, Q_A

$$Q_A = Q_B + Q_{RH}$$

$$\boldsymbol{Q_A = 917.7009625\ MW}$$

Pump Work, W_p

$$W_{P1} = (m - m_1 - m_2 - m_3)\ (h_{11}{}' - h_{10})$$

$$W_{P1} = (421.9217944 - 62.00411321 - 8.959184082 - 34.28417738)(143.9713298 - 137.82)$$

$$\boldsymbol{W_{P1} = 0.018362426\ MW}$$

$$W_{P2} = m\ (h_{19}{}' - h_{18})$$

$$\boldsymbol{W_{P2} = 10.02237336}\ \text{MW}$$

$$W_p = W_{P1} + W_{P2}$$

$$\boldsymbol{W_p = 10.04073578\ \text{MW}}$$

Net Cycle Work, W_{net}

$$W_{net} = W_T - W_p$$

$$\boldsymbol{W_{net} = 289.9592642 MW}$$

Thermal efficiency, e_{th}

$$e_{th} = \frac{W_{net}}{Q_A}\ x\ 100\%$$

$$\boldsymbol{e_{th} = 31.5962689}\%$$

FUEL CONSUMPTION AND ENVIRONMENTAL PARAMETERS

Fuel Consumption

$$\boldsymbol{m_f = \frac{Q_A}{Q_{HHV}}}$$

For Design Option 1:

$$\boldsymbol{m_f} = \frac{973974.8222}{19105.5794}$$

$$\boldsymbol{m_f = 50.97855458\ kg/s}$$

For both steam turbine units = 101.9571092 kg/s

Environmental Parameters

Carbon oxides emission, CO_x

$$m_{CO_x} = mass\ of\ CO_x * m_f$$

$$m_{CO_x} = \frac{0.5348 * 44}{12} \frac{kg_{CO_x}}{kg_{fuel}} * 50.97855458 \frac{kg_{fuel}}{s}$$

$$\boldsymbol{m_{CO_x} = 99.96554696 \frac{kg_{CO_x}}{s}}$$

Nitrogen oxides emission, NO_x

$$m_{NO_x} = mass\ of\ NO_x * m_f$$

$$m_{NO_x} = \frac{0.0099 * 46}{14} \frac{kg_{NO_x}}{kg_{fuel}} * 50.97855458\ \frac{kg_{fuel}}{s}$$

$$\boldsymbol{m_{NO_x} = 1.658259554 \frac{kg_{NO_x}}{s}}$$

Sulfur oxides emission, SO_x

$$m_{SO_x} = mass\ of\ SO_x * m_f$$

$$m_{SO_x} = \frac{0.0072 * 64}{32} \frac{kg_{SO_x}}{kg_{fuel}} * 50.97855458\ \frac{kg_{fuel}}{s}$$

$$\boldsymbol{m_{SO_x} = 0.734091186 \frac{kg_{SO_x}}{s}}$$

Ash Disposal

$$m_{ash} = \ mass\ of\ ash * m_f$$

$$m_{ash} = \ 0.2471 \frac{kg_{ash}}{kg_{fuel}} * 50.97855458\ \frac{kg_{fuel}}{s}$$

$$\boldsymbol{m_{ash} = 12.59680084 \frac{kg_{ash}}{s}}$$

For Design Option 2:

$$\boldsymbol{m_f} = \frac{899592.205}{19105.5794}$$

$$\boldsymbol{m_f = 47.08531399\ kg/s}$$

For both steam turbine units = 94.17062798 kg/s

Carbon oxides emission, CO_x

$$m_{CO_x} = mass\ of\ CO_x * m_f$$

$$m_{CO_x} = \frac{0.5348 * 44}{12} \frac{kg_{CO_x}}{kg_{fuel}} * 47.08531399 \frac{kg_{fuel}}{s}$$

$$\boldsymbol{m_{CO_x} = 92.3316171 \frac{kg_{CO_x}}{s}}$$

Nitrogen oxides emission, NO_x

$$m_{NO_x} = mass\ of\ NO_x * m_f$$

$$m_{NO_x} = \frac{0.0099 * 46}{14} \frac{kg_{NO_x}}{kg_{fuel}} * 47.08531399\ \frac{kg_{fuel}}{s}$$

$$\boldsymbol{m_{NO_x} = 1.392379999 \frac{kg_{NO_x}}{s}}$$

Sulfur oxides emission, SO_x

$$m_{SO_x} = mass\ of\ SO_x * m_f$$

$$m_{SO_x} = \frac{0.0072 * 64}{32} \frac{kg_{SO_x}}{kg_{fuel}} * 47.08531399\ \frac{kg_{fuel}}{s}$$

$$\boldsymbol{m_{SO_x} = 0.6780285215 \frac{kg_{SO_x}}{s}}$$

Ash Disposal

$$m_{ash} = \ mass\ of\ ash * m_f$$

$$m_{ash} = \ 0.2471 \frac{kg_{ash}}{kg_{fuel}} * 47.08531399\ \frac{kg_{fuel}}{s}$$

$$\boldsymbol{m_{ash} = 11.64478109 \frac{kg_{ash}}{s}}$$

For Design Option 3:

$$\boldsymbol{m_f} = \frac{917700.9625}{19105.5794}$$

$$\boldsymbol{m_f = 48.0331396\ kg/s}$$

For both steam turbine units = 96.0662792 kg/s

Carbon oxides emission, CO_x

$$m_{CO_x} = mass\ of\ CO_x * m_f$$

$$m_{CO_x} = \frac{0.5348 * 44}{12} \frac{kg_{CO_x}}{kg_{fuel}} * 48.0331396\ \frac{kg_{fuel}}{s}$$

$$\boldsymbol{m_{CO_x} = 94.18978455 \frac{kg_{CO_x}}{s}}$$

Nitrogen oxides emission, NO_x

$$m_{NO_x} = mass\ of\ NO_x * m_f$$

$$m_{NO_x} = \frac{0.0099 * 46}{14} \frac{kg_{NO_x}}{kg_{fuel}} * 48.0331396\ \frac{kg_{fuel}}{s}$$

$$\boldsymbol{m_{NO_x} = 1.562449412\,\frac{kg_{NO_x}}{s}}$$

Sulfur oxides emission, SO_x

$$m_{SO_x} = mass\ of\ SO_x * m_f$$

$$m_{SO_x} = \frac{0.0072 * 64}{32}\frac{kg_{SO_x}}{kg_{fuel}} * 48.0331396\,\frac{kg_{fuel}}{s}$$

$$\boldsymbol{m_{SO_x} = 0.7000815183\,\frac{kg_{SO_x}}{s}}$$

Ash Disposal

$$m_{ash} = mass\ of\ ash * m_f$$

$$m_{ash} = 0.2471\,\frac{kg_{ash}}{kg_{fuel}} * 48.0331396\,\frac{kg_{fuel}}{s}$$

$$\boldsymbol{m_{ash} = 11.8689888\,\frac{kg_{ash}}{s}}$$

For SST 4000:

$$\boldsymbol{m_f} = \frac{1103343.129}{19105.5794}$$

$$\boldsymbol{m_f = 57.74978638\ kg/s}$$

For both steam turbine units = 115.4995728 kg/s

Carbon oxides emission, CO_x

$$m_{CO_x} = mass\ of\ CO_x * m_f$$

$$m_{CO_x} = \frac{0.5348 * 44}{12}\frac{kg_{CO_x}}{kg_{fuel}} * 57.74978638\,\frac{kg_{fuel}}{s}$$

$$\boldsymbol{m_{CO_x} = 113.2434757\,\frac{kg_{CO_x}}{s}}$$

Nitrogen oxides emission, NO_x

$$m_{NO_x} = mass\ of\ NO_x * m_f$$

$$m_{NO_x} = \frac{0.0099 * 46}{14} \frac{kg_{NO_x}}{kg_{fuel}} * 57.74978638\ \frac{kg_{fuel}}{s}$$

$$\boldsymbol{m_{NO_x} = 1.878517962\,\frac{kg_{NO_x}}{s}}$$

Sulfur oxides emission, SO_x

$$m_{SO_x} = mass\ of\ SO_x * m_f$$

$$m_{SO_x} = \frac{0.0072 * 64}{32} \frac{kg_{SO_x}}{kg_{fuel}} * 57.74978638\,\frac{kg_{fuel}}{s}$$

$$\boldsymbol{m_{SO_x} = 0.831596844\,\frac{kg_{SO_x}}{s}}$$

Ash Disposal

$$m_{ash} = \ mass\ of\ ash * m_f$$

$$m_{ash} = \ 0.2471\,\frac{kg_{ash}}{kg_{fuel}} * 47.08531399\ \frac{kg_{fuel}}{s}$$

$$\boldsymbol{m_{ash} = 14.26997154\,\frac{kg_{ash}}{s}}$$

For STF D650:

$$\boldsymbol{m_f} = \frac{961699.0445}{19105.5794}$$

$$\boldsymbol{m_f = 50.3360314\ kg/s}$$

For both steam turbine units = 100.6720628 kg/s

Carbon oxides emission, CO_x

$$m_{CO_x} = mass\ of\ CO_x * m_f$$

$$m_{CO_x} = \frac{0.5348 * 44}{12} \frac{kg_{CO_x}}{kg_{fuel}} * 50.3360314\,\frac{kg_{fuel}}{s}$$

$$\boldsymbol{m_{CO_x} = 98.70560184\,\frac{kg_{CO_x}}{s}}$$

Nitrogen oxides emission, NO_x

$$m_{NO_x} = mass\ of\ NO_x * m_f$$

$$m_{NO_x} = \frac{0.0099 * 46}{14} \frac{kg_{NO_x}}{kg_{fuel}} * 57.74978638\ \frac{kg_{fuel}}{s}$$

$$\boldsymbol{m_{NO_x} = 1.637359193\, \frac{kg_{NO_x}}{s}}$$

Sulfur oxides emission, SO_x

$$m_{SO_x} = mass\ of\ SO_x * m_f$$

$$m_{SO_x} = \frac{0.0072 * 64}{32} \frac{kg_{SO_x}}{kg_{fuel}} * 57.74978638 \frac{kg_{fuel}}{s}$$

$$\boldsymbol{m_{SO_x} = 0.7248388522\, \frac{kg_{SO_x}}{s}}$$

Ash Disposal

$$m_{ash} = \ mass\ of\ ash * m_f$$

$$m_{ash} = \ 0.2471 \frac{kg_{ash}}{kg_{fuel}} * 47.08531399\ \frac{kg_{fuel}}{s}$$

$$\boldsymbol{m_{ash} = 12.43803336\, \frac{kg_{ash}}{s}}$$

COMPUTATIONS OF OTHER COMPONENTS

Coal Storage Facility

$$\boldsymbol{m_f = 47.08531399\ kg/s}$$

$$\boldsymbol{\rho_f = 1330\mathrm{kg}/m^3}$$

For 1 month storage of coal:

$$\boldsymbol{V_f = 47.08531399 \frac{kg}{s} x \frac{3600\ s}{1\ hr} x \frac{24hr}{1\ day} x \frac{30\ days}{1\ month} x \frac{1\ m^3{}_f}{1330\ kg_f} x2\ units}$$

$$\boldsymbol{V_f = 183526.5171\ m^3/month}$$

The coal storage facility has an area of 260mx125mx2=65000m^2.

To determine the height of the storage area:

$$\boldsymbol{H_{cs} = \frac{V_f}{A_{cs}}}$$

$$\boldsymbol{H_{cs} = \frac{183526.5171\ m^3}{65000m2}}$$

$$\boldsymbol{H_{cs} = 2.823848m^3}$$

The height of the coal storage area was approximated to 3m.

Chimney

$$m_f = 47.08531399\ kg/s$$

$$\frac{A}{F_{actual}} = 8.98519387 \frac{kg_{wet\ air}}{kg_{fuel}}$$

$$\frac{m_{fg}}{m_f} = 9.98519387 \frac{kg_{flue\ gas}}{kg_{fuel}}$$

$$m_{fg} = (47.08531399\ kg/s)\left(9.98519387 \frac{kg_{flue\ gas}}{kg_{fuel}}\right)$$

$$\boldsymbol{m_{fg} = 470.1559387\ kg/s}$$

Assume exit temperature = 150 ^{o}C, M_{fg} = 30

$$\rho_{fg} = \frac{P}{RT}$$

$$\rho_{fg} = \frac{101.325kPa}{\frac{8.314 \frac{kJ}{kg-K}}{30}(150+273)K}$$

$$\rho_{fg} = 0.8643457\text{kg}/m^3$$

$$Q_{fg} = \frac{m_{fg}}{\rho_{fg}}$$

$$Q_{fg} = \frac{470.1559387\ kg/s}{0.8643457\text{kg}/m^3}$$

$$\boldsymbol{Q_{fg} = 543.9443206 m^3/s}$$

For chimney diameter:

Maximum allowable exit velocity=7.5m/s

$$Q = AV$$

$$543.9443206 m^3/s = \frac{\pi}{4} D^2 (7.5 m/s)$$

$$\boldsymbol{D = 9.6095 m^2 \approx 10 m^2}$$

For chimney pressure drop:

Chimney height =220m

$$P.D. = H(\rho_o - \rho_{fg})g$$

Air density at 27 ^oC, 61% humidity, 101.4kPa

ρ_o=1.171kg/m^3

$$P.D. = (220m)(1.171\text{kg/m3} - 0.8643457\text{kg}/m^3)(9.81 m/s^2)$$

$$\boldsymbol{P.D. = 706.9033026 Pa}$$

Cooling Water Requirement

$$\text{Ave. cooling water requirement} = m_s(65\ to\ 70)$$

$$\text{Ave. cooling water requirement} = 317.278\text{kg/s}(65\ to\ 70)$$

$$\text{Ave. cooling water requirement} \approx 21000\text{kg/s}$$

@ Balayan Bay; water temp T_1=30 ^oC

@ Statepoint 9, h=2397.241 kJ/kg; @ Statepoint 10. h=137.802kJ/kg

Pump flowrate =50m^3/s(utilized); 50.47222 m^3/s(max)

Density of water at 30 ^{o}C = 995.67kg/m^3

$$Q_{fg} = \frac{m_w}{\rho_{fg}}$$

$$50m^3/\mathrm{s} = \frac{m_w}{995.67\mathrm{kg}/m^3}$$

$$m_w = 49783.5kg/s$$

$$m_w C_p \Delta T = m_s \Delta h$$

$$(49783.5kg/s)\left(\frac{4.18kJ}{kg-K}\right)\Delta T = (317.278\mathrm{kg/s})\left(2397.241\frac{\mathrm{kJ}}{\mathrm{kg}} - 137.802\mathrm{kJ/kg}\right)$$

$$\boldsymbol{\Delta T = 3.444917K}$$

DENR permits a temperature increase of 3 ^{o}C for waste water disposal, therefore waste water should be cooled by 0. 444917 ^{o}C before exit.

ENGINEERING ECONOMIC ANALYSIS

Using Siemens SST 5000 catalogue

Design Option 2

Power Demand Analysis

installed capacity	[MW]	600
capacity factor		0.40
Energy	GWh/year	2102.400
cost/kW	[Php/kW]	9.7599
capital cost	[Php]	317,380,808,316.37
Life	Years	25
discount rate		0.05
Capital recovery factor		0.070952457
Annual capacity cost	PHP	31,738,080,831.64
Fixed O&M	PHP	164,173,062,400.00
total fixed cost	Php	317,380,808,316.37
Fixed cost/kWh	[Php /kWh]	146,732,581.52
Variable cost/kWh	[Php /kWh]	5,139,246.785
LCOE	[Php /kWh]	21.9836457

Depreciation

	Book Value(Php)	Salvage Value	Service Life (yrs)	Depreciation (BV-SV)/SL
Purchased Equipment	193,911,717,260.00	69,885,146,260.00	25	4,961,062,839.00
Instrumentation and Control	38,782,343,452.00	13,977,029,252.00	25	992,212,567.00
Service Facilities	19,391,171,726.00	6,988,514,626.00	25	496,106,283.00
Etc	29,086,757,589.00	10,482,771,939.00	25	744,159,425.00
			Total	7,193,541,117.00

Return of Investment

Year	Period	TCI (Php)	Net Income After Tax (Php)	ROI (%)
2019	2	316,888,599,133.8	45,118,262,840.00	14.2378939
2020	3	271,770,336,293.8	45,118,262,840.00	16.6016142
2021	4	226,652,073,453.8	45,118,262,840.00	19.9063975
2022	5	181,533,810,613.8	45,118,262,840.00	24.8539171
2023	6	136,415,547,773.8	45,118,262,840.00	33.0741352
2024	7	91,297,284,933.8	45,118,262,840.00	49.4190630
2025	8	46,179,022,093.8	45,118,262,840.00	97.7029412

			Average	**36.5422803**

Payback Period

Year	**Net Income after Tax (Php)**	**TCI (Php)**	**Depreciation (Php)**
2019	45,118,262,840.00	316,888,599,133.8	7,193,541,117.95
2020	45,118,262,840.00	271,770,336,293.8	7,193,541,117.95
2021	45,118,262,840.00	226,652,073,453.8	7,193,541,117.95
2022	45,118,262,840.00	181,533,810,613.8	7,193,541,117.95
2023	45,118,262,840.00	91,297,284,933.8	7,193,541,117.95
2024	45,118,262,840.00	46,179,022,093.8	7,193,541,117.95
Payback Period		5 years	

Sensitivity Analysis

	Change	ENPV	EIRR
Base Case		PHP	%
Construction delay	1 year	97,456,823.15	11.674333
Reduce of Power Generation by 10%	10%	55,220,734,218	0.7643
Increase of Fuel Price by 10%	10%	83,892,331,143	8.2321
Drop of Fuel Price by 10%	10%	93,342,756,912	9.1181

Economical Parameters

A. Land Cost

Land Cost = Total Land Area x current land cost

Land Cost = 325,000 m^2 (Php2500/m^2)

Land Cost = PHP 812,500,000.00

B. Equipment Cost

Total PHP 193,911,717,260.00

C. Electrical Cost

Electrical Cost = Equipment Cost x 25%

For Design Option 1

Electrical Cost = PHP 193,911,717,260.00 x 0.25
Electrical Cost = PHP 38,782,343,452.00

D. Building Cost

For Design Option 1

Building Cost = Equipment Cost x 33%

Building Cost = PHP 193,911,717,260.00 x 0.33

Building Cost = PHP 63,990,866,695.8

E. Miscellaneous Cost

Miscellaneous Cost = Equipment Cost x 10%

Miscellaneous Cost = PHP 193,911,717,260.00 x 0.1

Miscellaneous Cost = **PHP 19,391,171,726.00**

F. Total Capital Expenditures Cost

Total Capital Expenditures Cost = ∑ cost of sub-parameters

For Design Option 1

Total = PHP 316,888,599,133.8

Operating Expenditure

A. Fuel Cost

HHV = 18311.95989 kJ/kg

Fuel Flow = 169507.1304 kg/hr

Electrical Power = 300,000 kW

Heat Rate = $\frac{\text{Fuel Flow x HHV}}{\text{Electrical Power}}$

Heat Rate = $\frac{169{,}507.1304\ \frac{\text{kg}}{\text{hr}} \text{ x } 18{,}311.95989\ \text{kJ/kg}}{300{,}000\ \text{kW}}$

Heat Rate = 10346.692588 kJ/kW-hr

Lignite coal price = $ 18.51/short ton (2000 lbs) = PHP 2.755267423/kg

Capacity = Electrical Power x 24 hr

Capacity = 300,000 kW x 24 hr

Capacity = 7,200,000 kW-hr

Fuel Cost = $\frac{\text{PHP } 2.755267423}{10{,}592.3849 \text{ kJ/kg}}\ x\ 10346.692588\,\frac{\text{kJ}}{\text{kW}-\text{hr}}\ x$ 7,200,000 kW-hr x (2 units)

Fuel Cost = **PHP 22,417,798.77**

B. Labor Cost

Labor Cost = Fuel Cost x 20%

Labor Cost = PHP 22,417,798.77 x 20%

Labor Cost = **PHP 4,483,559.754**

C. Maintenance and Repair

Maintenance and Repair = Fuel Cost x 20%

Maintenance and Repair = PHP 22,417,798.77 x 20%

Maintenance and Repair = **PHP 4,483,559.754**

D. Supplies Cost

Supply Cost = Fuel Cost x 10%

Supply Cost = PHP 22,417,798.77 x 10%

Supply Cost = **PHP 2,241,779.87**

E. Supervision Cost

Supervision Cost = Fuel Cost x 20%

Supervision Cost = PHP 22,417,798.77 x 20%

Supervision Cost = **PHP 4,483,559.754**

F. Operating Taxes

Operating Taxes = Fuel Cost x 10%

Operating Taxes = PHP 22,417,798.77 x 10%

Operating Taxes = **PHP 2,241,779.87**

G. Total Operating Expenditure

Total = PHP 40,352,037.786

H. Depreciation

$$\text{Depreciation Rate} = \frac{1 \text{ year}}{n} \times 100$$

$$\text{Depreciation Rate} = \frac{1 \text{ year}}{25 \text{ years}} \times 100$$

Depreciation Rate = 4%

Solving for the Salvage Value of the Plant

Salvage Value = Capital Expenditures x (1 - Depreciation Rate) ^{n}

Where n = Salvage Life of the Plant

Solving for the Plant Salvage Value

Salvage Value = Capital Expenditures x (1 - Depreciation Rate) ^{n}

Salvage Value = PHP 316,888,599,133.8 x (1 - 4%)^{25}

Salvage Value = PHP 114,205,610,737.558

$$\text{Annual Plant Depreciation} = \frac{\text{Total Capital Cost} - \text{Salvage Value}}{n}$$

n = maximum useful life of the plant

$$\text{Annual Plant Depreciation} = \frac{\text{PHP } 316{,}888{,}599{,}133.8 - \text{PHP } \mathbf{114{,}205{,}610{,}737.558}}{25}$$

Annual Plant Depreciation = **PHP 8,107,319,535.84/year**

I. Revenue

Annual revenue = Power Generation Rate x Actual Plant Output

Annual Revenue = PHP 9.7599/kW-hr x (600,000 kW x 0.915) (8760hrs/yr)

Annual Revenue = **PHP 46,937,701,480.00**

J. Net Present Value

Net Present Value = Future Cash Flow – Total Capital Cost

Where:

Future Cash Flow = Future Revenue+ Salvage Value

Total Capital Cost = Initial Capital Cost +Operating Cost

$$\text{Future Revenue} = \text{Annual Revenue} \times \frac{1-(1+\text{roi})^{n}}{\text{roi}}$$

roi (Rate of Investment) = 4%

n (maximum useful life) = 25

Future Revenue = PHP 46,937,701,480.00 x $\frac{1\text{-}1.04^{-25}}{0.04}$

Future Revenue = **PHP 572,540,296,410.542**

Salvage Value = Annual Revenue x $(1+\text{roi})^{-n}$

Salvage Value = PHP **46,937,701,480.00** x $(1+0.04)^{-25}$

Salvage Value = **PHP 9,722,582,213.31**

Future Cash Flow = PHP 572,540,296,410.542 + PHP 9,722,582,213.31

Future Cash Flow = **PHP 582,262,878,623.857**

Operating Cost = Operating Expenditures x $\frac{1-(1+\text{roi})^{-n}}{\text{roi}}$

Operating Cost = PHP 40,352,037.79 $x\,\frac{1-(1.04)^{-25}}{0.04}$

Operating Cost = **PHP 492,209,182.56**

Solving for the Total Capital Cost

Total Capital Cost = PHP 316,888,599,133.8+ PHP 492,209,182.56

Total Capital Cost = PHP 317,380,808,316.367

Net Present Value = PHP 582,262,878,623.857- PHP 317,380,808,316.367

Net Present Value = PHP 264,882,070,307.489

K. Payback Period

Payback Period = $\frac{\text{Capital Cost}}{\text{Annual Revenue}-\text{Operating Expenditures}}$

For Design Option 1

Payback Period = $\frac{\text{PHP } 316{,}888{,}599{,}133.8}{\text{PHP } 46{,}937{,}701{,}480.00-(\text{PHP } 40{,}352{,}037.786+8{,}107{,}319{,}535.84)}$

Payback Period = 5. 16933113737663 Years

L. Return of Investment (ROI)

$$\text{ROI} = \frac{\text{Profit Gain}}{\text{Total Capital Cost}}$$

$$\text{Return of Investment} = \frac{46{,}937{,}701{,}480.00\text{- (PHP } 40{,}352{,}037.786 + \text{PHP } 8{,}107{,}319{,}535.84/\text{year})}{\text{PHP } 316{,}888{,}599{,}133.8} \text{ x } 100$$

Return of Investment = 12.2409042%

Using SIEMENS SST 4000 catalogue

Design Option 2

Power Demand Analysis

installed capacity	[MW]	600
capacity factor		0.40
Energy	GWh/year	2102.400
cost/kW	[Php/kW]	9.7599
capital cost	[Php]	323,352,682,813.56
Life	Years	25
discount rate		0.05
Capital recovery factor		0.070952457
Annual capacity cost	PHP	32,335,268,281.35
Fixed O&M	PHP	176,214,143,300.00
total fixed cost	Php	323,352,682,813.56
Fixed cost/kWh	[Php /kWh]	138,651,234.52
Variable cost/kWh	[Php /kWh]	5,923,653.164

Depreciation

	Book Value(Php)	**Salvage Value**	**Service Life (yrs)**	**Depreciation (BV-SV)/SL**
Purchased Equipment	197,507,050,260.00	69,885,146,260.80	25	5,053,046,311.59
Instrumentation and Control	39,501,410,052.00	13,977,029,252.16	25	1,010,609,262.31
Service Facilities	19,750,705,026.00	6,988,514,626.08	25	505,304,631.15
Etc	29,626,057,539.00	10,482,771,939.12	25	757,956,946.73
			Total	7,326,917,151.81

Return of Investment

Year	**Period**	**TCI**	**Net Income After Tax**	**ROI**
		(Php)	**(Php)**	**(%)**

2019	2	322,748,991,923.8	45,118,262,840.00	13.97936
2020	3	277,630,729,083.8	45,118,262,840.00	16.25117
2021	4	232,512,466,243.8	45,118,262,840.00	19.40466
2022	5	187,394,203,403.8	45,118,262,840.00	24.07665
2023	6	142,275,940,563.8	45,118,262,840.00	31.71180
2024	7	97,157,677,723.8	45,118,262,840.00	46.43818
2025	8	52,039,414,883.8	45,118,262,840.00	86.70017
			Average	**34.08028**

Payback Period

	Net Income after Tax (Php)	TCI (Php)	Depreciation (Php)
2019	4,511,826,840.00	322,748,991,923.8	7,326,917,151.81
2020	4,511,826,840.00	277,630,729,083.8	7,326,917,151.81
2021	4,511,826,840.00	232,512,466,243.8	7,326,917,151.81
2022	4,511,826,840.00	1873,94,203,403.8	7,326,917,151.81
2023	4,511,826,840.00	142,275,940,563.8	7,326,917,151.81
2024	4,511,826,840.00	97,157,677,723.8	7,326,917,151.81
2025	4,511,826,840.00	52,039414,,883.8	7,326,917,151.81
Payback Period	6 years		

Sensitivity Analysis

	Change	ENPV	EIRR
Base Case		PHP	%
Construction delay	1 year	93,543,765.21	10.312423
Reduce of Power Generation by 10%	10%	43,110,238,275	0.69141
Increase of Fuel Price by 10%	10%	76,546,123,976	7.8364
Drop of Fuel Price by 10%	10%	84,742,528,369	8.9262

Economical Parameters

A. **Land Cost**

Land Cost = Total Land Area x current land cost

Land Cost = 325,000 m^2 (Php2500/m^2)

Land Cost = PHP 812,500,000.00

B. Equipment Cost

Total PHP 197,507,050,260.00

C. Electrical Cost

Electrical Cost = Equipment Cost x 25%

For Design Option 1

Electrical Cost = PHP 197,507,050,260.00x 0.20
Electrical Cost = PHP 39,501,410,052.00

D. Building Cost

For Design Option 1

Building Cost = Equipment Cost x 33%

Building Cost = PHP 197,507,050,260.00x 0.33

Building Cost = PHP 65,177,326,585.8

E. Miscellaneous Cost

Miscellaneous Cost = Equipment Cost x 10%

Miscellaneous Cost = PHP 197,507,050,260.00x 0.1

Miscellaneous Cost = **PHP 19,750,705,026.00**

F. Total Capital Expenditures Cost

Total Capital Expenditures Cost = ∑ cost of sub-parameters

Total = PHP 322,748,991,923.8

Operating Expenditure

A. Fuel Cost

HHV = 18311.95989 kJ/kg

Fuel Flow = 207899.2302kg/hr

Electrical Power = 300,000 kW

Heat Rate = $\frac{\text{Fuel Flow x HHV}}{\text{Electrical Power}}$

Heat Rate = $\frac{207{,}899.2302\frac{\text{kg}}{\text{hr}} \text{ x } 18{,}311.95989\ \text{kJ/kg}}{300{,}000\ \text{kW}}$

Heat Rate = 12,690.14124 kJ/kW-hr

Lignite coal price = $ 18.51/short ton (2000 lbs) = PHP 2.755267423/kg

Capacity = Electrical Power x 24 hr

Capacity = 300,000 kW x 24 hr

Capacity = 7,200,000 kW-hr

Fuel Cost = $\frac{\text{PHP } 2.755267423}{10{,}592.3849\ \text{kJ/kg}}\ x\ \ 12690.14124\ \frac{\text{kJ}}{\text{kW}-\text{hr}}\ x$ 7,200,000 kW-hr x (2 units)

Fuel Cost = **PHP 27,495,262.92**

B. Labor Cost

Labor Cost = Fuel Cost x 20%

Labor Cost = PHP 27,495,262.92x 20%

Labor Cost = **PHP 5,499,052.584**

C. Maintenance and Repair

Maintenance and Repair = Fuel Cost x 20%

Maintenance and Repair = PHP 27,495,262.92 x 20%

Maintenance and Repair = **PHP 5,499,052.584**

D. Supplies Cost

Supply Cost = Fuel Cost x 10%

Supply Cost = PHP 27,495,262.92x 10%

Supply Cost = **PHP 2,749,526.292**

E. Supervision Cost

Supervision Cost = Fuel Cost x 20%

Supervision Cost = PHP 27,495,262.92x 20%

Supervision Cost = **PHP 5,499,052.584**

F. Operating Taxes

Operating Taxes = Fuel Cost x 10%

Operating Taxes = PHP 27,495,262.92x 10%

Operating Taxes = **PHP 2,749,526.292**

G. Total Operating Expenditure

Total = PHP 49,491,473.256

H. Depreciation

$$\text{Depreciation Rate} = \frac{1\text{ year}}{n} \times 100$$

$$\text{Depreciation Rate} = \frac{1\text{ year}}{25\text{ years}} \times 100$$

Depreciation Rate = 4%

Solving for the Salvage Value of the Plant

Salvage Value = Capital Expenditures x (1 - Depreciation Rate) ^{n}

Where n = Salvage Life of the Plant

Solving for the Plant Salvage Value

Salvage Value = Capital Expenditures x (1 - Depreciation Rate) ^{n}

Salvage Value = PHP 322,748,991,923.8x (1 - 4%)^{25}

Salvage Value = PHP 116,317,677,058.573

$$\text{Annual Plant Depreciation} = \frac{\text{Total Capital Cost} - \text{Salvage Value}}{n}$$

n = maximum useful life of the plant

$$\text{Annual Plant Depreciation} = \frac{\text{PHP } 322{,}748{,}991{,}923.8 - \text{PHP } 116{,}317{,}677{,}058.573}{25}$$

Annual Plant Depreciation = **PHP 8,257,252,594.6091/year**

I. Revenue

Annual revenue = Power Generation Rate x Actual Plant Output

Annual Revenue = PHP 9.7599/kW-hr x (600,000 kW x 0.915) (8760hrs/yr)

Annual Revenue = **PHP 46,937,701,480.00**

J. Net Present Value

Net Present Value = Future Cash Flow – Total Capital Cost

Where:

Future Cash Flow = Future Revenue+ Salvage Value

Total Capital Cost = Initial Capital Cost +Operating Cost

Future Revenue = Annual Revenue x $\frac{1-(1+roi)^{n}}{roi}$

roi (Rate of Investment) = 4%

n (maximum useful life) = 25

Future Revenue = PHP 46,937,701,480.00 x $\frac{1\text{-}1.04^{-25}}{0.04}$

Future Revenue = **PHP 572,540,296,410.542**

Salvage Value = Annual Revenue x $(1+roi)^{-n}$

Salvage Value = PHP **46,937,701,480.00** x $(1+0.04)^{-25}$

Salvage Value = **PHP 9,722,582,213.31**

Future Cash Flow = PHP 572,540,296,410.542 + PHP 9,722,582,213.31

Future Cash Flow = **PHP 582,262,878,623.857**

Operating Cost = Operating Expenditures x $\frac{1-(1+roi)^{-n}}{roi}$

Operating Cost = PHP 49,491,473.256$x\,\frac{1-(1.04)^{-25}}{0.04}$

Operating Cost = **PHP 603,690,889.76691**

Solving for the Total Capital Cost

Total Capital Cost = PHP 322,748,991,923.8+ PHP 603,690,889.76

Total Capital Cost = PHP 323,352,682,813.567

Net Present Value = PHP 582,262,878,623.857- PHP 323,352,682,813.567

Net Present Value = PHP 258,910,195,810.29

K. Payback Period

$$\text{Payback Period} = \frac{\text{Capital Cost}}{\text{Annual Revenue} - \text{Operating Expenditures}}$$

For Design Option 1

$$\text{Payback Period} = \frac{\text{PHP } 322{,}748{,}991{,}923.8}{\text{PHP } 46{,}937{,}701{,}480.00 - (\text{PHP } 49{,}491{,}473.256 + 8{,}257{,}252{,}594.6091)}$$

Payback Period = 6. 35467235462433 Years

L. Return of Investment (ROI)

$$\text{ROI} = \frac{\text{Profit Gain}}{\text{Total Capital Cost}}$$

$$\text{Return of Investment} = \frac{46{,}937{,}701{,}480.00 - (\text{PHP } 49{,}491{,}473.256 + \text{PHP } 8{,}257{,}252{,}594.6091/\text{year})}{\text{PHP } 322{,}748{,}991{,}923.8} \text{ x } 100$$

Return of Investment = 11.9693502%

Using GE STF D650 Catalogue

Design Option 2

Power Demand Analysis

installed capacity	[MW]	600
capacity factor		0.40
Energy	GWh/year	2102.400
cost/kW	[Php/kW]	9.7599
capital cost	[Php]	327,544,792,888.92
Life	Years	25
discount rate		0.05
Capital recovery factor		0.070952457
Annual capacity cost	PHP	32,754,479,288.89
Fixed O&M	PHP	187,093,264,348.00
total fixed cost	Php	327,544,792,888.92
Fixed cost/kWh	[Php /kWh]	133,631,234.52
Variable cost/kWh	[Php /kWh]	6,375,836.785
LCOE	[Php /kWh]	26.342765

Depreciation

	Book Value(Php)	Salvage Value	Service Life (yrs)	Depreciation (BV-SV)/SL
Purchased Equipment	200,126,507,160.00	72,124,936,136.72	25	5,120,062,840.93
Instrumentation	40,025,301,432.00	14424987227.34	25	1,024,012,568.18

and Control				
Service Facilities	20,012,650,716.00	7,212,493,613.67	25	512,006,284.09
Etc	30,018,976,074.00	10,818,740,420.50	25	768,009,426.13
			Total	7,424,091,119.34

Return of Investment

Year	Period	TCI	Net Income After Tax	ROI
		(Php)	(Php)	(%)
2019	2	327018706670.8	45,118,262,840.00	13.79684
2020	3	281900443830.8	45,118,262,840.00	16.00503
2021	4	236782180990.8	45,118,262,840.00	19.05475
2022	5	191663918150.8	45,118,262,840.00	23.54030
2023	6	146545655310.8	45,118,262,840.00	30.78785
2024	7	101427392470.8	45,118,262,840.00	44.48331
2025	8	56309129630.8	45,118,262,840.00	80.12601
			Average	**32.54201**

Payback Period

Year	Net Income after Tax (Php)	TCI (Php)	Depreciation (Php)
2019	4,511,826,840.00	327018706670.8	7,326,917,151.81
2020	4,511,826,840.00	281900443830.8	7,326,917,151.81
2021	4,511,826,840.00	236782180990.8	7,326,917,151.81
2022	4,511,826,840.00	191663918150.8	7,326,917,151.81
2023	4,511,826,840.00	146545655310.8	7,326,917,151.81
2024	4,511,826,840.00	101427392470.8	7,326,917,151.81
2025	4,511,826,840.00	56309129630.8	7,326,917,151.81
Payback Period	6 years		

Sensitivity Analysis

	Change	ENPV	EIRR
Base Case		PHP	%
Construction delay	1 year	89,001,730.15	10.674333
Reduce of Power Generation by 10%	10%	50,091,723,000	0.7198

Increase of Fuel Price by 10%	10%	81,063,172.00	7.7361
Drop of Fuel Price by 10%	10%	90,149,001,.98	8.6972

Summary Economic Analysis of the Three Catalogues (Design Option 2)

Parameters	**SIEMENS SST 5000**	**SIEMENS SST 4000**	**GE STF D650**
Cost (Php)	Php 193,911,717,260.0	Php 197,507,050,260.00	Php 200,126,507,160.00
Payback Period	5 years	6 years	6 years

Economical Parameters

A. Land Cost

Land Cost = Total Land Area x current land cost

Land Cost = 325,000 m^2 (Php2500/m^2)

Land Cost = PHP 812,500,000.00

B. Equipment Cost

Total PHP 200,126,507,160.00

C. Electrical Cost

Electrical Cost = Equipment Cost x 20%

Electrical Cost = PHP 200,126,507,160.00x 0.2
Electrical Cost = PHP 40,025,301,432.00

D. Building Cost

For Design Option 1

Building Cost = Equipment Cost x 33%

Building Cost = PHP 200,126,507,160.00x 0.33

Building Cost = PHP 66,041,747,362.8

E. Miscellaneous Cost

Miscellaneous Cost = Equipment Cost x 10%

Miscellaneous Cost = PHP 200,126,507,160.00x 0.1

Miscellaneous Cost = **PHP 20,012,650,716.00**

F. Total Capital Expenditures Cost

Total Capital Expenditures Cost = ∑ cost of sub-parameters

For Design Option 1

Total = PHP 327,018,706,670.8

Operating Expenditure

A. Fuel Cost

HHV = 18311.95989 kJ/kg

Fuel Flow = 181173.713 kg/hr

Electrical Power = 300,000 kW

Heat Rate = $\frac{\text{Fuel Flow x HHV}}{\text{Electrical Power}}$

Heat Rate = $\frac{169{,}507.1304\ \frac{\text{kg}}{\text{hr}}\text{ x }18{,}311.95989\text{ kJ/kg}}{300{,}000\text{ kW}}$

Heat Rate = 11058.91922 kJ/kW-hr

Lignite coal price = \$ 18.51/short ton (2000 lbs) = PHP 2.755267423/kg

Capacity = Electrical Power x 24 hr

Capacity = 300,000 kW x 24 hr

Capacity = 7,200,000 kW-hr

Fuel Cost = $\frac{\text{PHP }2.755267423}{10{,}592.3849\text{ kJ/kg}}\ x\ 11058.91922\ \frac{\text{kJ}}{\text{kW}-\text{hr}}\ x$ 7,200,000 kW-hr x (2 units)

Fuel Cost = **PHP 23,960,737.41**

B. Labor Cost

Labor Cost = Fuel Cost x 20%

Labor Cost = PHP 23,960,737.41x 20%

Labor Cost = **PHP 4,792,147.482**

C. Maintenance and Repair

Maintenance and Repair = Fuel Cost x 20%

Maintenance and Repair = PHP 23,960,737.41x 20%

Maintenance and Repair = **PHP 4,792,147.482**

D. Supplies Cost

Supply Cost = Fuel Cost x 10%

Supply Cost = PHP **23,960,737.41**x 10%

Supply Cost = **PHP 2,396,073.741**

E. Supervision Cost

Supervision Cost = Fuel Cost x 20%

Supervision Cost = PHP **23,960,737.41**x 20%

Supervision Cost = **PHP 4,792,147.482**

F. Operating Taxes

Operating Taxes = Fuel Cost x 10%

Operating Taxes = PHP **23,960,737.41**x 10%

Operating Taxes = **PHP 2,396,073.741**

G. Total Operating Expenditure

Total = PHP 43,129,327.338

H. Depreciation

$$\text{Depreciation Rate} = \frac{1 \text{ year}}{n} \times 100$$

$$\text{Depreciation Rate} = \frac{1 \text{ year}}{25 \text{ years}} \times 100$$

Depreciation Rate = 4%

Solving for the Salvage Value of the Plant

Salvage Value = Capital Expenditures x (1 - Depreciation Rate)^{n}

Where n = Salvage Life of the Plant

Solving for the Plant Salvage Value

Salvage Value = Capital Expenditures x (1 - Depreciation Rate) ^{n}

Salvage Value = PHP 327,018,706,670.8x (1 - 4%)^{25}

Salvage Value = PHP 117,856,468,235.312

Annual Plant Depreciation = $\frac{\text{Total Capital Cost} - \text{Salvage Value}}{n}$

n = maximum useful life of the plant

Annual Plant Depreciation = $\frac{\text{PHP } 327{,}018{,}706{,}670.8 \ - \text{PHP } 117{,}856{,}468{,}235.312}{25}$

Annual Plant Depreciation = **PHP 8,366,489,537.41953/year**

I. Revenue

Annual revenue = Power Generation Rate x Actual Plant Output

Annual Revenue = PHP 9.7599/kW-hr x (600,000 kW x 0.915) (8760hrs/yr)

Annual Revenue = **PHP 46,937,701,480.00**

J. Net Present Value

Net Present Value = Future Cash Flow – Total Capital Cost

Where:

Future Cash Flow = Future Revenue+ Salvage Value

Total Capital Cost = Initial Capital Cost +Operating Cost

Future Revenue = Annual Revenue x $\frac{1-(1+\text{roi})^{n}}{\text{roi}}$

roi (Rate of Investment) = 4%

n (maximum useful life) = 25

Future Revenue = PHP 46,937,701,480.00 x $\frac{1\text{-}1.04^{-25}}{0.04}$

Future Revenue = **PHP 572,540,296,410.542**

Salvage Value = Annual Revenue x (1+roi)$^{-n}$

Salvage Value = PHP **46,937,701,480.00** x (1+0.04)$^{-25}$

Salvage Value = **PHP 9,722,582,213.31**

Future Cash Flow = PHP 572,540,296,410.542 + PHP 9,722,582,213.31

Future Cash Flow = **PHP 582,262,878,623.857**

Operating Cost = Operating Expenditures x $\frac{1-(1+roi)^{-n}}{roi}$

Operating Cost = PHP $x \frac{1-(1.04)^{-25}}{0.04}$

Operating Cost = **PHP 526,086,218.127929**

Solving for the Total Capital Cost

Total Capital Cost = PHP 327,018,706,670.8+ PHP 526,086,218.12

Total Capital Cost = PHP 327,544,792,888.928

Net Present Value = PHP 582,262,878,623.857- PHP 327,544,792,888.928

Net Present Value = PHP 254,718,085,734.929

K. Payback Period

Payback Period = $\frac{\text{Capital Cost}}{\text{Annual Revenue}-\text{Operating Expenditures}}$

For Design Option 1

Payback Period = $\frac{\text{PHP } 327{,}018{,}706{,}670.8}{\text{PHP } \mathbf{46{,}937{,}701{,}480.00} - (\text{PHP } 43{,}129{,}327.34 + 8{,}366{,}489{,}537.41953)}$

Payback Period = 6. 16933113737663 Years

L. Return of Investment (ROI)

ROI = $\frac{\text{Profit Gain}}{\text{Total Capital Cost}}$

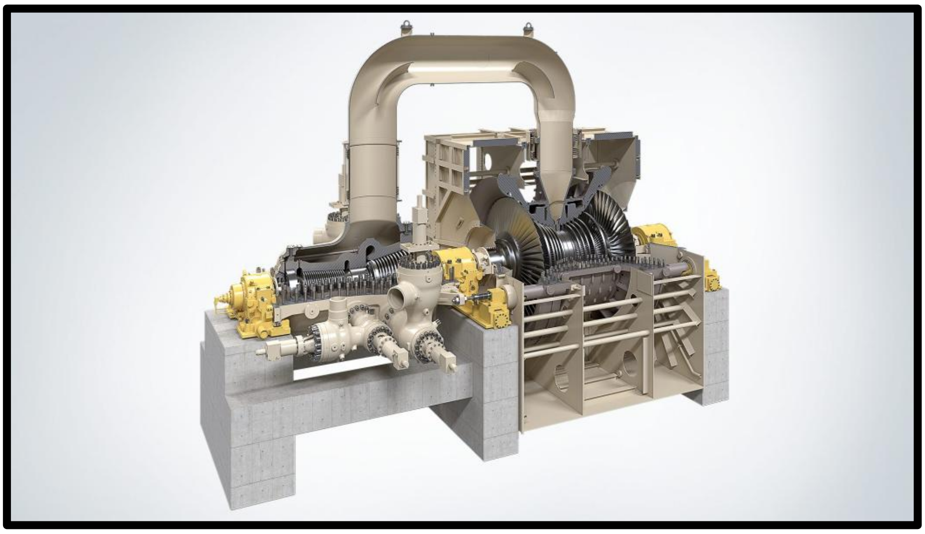
$$\text{Return of Investment} = \frac{46{,}937{,}701{,}480 - (\text{PHP } 43{,}129{,}327.34 + \text{PHP } 8{,}366{,}489{,}537.41953\text{year})}{\text{PHP } 327{,}018{,}706{,}670.8} \text{ x } 100$$

Return of Investment = 11.78161427%

APPENDIX B

CATALOGUE

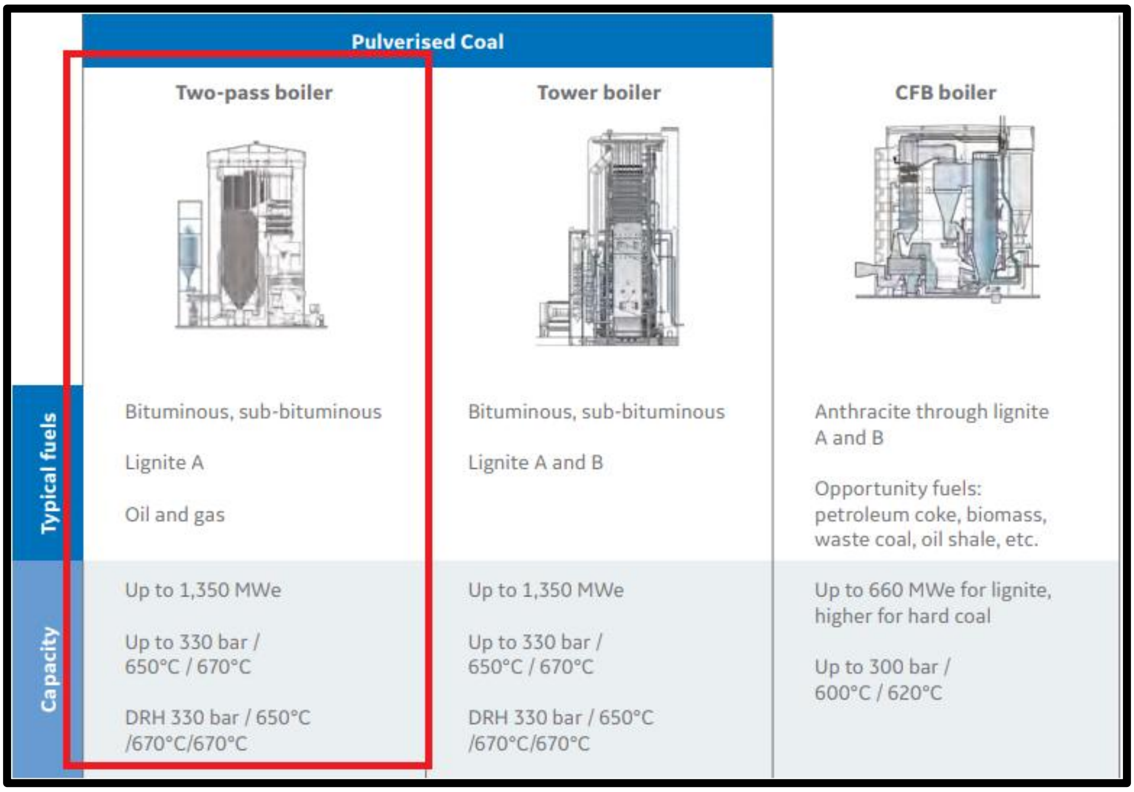
CATALOGUE FOR STEAM TURBINE



SST-5000	CCPP	SPP
Power output	120 MW to 650 MW	200 MW to 500 MW
Efficiency	61.5 % in combined cycle	43 % for subcritical 46,4 % for supercritical
Frequency	50 or 60 Hz	50 or 60 Hz
Main steam conditions		
Inlet pressure	up to 177 bar / 2,567 psi	up to 260 bar / 3,770 psi
Inlet temperature	up to 600 °C / 1,112 °F	up to 600 °C / 1,112 °F
Reheat steam conditions		
Temperature	up to 610 °C / 1,130 °F	up to 610 °C / 1,130 °F
Last stage blade length		
50 Hz	66 cm to 142 cm / 26 inches to 56 inches	
60 Hz	66 cm to 95 cm / 26 inches to 38 inches	

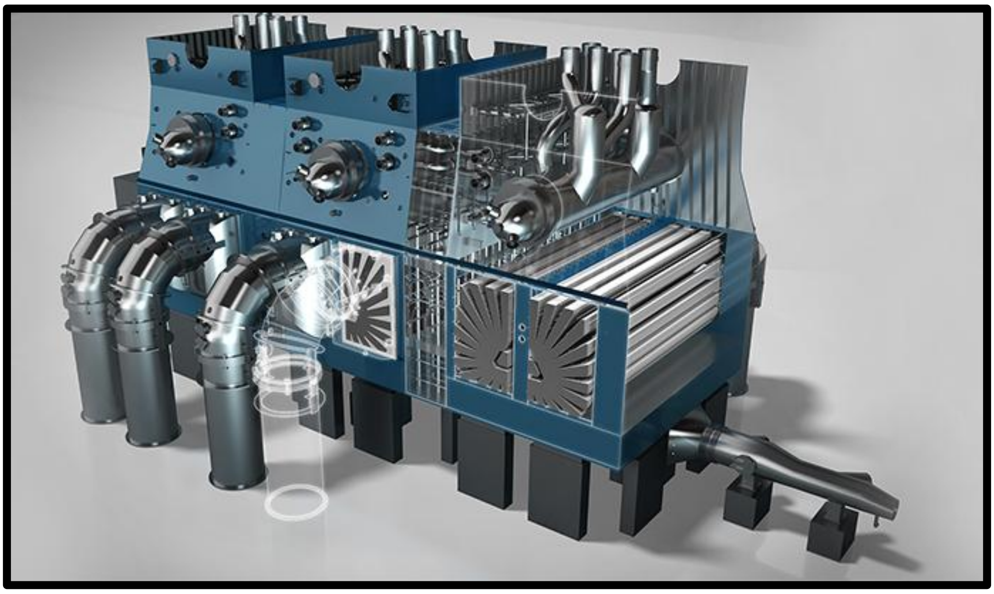
Steam turbine type	Output SPP MW	Output CCPP MW	Net efficiency SPP %	Net efficiency CCPP %	Frequency Hz	Inlet pressure bar / psi	Inlet temperature °C / °F	Reheat temperature °C / °F	Rotational Speed rpm
SST-9000	1,000–1,900				50 / 60	80 / 1,160	310 / 590		3,000–3,600
SST-6000	300–1,200		46,5 (Double reheat 48)		50 / 60	330 / 4,786	600 / 1,112	600 / 1,112	3,000–3,600
SST-5000	200–500	120–700	43 (subcritical) 46,4 (supercritical)	61.5	50 / 60	260 / 3,771 (SPP) 177 / 2,567 (CCPP)	600 / 1,112 (SPP) 600 / 1,112 (CCPP)	610 / 1,130 (SPP) 610 / 1,130 (CCPP)	3,000–3,600
SST-4000		100–500			50 / 60	105 / 1,523	565 / 1,049		3,000–3,600
SST-3000		90–250			50 / 60	177 / 2,567	565 / 1,049	610 / 1,130	3,000–3,600
SST-700 / 900	≤ 250	≤ 230			50 / 60	180 / 2,611	585 / 1,085	565 / 1,049	3,000–3,600
SST-800	≤ 200	≤ 200			50 / 60	165 / 2,393	565 / 1,049		3,000–3,600
SST-600	≤ 200	≤ 200			50 / 60	165 / 2,393	565 / 1,049		3,000–18,000
SST-500	≤ 100				50 / 60	30 / 435	400 / 750		15,000
SST-400	≤ 60				50 / 60	140 / 2,030	540 / 1,004		3,000–8,000
SST-300	≤ 45				50 / 60	140 / 2,030	540 / 1,004		12,000
SST-200	≤ 20				50 / 60	120 / 1,740	540 / 1,004		14,600

CATALOGUE FOR BOILER



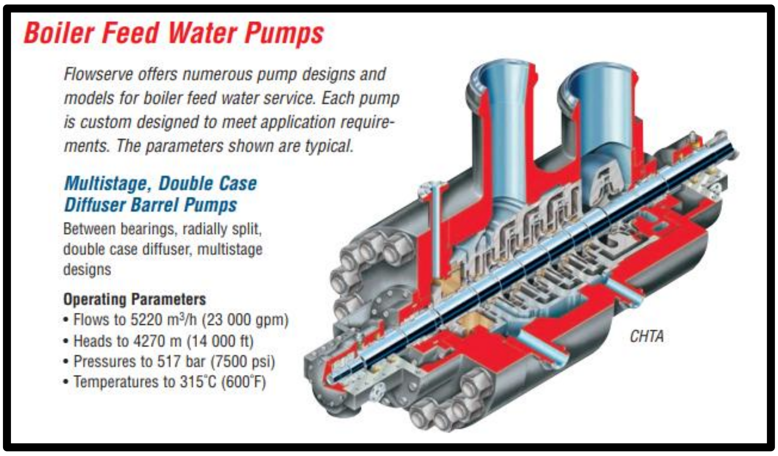
	Pulverised Coal		
	Two-pass boiler	Tower boiler	CFB boiler
Typical fuels	Bituminous, sub-bituminous Lignite A Oil and gas	Bituminous, sub-bituminous Lignite A and B	Anthracite through lignite A and B Opportunity fuels: petroleum coke, biomass, waste coal, oil shale, etc.
Capacity	Up to 1,350 MWe Up to 330 bar / 650°C / 670°C DRH 330 bar / 650°C /670°C/670°C	Up to 1,350 MWe Up to 330 bar / 650°C / 670°C DRH 330 bar / 650°C /670°C/670°C	Up to 660 MWe for lignite, higher for hard coal Up to 300 bar / 600°C / 620°C

CATALOGUE FOR CONDENSER



Typical Reference Solutions for:	1000 MW	1200 MW	1700 MW
Condenser Vacuum Type	Single	Dual	Single
Condenser Thermal Load (MW)	1,820	2,030	2,750
Absolute Pressure at Turbine/Condenser Connection (mbar abs)	55	52/70	35
Max Condensate O_2 Content at 100 % Load (ppm)	20	20	10

CATALOGUE FOR PUMPS



Boiler Feed Water Pumps

Flowserve offers numerous pump designs and models for boiler feed water service. Each pump is custom designed to meet application requirements. The parameters shown are typical.

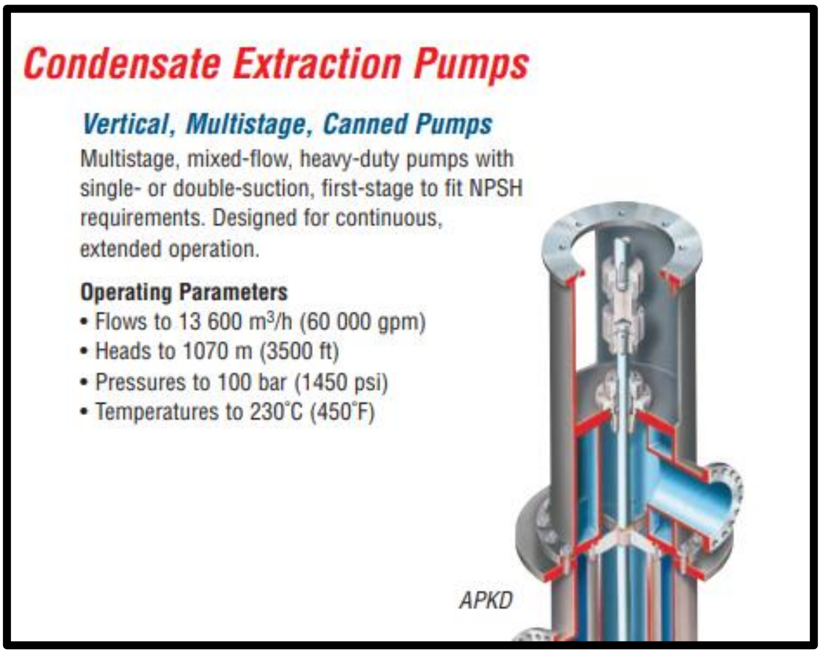
Multistage, Double Case Diffuser Barrel Pumps

Between bearings, radially split, double case diffuser, multistage designs

Operating Parameters

- Flows to 5220 m^3/h (23 000 gpm)
- Heads to 4270 m (14 000 ft)
- Pressures to 517 bar (7500 psi)
- Temperatures to 315°C (600°F)

CHTA



Condensate Extraction Pumps

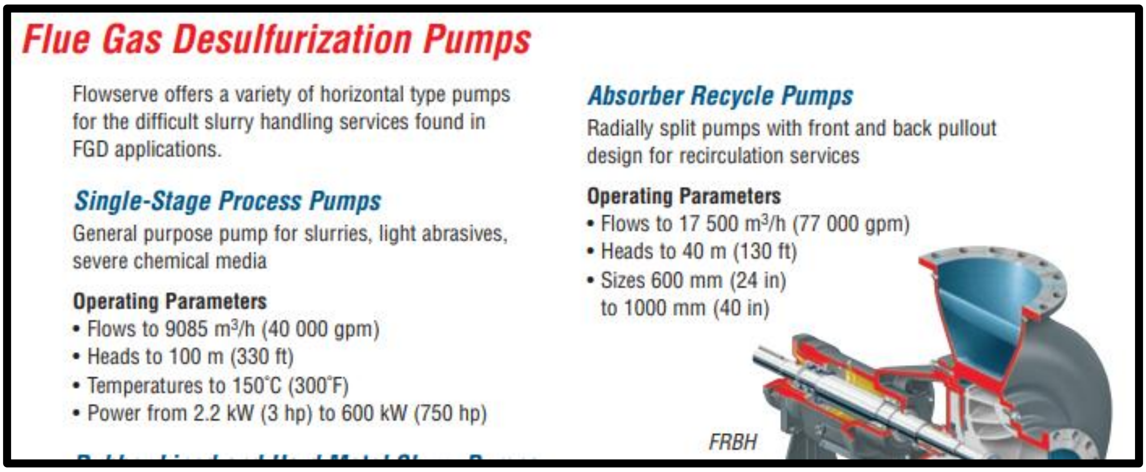
Vertical, Multistage, Canned Pumps

Multistage, mixed-flow, heavy-duty pumps with single- or double-suction, first-stage to fit NPSH requirements. Designed for continuous, extended operation.

Operating Parameters

- Flows to 13 600 m^3/h (60 000 gpm)
- Heads to 1070 m (3500 ft)
- Pressures to 100 bar (1450 psi)
- Temperatures to 230°C (450°F)

APKD



Flue Gas Desulfurization Pumps

Flowserve offers a variety of horizontal type pumps for the difficult slurry handling services found in FGD applications.

Single-Stage Process Pumps

General purpose pump for slurries, light abrasives, severe chemical media

Operating Parameters

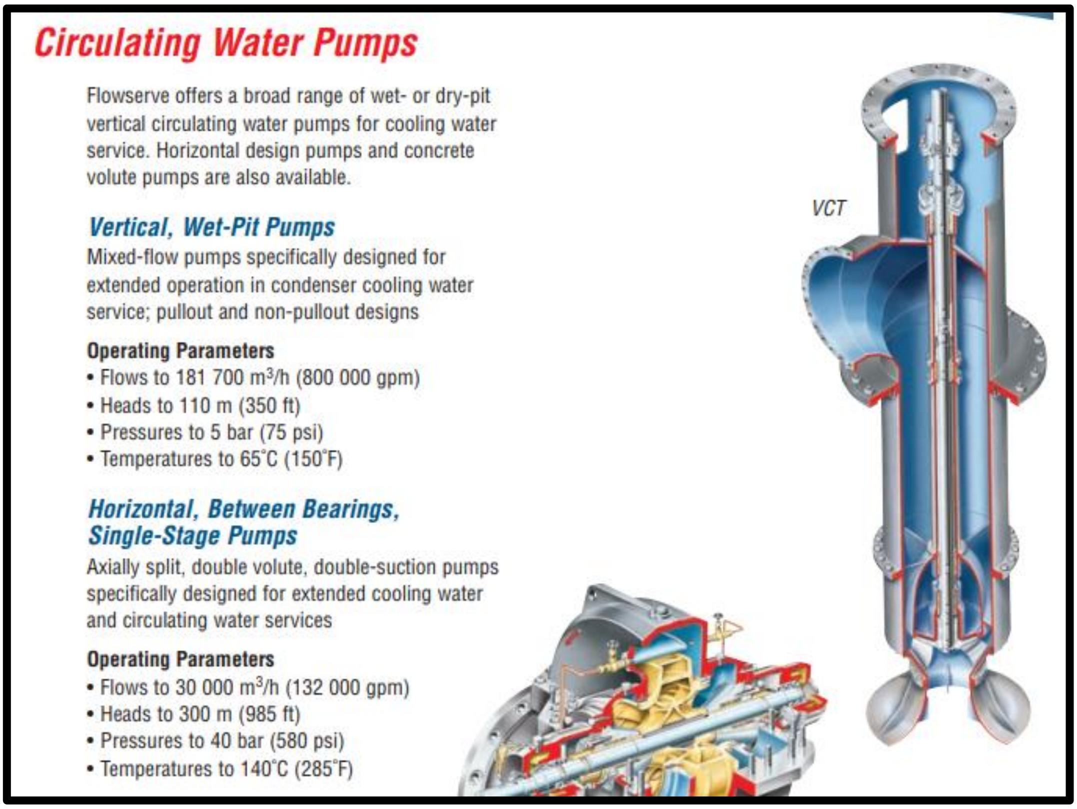
- Flows to 9085 m^3/h (40 000 gpm)
- Heads to 100 m (330 ft)
- Temperatures to 150°C (300°F)
- Power from 2.2 kW (3 hp) to 600 kW (750 hp)

Absorber Recycle Pumps

Radially split pumps with front and back pullout design for recirculation services

Operating Parameters

- Flows to 17 500 m^3/h (77 000 gpm)
- Heads to 40 m (130 ft)
- Sizes 600 mm (24 in) to 1000 mm (40 in)



Circulating Water Pumps

Flowserve offers a broad range of wet- or dry-pit vertical circulating water pumps for cooling water service. Horizontal design pumps and concrete volute pumps are also available.

Vertical, Wet-Pit Pumps

Mixed-flow pumps specifically designed for extended operation in condenser cooling water service; pullout and non-pullout designs

Operating Parameters

- Flows to 181 700 m^3/h (800 000 gpm)
- Heads to 110 m (350 ft)
- Pressures to 5 bar (75 psi)
- Temperatures to 65°C (150°F)

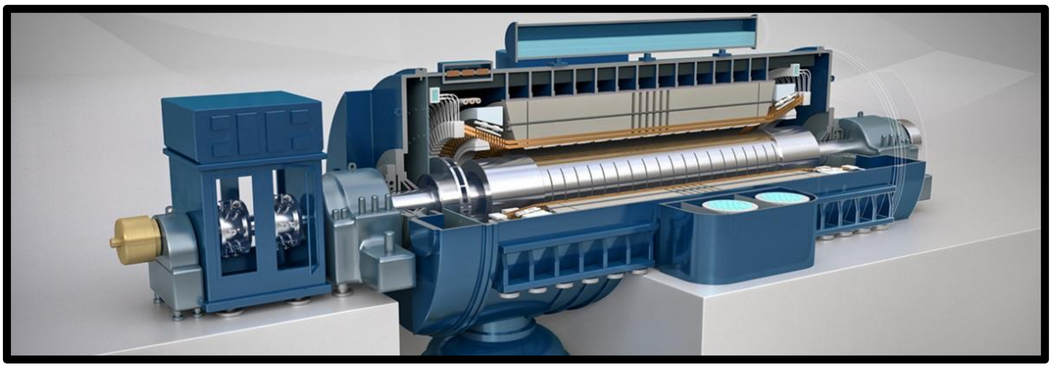
Horizontal, Between Bearings, Single-Stage Pumps

Axially split, double volute, double-suction pumps specifically designed for extended cooling water and circulating water services

Operating Parameters

- Flows to 30 000 m^3/h (132 000 gpm)
- Heads to 300 m (985 ft)
- Pressures to 40 bar (580 psi)
- Temperatures to 140°C (285°F)

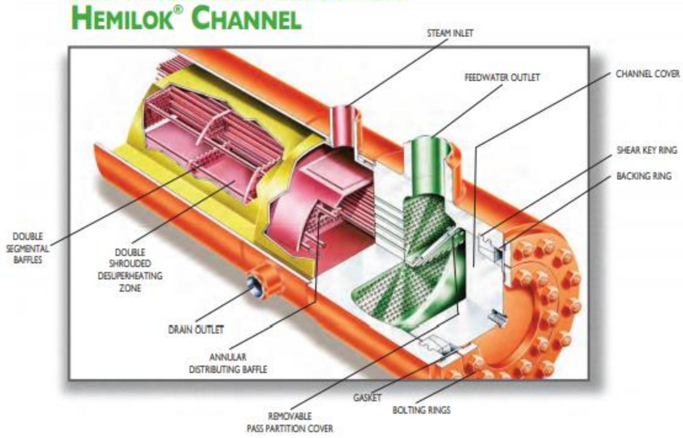
CATALOGUE FOR DAERATOR



Frequency	50 Hz	60 Hz
Power factor	0.8	0.85
Apparent power	320 MVA to 710 MVA	280 MVA to 690 MVA
Efficiency	Up to 98.9%	Up to 99%
Terminal voltage	18 kV to 23 kV	19 kV to 25 kV
Reliability*	99.715%	99.715%

CATALOGUE FOR CLOSED FEEDWATER HEATER

HIGH PRESSURE FULL ACCESS HEMILOK® CHANNEL



SPX Heat Transfer designs and manufactures both low pressure and high pressure feedwater heaters which may be installed either vertically or horizontally, depending on the plant design requirements. The physical and thermal characteristics are vastly different for high and low pressure feedwater heaters. Low pressure feedwater pressure ratings range between 400 and 800 psig, and high pressures range from 1,600 to 4,800 psig.

CATALOGUE FOR GENERATOR

WATER-COOLED

GIGATOP GENERATOR

HIGH POWER DENSITY

GE's water-cooled generators are exceptionally well suited to large power station applications where output requirements exceed the cooling capabilities of air-cooled or conventional hydrogen-cooled options. This reliable generator incorporates advanced technology and robust construction for enhanced operability and ease of maintenance.

	50 Hz	60 Hz
Power Factor	0.80	0.85
Apparent Power	Up to 1,400 MVA	Up to 1,120 MVA
Efficiency	Up to 99.0%	Up to 98.9%
Terminal Voltage	Up to 27 kV	Up to 26 kV

Industry-Leading Reliability

Use of stainless steel tubes in stator bars reduces forced outages due to cooling tube clogging.

Less Manual Intervention

Automated hydrogen gas control and sealing, enabled by the Mark* VIe control system, reduces the need for manual intervention and allows more efficient accessories operation.

CATALOGUE FOR PULVERIZER

	 Bowl mills - HP Type	 Bowl mills - SM Type	 Beater wheel mills - Type S, V, SV
Capacity range (t/h)	18 to 170	12 to 170	44 to 170
Classifier	Static or Dynamic	Static, Dynamic & Combined	Box Type (Static)
Loading	Spring (Hydraulic Option)	Hydraulic (Spring Option)	Speed Control for Operational Flexibility
Coal	Bituminous/Sub-Bituminous Lignite A	Bituminous/sub-bituminous Lignite A Anthracite Petroleum coke	Bituminous/Sub-Bituminous Lignite A

Table A-2 Low and Intermediate Alloy Steel (Cont'd)

Maximum Allowable Stress Values in Tension, ksi, for Metal Temperature, °F, Not Exceeding

−20 to 100	200	300	400	500	600	650	700	750	800	850	900	950	1,000	1,050	1,100	1,150	1,200	Grade	Spec. No.
																			Castings
14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.7	14.3	13.9	13.5	...	...	...	...	...	...	...	WC1	A 217
16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	15.4	12.0	*7.4*	*4.7*	...	...	...	...	WC4	
16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	15.4	*13.0*	*8.8*	*5.5*	*3.7*	*2.2*	...	...	WC5	
16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	15.8	15.4	15.0	*11.0*	*7.4*	*5.0*	*3.4*	*2.2*	...	...	WC6	
16.0	16.0	15.8	15.5	15.4	15.4	15.3	15.0	14.8	14.3	13.8	*12.6*	*9.1*	*6.2*	*4.1*	*2.6*	...	...	WC9	A 217
20.6	20.6	19.9	19.8	19.7	19.4	19.1	18.7	18.2	15.3	*11.4*	*8.7*	*6.4*	*4.6*	*3.4*	*2.3*	*1.4*	*0.8*	C5	
20.6	20.6	19.9	19.8	19.7	19.4	19.1	18.7	18.2	17.4	16.6	*13.1*	*8.8*	*5.9*	*4.0*	*2.6*	*1.8*	*1.2*	C12	
19.4	19.4	19.4	19.4	19.3	19.0	18.7	18.3	17.7	17.1	16.2	15.3	14.2	13.0	*11.2*	*8.2*	*5.6*	*3.4*	C12A	
																			Bolts, Nuts, and Studs
20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	18.5	*14.5*	*10.4*	*7.6*	*5.6*	*4.2*	*3.1*	*2.0*	*1.3*	B5	A 193
23.0	23.0	23.0	23.0	23.0	23.0	23.0	23.0	22.2	20.0	*16.3*	*12.5*	*8.5*	*4.5*	...	...	...	...	B7	
18.8	18.8	18.8	18.8	18.8	18.8	18.8	18.8	18.8	18.0	*16.3*	*12.5*	*8.5*	*4.5*	...	...	...	...	B7	
20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	18.5	*16.3*	*12.5*	*8.5*	*4.5*	...	...	...	...	B7M	
25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	23.5	*20.5*	*16.0*	*11.0*	*6.3*	*2.8*	...	...	B16	A 193
22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	21.0	*18.5*	*15.3*	*11.0*	*6.3*	*2.8*	...	...	B16	
20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	18.8	*16.7*	*14.3*	*11.0*	*6.3*	*2.8*	...	...	B16	
																			Wrought Fittings (Seamless and Welded)
5.7	15.7	15.7	15.7	15.7	15.7	15.7	15.7	15.4	14.9	14.5	...	...	...	...	...	...	...	WP1	A 234
7.1	17.1	16.6	16.5	16.4	16.2	15.9	15.6	15.1	14.5	13.8	*10.9*	*8.0*	*5.8*	*4.2*	*2.9*	*1.8*	*1.0*	WP5	
17.1	17.1	17.1	16.8	16.2	15.7	15.4	15.1	14.8	14.4	14.0	13.6	*9.3*	*6.3*	*4.2*	*2.8*	...	...	WP11	
17.1	16.8	16.5	16.5	16.5	16.3	16.0	15.8	15.5	15.3	14.9	14.5	*11.3*	*7.2*	*4.5*	*2.8*	...	...	WP12	

Table A-2 Low and Intermediate Alloy Steel

Maximum Allowable Stress Values in Tension, ksi, for Metal Temperature, °F, Not Exceeding

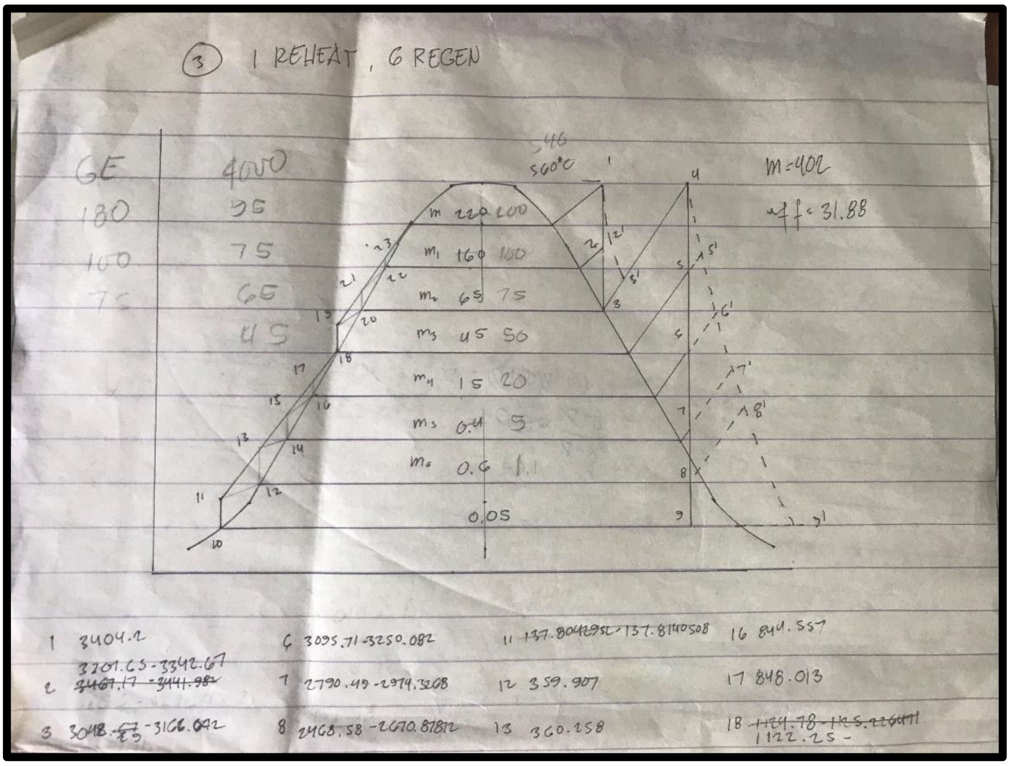
−20 to 100	200	300	400	500	600	650	700	750	800	850	900	950	1,000	1,050	1,100	1,150	1,200	Grade	Spec. No.	
																			Seamless Pipe and Tube	
16.7	15.1	14.5	14.3	14.2	14.0	13.8	13.6	13.3	12.8	12.3	*10.9*	*8.0*	*5.8*	*4.2*	*2.9*	*1.8*	*1.3*	T5	A 199	
16.7	15.1	14.5	14.3	14.2	14.0	13.8	13.6	13.3	12.8	12.3	11.7	*10.6*	*7.4*	*5.0*	*3.3*	*2.2*	*1.5*	T9		
16.7	15.4	14.6	14.0	13.5	13.1	12.8	12.6	12.3	12.0	11.7	11.3	*9.3*	*6.3*	*4.2*	*2.8*	*1.9*	*1.2*	T11	A 199	
16.7	15.6	15.1	15.0	15.0	15.0	15.0	15.0	14.9	14.8	14.5	*12.0*	*9.0*	*7.0*	*5.5*	*4.0*	*2.7*	*1.5*	T21		
16.7	15.6	15.1	15.0	15.0	15.0	15.0	15.0	14.9	14.8	14.5	*13.6*	*10.8*	*8.0*	*5.7*	*3.8*	*2.4*	*1.4*	T22		
																			A 213	
17.1	17.1	16.6	16.5	16.4	16.2	15.9	15.6	15.1	14.5	13.8	*10.9*	*8.0*	*5.8*	*4.2*	*2.9*	*1.8*	*1.0*	T5		
17.1	17.1	16.6	16.5	16.4	16.2	15.9	15.6	15.1	14.5	13.8	*10.9*	*8.0*	*5.8*	*4.2*	*2.9*	*1.8*	*1.0*	T5c	A 213	
17.1	17.1	16.6	16.5	16.4	16.2	15.9	15.6	15.1	14.5	13.8	13.0	*10.6*	*7.4*	*5.0*	*3.3*	*2.2*	*1.5*	T9		
17.1	17.1	17.1	16.8	16.2	15.7	15.4	15.1	14.8	14.4	14.0	13.6	*9.3*	*6.3*	*4.2*	*2.8*	...	...	T11		
17.1	16.8	16.5	16.5	16.5	16.3	16.0	15.8	15.5	15.3	14.9	14.5	*11.3*	*7.2*	*4.5*	*2.8*	...	...	T12	A 213	
17.1	17.1	16.6	16.6	16.6	16.6	16.6	16.6	16.6	16.6	*16.0*	*12.0*	*9.0*	*7.0*	*5.5*	*4.0*	...	...	T21		
17.1	17.1	16.6	16.6	16.6	16.6	16.6	16.6	16.6	16.6	*16.6*	*13.6*	*10.8*	*8.0*	*5.7*	*3.8*	...	...	T22		
24.3	24.3	24.3	24.2	24.1	23.7	23.4	22.9	22.2	21.3	20.3	19.1	17.8	16.3	*14.0*	*10.3*	*7.0*	*4.3*	T91		**(A09)**
24.3	24.3	24.3	24.2	24.1	23.7	23.4	22.9	22.2	21.3	20.3	19.1	17.8	16.3	*12.9*	*9.6*	*7.0*	*4.3*	T91		**(A09)**

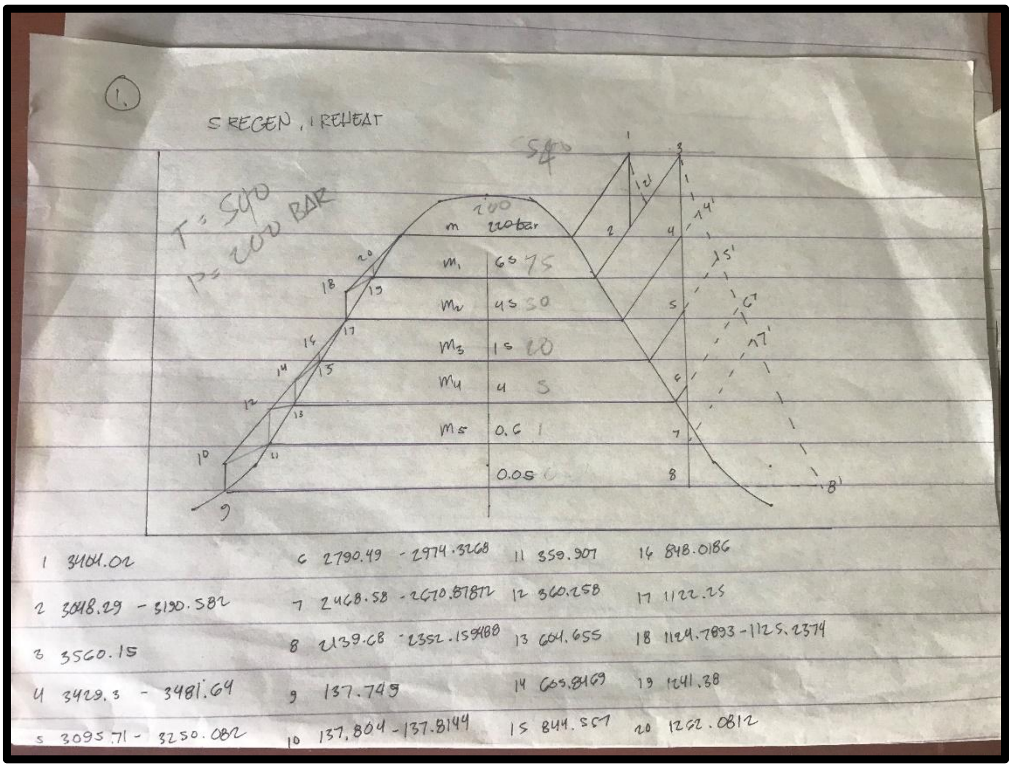
APPENDIX C

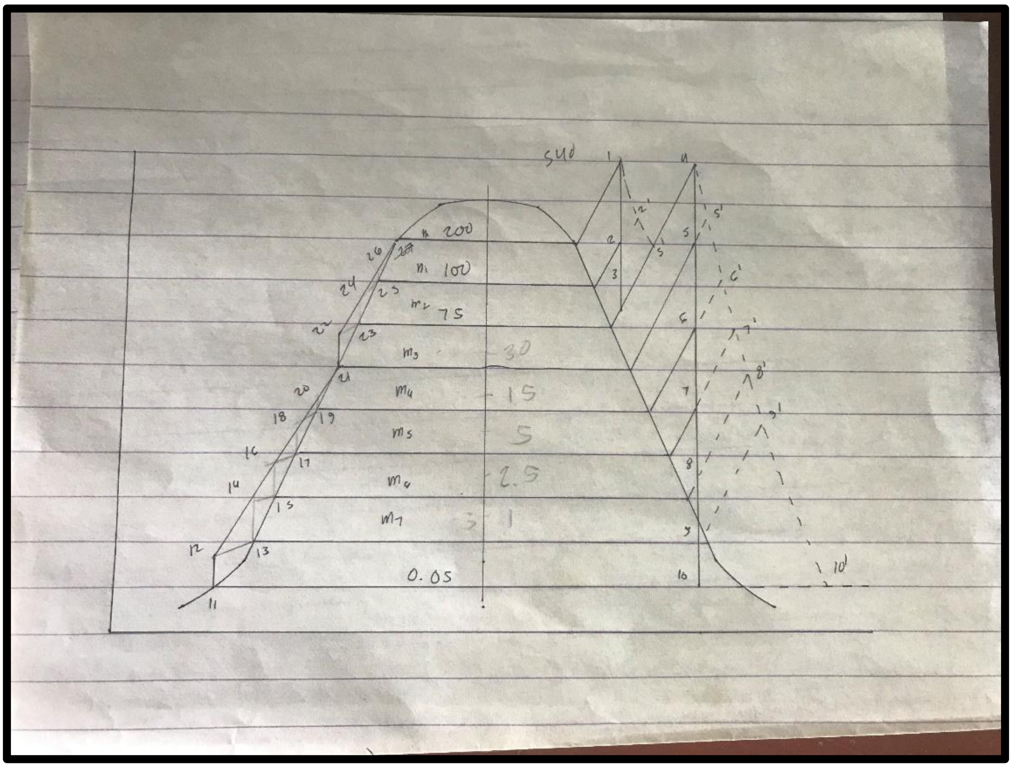
PROJECT DOCUMENTATION

DOCUMENTATION

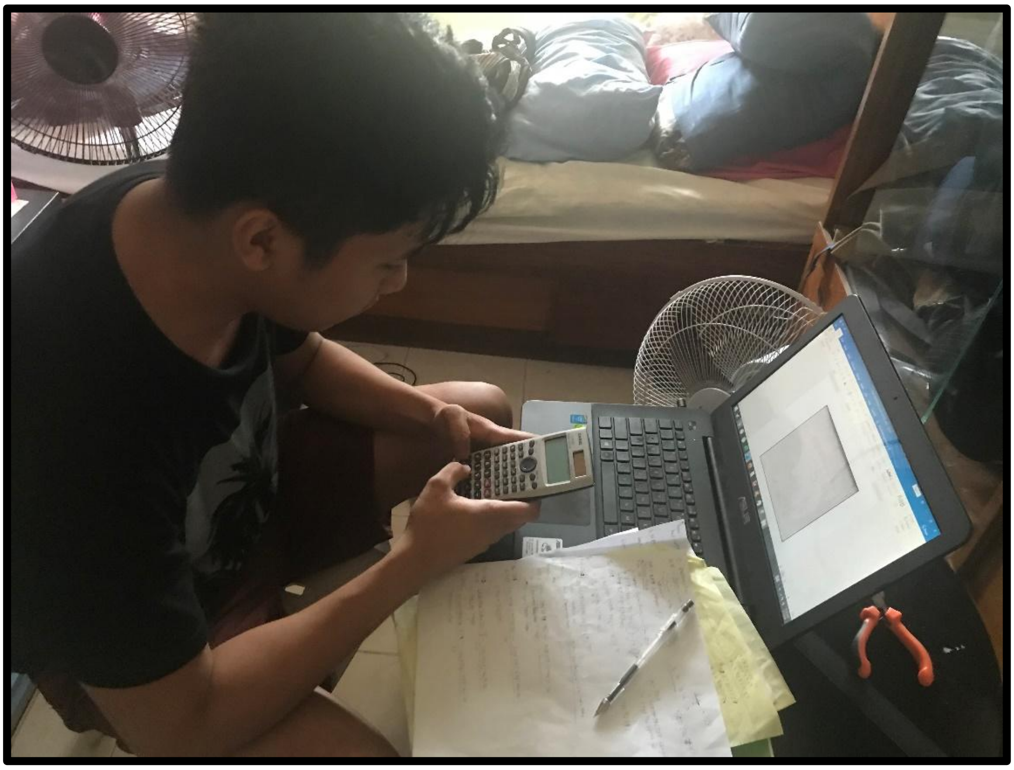
Before the selection of the final design, different design options were made. See photos below:

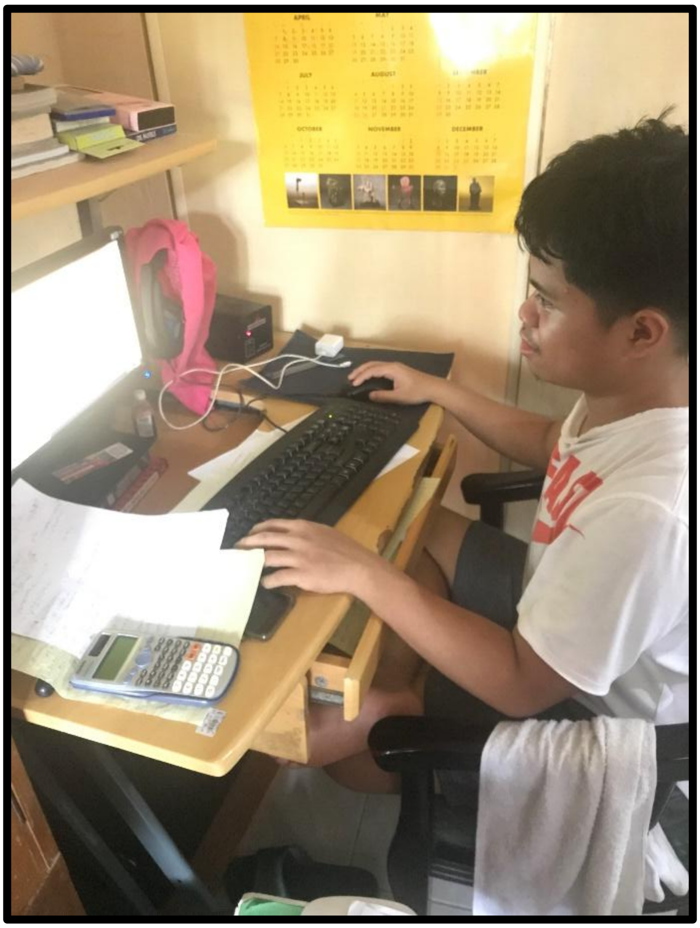


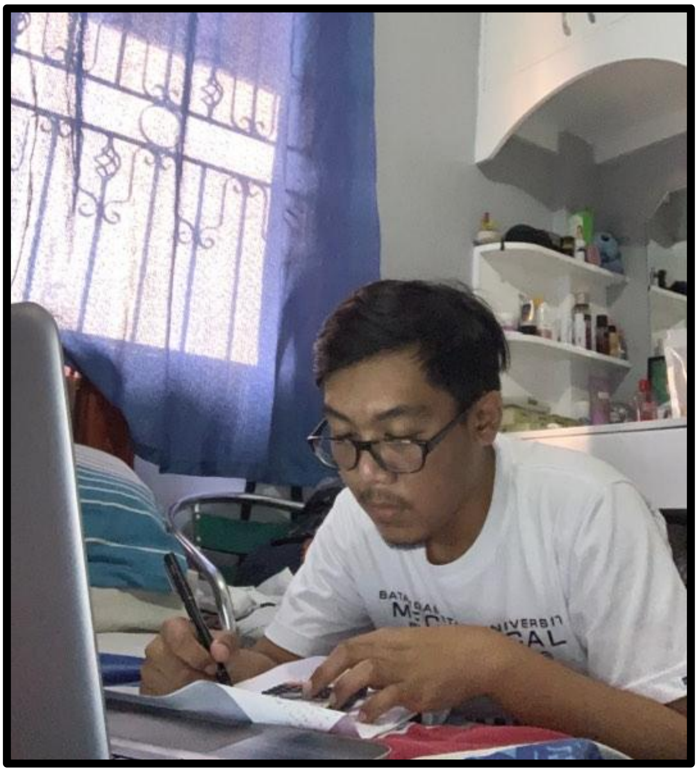




Here are photos of the proponents analyzing and evaluating the calculations obtained:







ORAL DEFENSE